Why Is the Practice of Levirate Marriage Disappearing in Africa? HIV/AIDS as an Agent of Institutional Change

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8 August 2018

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August, 2018

Abstract

Levirate marriage, whereby a widow is inherited by male relatives of her deceased husband, has anecdotally been viewed as an informal safety net for widows who have limited property rights. This study investigates why this widespread practice in sub-Saharan Africa has recently been disappearing. A developed game-theoretic analysis reveals that levirate marriage arises as a pure strategy subgame perfect equilibrium when a husband's clan desires to keep children of the deceased within its extended family and widows have limited independent livelihood means. Female empowerment renders levirate marriage redundant because it increases widows' reservation utility. HIV/AIDS also discourages a husband's clan from inheriting a widow who loses her husband to HIV/AIDS, reducing her remarriage prospects and thus, reservation utility because she is likely to be HIV positive. Consequently, widows' welfare tends to decline (resp., increase) in step with the deterioration of levirate marriage driven by HIV/AIDS (female empowerment). By exploiting long-term household panel data drawn from rural Tanzania and testing multiple theoretical predictions relevant to widows' welfare and women's fertility, this study finds that HIV/AIDS is primarily responsible for the deterioration of levirate marriage. Young widows in Africa may need some form of social protection against the influence of HIV/AIDS.

Keywords: cultural institution, female empowerment, HIV/AIDS, safety net, levirate marriage, widowhood protection
JEL classification: J12, J13, J16, K11, Z13

*An earlier version of this paper was circulated under the same title as the IDE (Institute of Developing Economies) Discussion Paper No. 627, January 2017. I am highly grateful to Kazunari Tsukada for his encouragement of the theoretical sophistication. I also thank Takeshi Aida, Monique Borgerhoff Mulder (for her anthropological expertise), Seiro Ito, Yoko Kijima, Booyuel Kim, Tomohiro Machikita, Momoe Makino, Petros Sekeris, and participants at conferences/workshops at ASREC 2016 (Orange), CSAE 2016 (Oxford), Hayami 2016 (Tokyo), IDE Trade and Development 2016 (Chiba), and MAEDA 2015 (Tokyo), and seminars at GRIPS, Hitotsubashi, IDEAS, IDE-JETRO, and University of Dar es Salaam for insightful comments and suggestions. My great thanks also go to Kathleen Beegle and Joachim De Weerdt for sharing the positional information of the KHDS communities. Financial support from the IDE-JETRO and the Japan Society for the Promotion of Science (# 25780180) for my field survey in Kagera and Mara in Tanzania is gratefully acknowledged. My great thanks in the survey go to Privatus Karugendo (one supervisor of the 2004 KHDS), Osoro Nyawangah, local NGOs, and rural respondents. The findings, interpretations, and conclusions expressed in this paper are entirely those of the author and do not represent the views of the IDE-JETRO. All errors are my own.

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1 Introduction

The economic knowledge and understanding of "culture" have considerably increased in recent years due to the significant improvements in empirical techniques and better data (e.g., Alesina and Giuliano, 2015; Fernández, 2008). Since culture is a form of social capital (e.g., Guiso et al., 2008), it is important to understand the mechanisms facilitating its emergence, persistence, and evolution.

Broadly speaking, two approaches have been exploited in economic research, one of which regards culture as (generalized) preferences/values internal to individuals (e.g., Guiso et al., 2006) and empirically examines factors driving its evolution, such as wars (e.g., Rohner et al., 2013), technology (e.g., Alesina et al., 2013), social organizations (e.g., Gneezy et al., 2016), economic shocks (e.g., Giuliano and Spilimbergo, 2014), and social fragmentation (e.g., Alesina and Ferrara, 2000, 2002). Since these preferences are relatively easy to measure through experimental games or survey questions and widely comparable across societies, empirical research taking this approach has exploded. However, any theoretical interpretation of data tends to be suggestive, with only a few exceptions (e.g., Lowes et al., 2017; Tabellini, 2008). Alternatively, defining culture as equilibrium outcomes (e.g., Greif and Kingston, 2011) and analyzing particular cultural institutions may lead to new insights with respect to the theoretical understanding of cultural change, as often seen in studies pertaining to marriage-related social institutions (e.g., Anderson and Bidner, 2015; Gould et al., 2008; Jacoby and Mansuri, 2010). However, the extent to which the empirical findings can be generalized is a priori ambiguous, which, along with the limited availability of appropriate date, apparently discourages economists from taking this approach and addressing the relevant important issues. While both approaches have pros and cons, there is a marked paucity of economic studies adopting the latter one. The present study fills this gap.

More precisely, this study explores the reasons for the deterioration of levirate marriage (also known as widow or wife inheritance) in sub-Saharan Africa. Levirate marriage is a common marital practice in many societies around the world. According to this practice, a widow is inherited by the brother or other male relative of her deceased husband. While this practice is still observed in many societies in present-day Africa (Potash, 1986; Radcliffe-Brown and Forde, 1987), as seen in Kenya (Agot, 2007), Nigeria (Doosuur and Arome, 2013), Sudan (Stern, 2012), Uganda (Ntozi, 1997), and Zambia (Malungo, 2001), this century-old practice has recently begun to disappear.

This institutional change should also be given considerable attention on its own because anecdotally levirate marriage has been considered to be an informal safety net that provides material support and social protection for widows despite it being seen as treating women as "property." Therefore, it is expected that this institutional change will have significant consequences for economic development by altering both ex-ante (for currently married women) and ex-post (for current widows) welfare gains associated with widowhood. Until now, however, there has been no effort by economists to better understand the role and socioeconomic consequences of this practice despite its popularity and economic significance.

This customary practice also has much policy relevance in sub-Saharan Africa, where widows comprise a significant proportion of the population because of their husbands' deaths being attributed to typical age differences between a couple and, more recently, the prevalence of HIV/AIDS. According to Potash (1986), a quarter of the adult female population is widowed in many African societies. Traditionally, a widow has limited rights to the property of both her natal and husband's families; therefore, her life is highly vulnerable. Furthermore, owing to a customary system of exogamous and patrilocal marriage, a widow's close relatives (e.g., parents, siblings) typically live outside her current residential village and, thus, cannot easily provide her with appropriate life protection. A relatively recent empirical study conducted in northern Tanzania also found that a large increase in the murder of "witches," typically elderly widowed women, is associated with their small contribution to a household's earning capacity (Miguel, 2005). Despite the evident vulnerability of widows' livelihood, however, their protection has, thus far, not been actively considered on the development agenda (compared with debates about "child" and "old-age" protection), and their lives and survival strategies are insufficiently understood (e.g., Djuikom and van de Walle, 2018; van de Walle, 2013).

To address the question, this study first develops a theoretical framework wherein levirate marriage arises as a pure strategy subgame perfect equilibrium in an extensive-form game played by two agents, i.e., a widow and her husband's clan.[1] This model builds upon the assumption that in a patriarchal African society, great emphasis is placed on continuation of generations (e.g., Caldwell and Caldwell, 1987; Tertilt, 2005). In this game, the clan first offers livelihood support to widows in the form of levirate marriage. Widows, who otherwise have only subsistence resources, have an incentive to accept this offer although the material support is marginal. A husband's clan responds to a widow's strategic choice by providing her with minimal social protection to keep the children and (as caretakers) wives of the deceased within its extended family (e.g., Muller, 2005; Stern, 2012).

Following this framework, two possible mechanisms (and their combination) that result in the disappearance of levirate marriage are considered. First, female empowerment (as a source of improved women's property rights, for example) may make this practice obsolete while potentially increasing widows' welfare, as analyzed in the context of other marriage-related social institutions (e.g., Anderson and Bidner, 2015; Tertilt, 2006).

Second, the recent spread of HIV/AIDS might also have destroyed this practice (e.g., Malungo, 2001; Ntozi, 1997; Perry et al., 2014). If a husband's death is attributed to AIDS, the wives may also be HIV positive. Then,

[1]While this theoretical framework is developed primarily in the African context, it may also apply to similar practices in other areas, such as widow remarriage in northern India (e.g., Chowndhry, 1994).

by having sexual intercourse with the widows, the inheritors (and their wives and even the children born to them later) may get infected with HIV. In addition, because HIV/AIDS impairing widows' health increases their effective child-rearing cost, a clan has to provide more livelihood support for HIV-positive widows than for seronegative ones even if such sexual intercourse is avoided. Therefore, a husband's clan has a strong incentive to avoid this practice. In this case, widows may lose this traditional safety net. Notably, this institutional change would not increase the widows' welfare, because a clan already squeezes utility from widows even in the presence of levirate marriage, and widows enjoy reservation utility both before and after the dissolution of levirate marriage. What is worse, since it is expected that HIV-positive widows also have difficulties in getting remarried, the spread of this infectious disease could decrease widows' welfare by reducing their reservation utility while simultaneously eliminating levirate marriage. This mechanism is not inconsistent with the markedly high HIV infection rate among widowed women in sub-Saharan Africa (e.g., Tenkorang, 2014); for example, formerly married women have higher HIV infection rate than any other (male and female) populations in Tanzania (Tanzania Commission for AIDS (TACAIDS), National Bureau of Statistics (NBS), and ORC Macro, 2005, p. 77).

To empirically examine why levirate marriage is disappearing, this study uses one unique setting observed in a long-term household panel survey conducted in Kagera, a rural region of northwest Tanzania (Kagera Health and Development Survey, KHDS). Group discussions with the village leaders revealed that the practice of levirate marriage had become less common in a significant proportion of the sample villages between 1991 (wave 1 of the KHDS) and 2004 (wave 5). This study exploits this setting and develops a testing strategy that allows it to address its question.

While one straightforward way to assess the mechanisms responsible for the disappearance of levirate marriage is to evaluate the probability that a widow enters into this customary marriage as a result of the spread of HIV/AIDS and/or female empowerment, this approach cannot be adopted in this study. This is because information relevant to widows' engagement in levirate marriage at the individual level is absent in the KHDS data.[2]

As an alternative, the above setting observed in the KHDS is used. As described above, it is theoretically predicted that widows' welfare tends to decline (resp., increase) in step with the dissolution of levirate marriage as a result of the spread of HIV/AIDS (female empowerment). Consequently, in this study, a correlation between the deterioration of levirate marriage and widows' welfare is explored to elucidate the mechanisms responsible for this institutional change, with the former discerned from the KHDS at the community level and the latter at the individual level. The theoretical model indicates that this correlation is likely to be negative (resp., positive) if a primary factor driving

[2]Such information is also rarely obtained (even at the community level) from standard household surveys currently in use. Collection of original panel data that records the deterioration of levirate marriage in the long term also prevents the immediate investigation of such a significant ongoing economic transition.

such institutional change is HIV/AIDS (female empowerment).

In addition, a correlation between this institutional change and parental fertility decisions is also empirically examined. As the theoretical model suggests, HIV/AIDS possibly increases fertility while destroying levirate marriage. This fertility response arises if widows' de facto property rights are established in response to the reduction of male labor force caused by HIV/AIDS, which in turn enables them to afford many children in widowhood. In Uganda (e.g., Mukiza-Gapere and Ntozi, 1995) and Zambia (e.g., Malungo, 2001), cases have increasingly been reported of property being left to widows and their children owing to HIV/AIDS and the resulting deterioration of levirate marriage.

Since the empirical goal is to identify a correlation attributed only to the theoretical mechanisms that this study focuses on, it is still required to exclude influence of any confounding factors that prevent the current investigation from estimating such a correlation. To meet this objective, this study takes a triple-difference strategy that compares relevant outcomes before (wave 1) and after (wave 5) the institutional change between villages that made the practice of levirate marriage less customary and the remaining villages. The third source of difference comes from a comparison between widows and other females for estimating consumption or that between the young and old population for the analysis of fertility. This approach allows controlling for time-varying village-level characteristics that affected the KHDS villages over time in a different manner, i.e., village-specific linear time trends.

As the empirical analysis shows, the disappearance of levirate marriage was negatively associated with "young" widows' consumption while having a positive correlation with "young" wives' fertility. Considering HIV/AIDS primarily affecting prime-age husbands as well as higher fecundity revealed by young women, the absence of significant correlations for the remaining age cohorts may be seen as a result of the relevant falsification test. In addition, based on further analyses pertaining to the prevalence of HIV/AIDS in a KHDS community, these correlations were more pronounced in villages whereby this communicable disease increasingly exerted an unfavorable health influence during the sample periods. Moreover, HIV/AIDS decreased young widows' consumption and encouraged fertility of young wives. The last two findings are also consistent with the theoretical predictions and may be seen as the reduced-form impacts of HIV/AIDS. Thus, all these findings collectively provide support for the view that a primary factor facilitating the recent deterioration of levirate marriage in sub-Saharan Africa is HIV/AIDS. The findings of prior case studies as well as my careful field observations in rural Tanzania also support this claim. According to this study's findings, young widows may urgently need social protection that shields them from the influence of HIV/AIDS.

Taking an important but less popular approach exploited in economic studies of culture, this study develops the "first" economic theory of levirate marriage and empirically analyzes the reasons for its deterioration. The demonstration of its deterioration would improve the general understanding of conditions that facilitate the transformation of cultural institutions (e.g., Anderson, 2003; de la Croix and Mariani, 2015). In particular, several previous studies indicate that "positive" socioeconomic shocks (e.g., English-education opportunities) affecting "disadvantaged" groups (e.g., girls) could erode traditional institutions (e.g., caste) while "increasing" their welfare (Luke and Munshi, 2011; Munshi and Rosenzweig, 2006). In contrast, this study will show that "negative" shocks (e.g., HIV/AIDS) supposedly influencing "advantaged" groups (e.g., a husband's clan) may also break down traditional institutions (e.g., levirate marriage), possibly swiftly, while "reducing" disadvantaged groups' (e.g., widows') welfare.

In the developing world, informal institutions (e.g., informal insurance arrangements) play a significant socioeconomic role by supplementing weak formal institutions (e.g., Townsend, 1994). Nevertheless, according to Greif and Iyigun (2013), "social institutions are ... all but absent from our analyses of economic growth and development." In addition, in such a region, infectious diseases (e.g., Ebola, HIV/AIDS, malaria) tend to strike an economy, and their unfavorable welfare consequences are often aggravated by a poor formal health system. Taken together, the present study may also provide a valuable lesson applicable in other development settings, particularly when considering the vulnerability or resistance of non-market institutions to deadly communicable diseases.

While previous studies have provided somewhat inconclusive evidence of the impact of HIV/AIDS on fertility (e.g., Fortson, 2009; Kalemli-Ozcan and Turan, 2011; Young, 2005, 2007), this research will also highlight the importance of exploring its heterogeneity by showing one mechanism through which this infectious disease affects fertility.

This paper is organized as follows. Section 2 provides a theoretical model that explains the mechanisms driving the deterioration of levirate marriage. A strategy to test for the mechanisms responsible for this institutional change is presented in Section 3, followed by the data overview in Section 4. Section 5 reports the empirical findings, whose interpretation is discussed in Section 6. Concluding remarks are summarized in Section 7.

2 A simple theoretical framework

This section offers a simple theoretical framework that considers the presence of levirate marriage in a traditional economy as a pure strategy subgame perfect equilibrium. The purpose is to facilitate the discussion that follows in Section 3, whereby a strategy to empirically explore the mechanisms responsible for the deterioration of levirate marriage is developed. All the relevant propositions are proved in Section S.7 in the supplemental appendix.

While the picture should not be over-simplified, the model builds upon several features of family relationships widely observed in sub-Saharan Africa, as noted in Caldwell and Caldwell (1987) and elsewhere (e.g., Tertilt, 2005). First, societies are patrilineal; succession is passed down the male line. Daughters, customarily, do not inherit their parents' property, and almost all females that reach marriageable age as determined by their respective societies, enter into marital relationships. Owing to the rules of clan exogamy and patrilocality, at marriage, a woman often moves some distance away from her natal village to her husband's home. Traditional belief systems place a great emphasis on the continuation of generations. Thus, marriage can be seen as acquisition of a bride's reproductive capacity by her husband's clan, which is made in exchange for bridewealth payments made to her parents. However, a bride is typically left out of fertility decisions as they are largely made by senior male members of her husband's clan (including the groom) in a patriarchal society. Nevertheless, mothers shoulder the main responsibility for providing for the day-to-day material and emotional care of their children. As males must accumulate sufficient wealth to afford a bride (including bride prices), they usually marry later than females (e.g., Goody and Tambiah, 1974). The resulting age differences between couples mean that it is common to find women who have lost their husbands.

Based on these stylized observations, consider an agrarian society with two agents: a widow (or her parents) (w) and an extended family of her deceased husband, called here a "clan" (c). The sequence of actions taken by both agents is as follows (see also Figure 1). First, after marriage, a husband's clan (particularly, male members) determines the number of children n that a woman should bear before her husband's death. This assumption simplifies the case of a man's family members putting some pressure on a young couple's fertility decisions during their married life, which is not implausible in reality. Second, after the husband's death, the clan chooses the amount of livelihood support $s \geq 0$ that will be provided to the widows in the form of levirate marriage. While it is presumed here that a husband surely dies before a wife does, analyses performed in subsection S.1.3 in the supplemental appendix relax this assumption.

In the face of an offer of livelihood support, a widow decides whether to accept levirate marriage. The acceptance (action a) allows a widow to exploit her husband's property (e.g., house, land) while living with her children. In case of rejection or absence of the provision (i.e., $s = 0$), she has two choices. First, she can formally inherit her husband's property and live with her children (action z). Else, she can leave her husband's home (action l). Consequently, the strategy profile taken by both agents can be characterized as (n, s, m), whereby $m \in (a, z, l)$ refers to choices that a woman can make after her husband dies.

Following Tertilt (2005)'s theoretical model of marriage and fertility developed in the context of sub-Saharan Africa, it is assumed that the clan chooses the number of children n, given the convex cost $c(n)$ of raising them, such that $c'(n) > 0$, $c''(n) > 0$, and $c(0) = 0$.[3] This cost is incurred by either a mother whenever she is available or female members of the clan. The payoffs $v_i(\cdot, \cdot, \cdot)$ of an agent i (either c or w) are demonstrated as follows; the first and second terms in parenthesis indicate the number of children n and the amount of s with the third term referring to a

[3]One example of the explanation for the convexity is unfavorable externalities that have a bearing on family members' health. If one child contracts some infectious disease, often the remaining children (or even parents) also get infected.

widow's action:

$$v_c(n,s,a) = u(n) - s, \tag{1}$$

$$v_w(n,s,a) = s - c(n), \tag{2}$$

$$v_c(n,s,l) = u(n) - c(n) - \tau, \tag{3}$$

$$v_w(n,s,l) = r, \tag{4}$$

$$v_c(n,s,z) = u(n) - k, \tag{5}$$

$$v_w(n,s,z) = k - c(n). \tag{6}$$

If the offered levirate marriage is accepted, the clan obtains positive utility $u(n)$ such that $u'(n) > 0$, $u''(n) < 0$, and $u(0) = 0$ by maintaining children of the deceased within its extended family. However, this utility can be achieved in exchange of (endogenously determined) material support s (e.g., provision of subsistence needs, permission of access to the clan's property). The widow can enjoy the support with children left in her charge, resulting in $v_c(n,s,a) = u(n) - s$ and $v_w(n,s,a) = s - c(n)$. Notably, it is assumed that a widow gains no utility from just staying with her children, which simplifies the analysis.

In case of the rejection or absence of the offered levirate marriage, a widow receives exogenously determined reservation utility $r \in R$ when she leaves her husband's home. For instance, she may receive this reservation utility by remarrying or inheriting her parents' property.[4] A widow can leave either with or without her children. If a widow leaves with her children, she incurs the child-rearing cost $c(n)$. If she leaves alone, she does not incur this cost while facilitating female members of her husband's clan to take care of the children left behind. The child-rearing cost incurred by the female members is assumed to be greater by an amount of $\tau > 0$, compared with the case where a widow takes care of her own children. This is because the clan's female members have work to do at their own homes (including raising their children) and thus, there are both the material and opportunity costs of taking care of the children of the deceased.[5] Note that given the aforementioned assumption that a widow receives no utility stemming from "just stay together," she does not lose utility by separating from her own children. Consequently, a widow strictly prefers to leave alone rather than to leave with her children, yielding $v_c(n,s,l) = u(n) - c(n) - \tau$ and $v_w(n,s,l) = r$.

[4]For example, it is reported that remarriage is an important alternative to levirate marriage for young widows' survival in Uganda (Nyanzi et al., 2009).

[5]The model included these costs to explicitly consider why a clan encourages a widow to accept levirate marriage, rather than facilitating its female members to take care of children of the deceased. However, the key theoretical implications demonstrated below remain unchanged by treating $\tau = 0$, provided it is alternatively assumed that $r_0 < 0$, $r_1 > r_0$, and $r_2 < r_0$. Moreover, it is also possible to regard the child-rearing cost incurred by a clan as $(1+\tau)c(n)$, rather than $c(n)+\tau$. In this case, a woman's fertility possibly decreases when a widow's reservation utility increases from $r_0 = 0$ to $r_1 > 0$, which is not indicated in the subsequent proposition 3. This fertility response arises because a clan's child-rearing cost arising from widows' action l increases in proportion to the number of children. However, the remaining theoretical implications are robust to this difference when modeling a clan's child-rearing cost.

A widow's separation from her own children is not uncommon in rural Africa, which is also reinforced by the practice of bride prices. If a widow leaves with her children, she or her parents typically have to repay the bride price (given to her parents at marriage) to the clan. On the other hand, if she moves out and leaves her children to the husband's clan, this repayment is not required. Moreover, a widow may not suffer much emotionally from leaving alone. For example, widowed women belonging to the Luo in Kenya, an ethnic group famous for the practice of levirate marriage, can easily return to meet their children even if they leave a husband's community (Potash, 1986, p. 41). Nevertheless, a widow's (emotional) cost resulting from separation from her own children is explicitly taken into account in subsection S.1.2 in the supplemental appendix. As seen from the analysis, the key theoretical implications demonstrated below are robust to this consideration.

Alternatively, a widow can also choose to make a livelihood with her children by using a socially accepted (and thus, exogenous) amount of a husband's bequest $k \geq 0$ transferred from a husband's clan to her (and measured by transferable utility), which enables them to be self-sufficient. For example, in a traditional society that does not allow a widow to inherit property of the deceased, this amount is expected to be zero. These yield the remaining payoff profiles $v_c(n, s, z) = u(n) - k$ and $v_w(n, s, z) = k - c(n)$.

[Here, Figure 1]

2.1 Optimal strategies and equilibrium

Depending upon the levels of a widow's property rights k and reservation utility r, it can be shown that levirate marriage is subgame perfect. Assume that widows have limited independent livelihood means such that $r = r_0 = 0$. In addition, widows' rights to inherit a husband's property is also highly limited in the sense that $k = k_0 \leq c(n^*)$, whereby n^* satisfies $u'(n^*) = c'(n^*)$. Then, it is easy to verify that

Proposition 1 *When $r = r_0 = 0$ and $k = k_0 \leq c(n^*)$, the strategy profile $(n^*, c(n^*), a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_0 = 0$.*

Since widows cannot support themselves independently, they have an incentive to receive support from their husband's clan. In contrast, a clan also has an incentive to offer levirate marriage to retain the widow's children within the extended family. Thus, this practice is sustained.

As the equilibrium payoff indicates, while a widow receives material support (i.e., $s = c(n^*)$) from her husband's clan by agreeing to a levirate marriage, the amount may not necessarily be large. Ethnographic studies (e.g., Doosuur and Arome, 2013; Luke, 2002; Nyanzi et al., 2009) show that material support provided by inheritors is typically minimal, because the inheritors normally have to take care of their wives and children at their original home in addition to the widows who continue to reside at their deceased husband's home (e.g., Ndisi, 1974). Thus, the model prediction may be consistent with this finding.[6] Furthermore, a clan protects widows because they take care of the deceased's children with the child-rearing cost being smaller than the corresponding cost incurred by a clan's female members, i.e., $c(n) < c(n) + \tau$.

2.2 Institutional change

Focusing on an economy that traditionally practices levirate marriage, the analysis in this subsection reveals several mechanisms that trigger institutional changes.

2.2.1 Female empowerment: An increase in k

Female empowerment may render the practice of levirate marriage redundant. In Tanzania, many gender-oriented perspectives were introduced in the political sphere in the 1990s. One remarkable example is the establishment of the Land Act of 1999 and the Village Land Act of 1999, enabling men and women to enjoy equal land rights (Killian, 2011). In fact, in the KHDS data, several villages that prohibited widows from inheriting a husband's major properties (e.g., land, house) appear to have removed this discrimination between 1991 and 2004. Assuming that a widow can inherit a sufficient amount of her husband's property such that $k = k_1 > c(n^*)$,

Proposition 2 *When $r = r_0 = 0$ and $k = k_1 > c(n^*)$, the strategy profiles $(n_1, c(n_1), a)$ and $(n_1, 0, z)$ are subgame perfect, along with the equilibrium number of children $n_1 > n^*$ and a widow's payoff $r_0 = 0$.*

Here, n_1 satisfies $k_1 - c(n_1) = 0$.

On one hand, securing a widow's right to inherit her husband's property increases her utility obtained outside a levirate marriage. To encourage such widows to remain in this traditional marriage, a clan must increase the amount of support s, which makes this practice costly and may undermine it. Note that increases in bequest amounts allow widows to afford many children. Accordingly, a clan increases the number of children to the level of $n_1 > n^*$. On the other hand, in an economy that already practices levirate marriage, the proposition 2 also suggests that solely improving widows' property rights may not always eliminate this social institution, because the strategy profile $(n_1, c(n_1), a)$ is still subgame perfect.

[6] From 2013 to 2015, I interviewed a number of rural people in Rorya, a district in the Mara region in northeast Tanzania. Rorya is primarily settled by the Luo, an ethnic group that traditionally practices levirate marriage. In this survey, a relatively large number of Luo widows indicated that material support from inheritors only helped satisfy their subsistence needs. This field observation is also compatible with the model prediction.

2.2.2 Female empowerment: An increase in r

The female empowerment one observed in Tanzania in the 1990s might also have secured women's rights to inherit their parents' property while increasing widows' reservation utility. Considering $r = r_1 > 0$, it can be shown that

Proposition 3 *When $r = r_1 > \tau$ and $k = k_0 \leq c(n^*)$, the strategy profile $(n^*, 0, l)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_1 > 0$. When $r = r_1 \leq \tau$ and $k = k_0 \leq c(n^*)$, the strategy profile $(n^*, c(n^*) + r_1, a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_1 > 0$.*

When widows can sufficiently afford their own livelihood such that $r_1 > \tau$, levirate marriage breaks down. Owing to an increase in the availability of outside options, widows do not have to rely on levirate marriage to make a livelihood. To prompt such widows to enter into a levirate marriage, a clan must increase the amount of support s, which makes the practice costly. As a result, this practice disappears. In this case, the dissolution of a levirate marriage coincides with an increase in a widow's welfare (i.e., $r_1 > 0$).

Indeed, this equilibrium appears to exist among some ethnic groups in Tanzania, such as the Zita (as determined through my field interviews) and Nyakusa (Wilson, 1987, p. 123), with the former group primarily settling in the Bunda district of the Mara region and the latter largely inhabiting the southern mountains of this country. For instance, Zita widows are traditionally allowed to return to their natal villages in case of their husband's death without repaying bride prices, conditional on their children being left behind. After returning home, they start a new life by inheriting their parents' property and/or re-marrying, with their new husband now making bridewealth payments to their parents.

2.2.3 HIV/AIDS

The spread of HIV/AIDS can also destroy the practice of levirate marriage. When a husband dies of HIV/AIDS, a widow is likely to be HIV positive. By inheriting (and having sexual intercourse with) a widow, a husband's clan members (e.g., an inheritor, an inheritor's wife) may also contract HIV/AIDS. In addition, a seronegative widow may also become infected with the deadly virus, provided that she is inherited by her husband's clan members who are HIV positive and/or that her inheritor already has (possibly multiple) wives. These expected infection costs of a husband's clan $h_c > 0$ and of a widow $h_w > 0$ can be included in payoffs realized in the strategy profile (n, s, a), i.e., $v_c(n, s, a) = u(n) - s - h_c$ and $v_w(n, s, a) = s - c(n) - h_w$.

In theory, it is possible for a clan's members to avoid having such sexual intercourse with a likely HIV-positive widow even if they inherit her. In a traditional society, however, the occurrence of levirate marriage typically follows sexual cleansing. In other words, a brother-in-law or a clan's other male members perform one-time ritual sex with a widow after the burial of her husband (e.g., Agot, 2007; Gunga, 2009). An uncleansed widow is perceived as impure and dangerous to a community and her social interactions are quite restricted. Thus, this cleansing is a pre-requisite for widows to be reintegrated into a society. Berger (1994) argues that in Uganda, levirate marriage is not possible unless it comes with the traditional component of sexual cleansing. As Malungo (2001) observed in Zambia, widows who underwent sexual cleansing are typically expected to contract levirate marriage. In addition, to fulfill the culturally prescribed rituals, using a condom is often unacceptable based on a traditional norms, as it means placing a barrier between the ritual performers (i.e., widows and the inheritors) (e.g., Ambasa-Shisanya, 2007; Luke, 2002; Perry et al., 2014). Furthermore, note that HIV/AIDS impairing widows' heath makes them less productive in various activities (e.g., agricultural work, child care) and thus, increases their effective child-rearing cost, which yields the same implication as $h_w > 0$. Therefore, a clan inheriting HIV-positive widows would have to increase the amount of livelihood support s, which makes levirate marriage more costly to the clan even if sexual intercourse is avoided.

The infection costs of HIV/AIDS do not necessarily make widows avoid levirate marriage. First, the infection risk of a husband's clan (h_c) does not affect a widow's decision to accept levirate marriage. In addition, a widow still has an incentive to follow the customary practice as long as her husband's clan compensates for her infection risk (h_w) by increasing the material support given to her.

Compared with widows, a husband's clan has more reason to stop the practice of levirate marriage. First, a clan becomes reluctant to offer levirate marriage as the corresponding expected infection risk h_c reduces the utility arising from adherence to this social custom. Second, to prompt a widow to accept levirate marriage, a clan must increase its material support by the amount h_w, which further discourages a clan from continuing this practice. Consequently,

Proposition 4 *Assume that $r = r_0 = 0$, $k = k_0 \leq c(n^*)$, and the disease cost is high enough such that $\tau < h_c + h_w$. Then, when $\tau \geq \Delta$, the strategy profile $(n_0, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_0 \leq n^*$ and a widow's payoff $r_0 = 0$. When $\tau < \Delta$, the strategy profile $(n^*, 0, l)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_0 = 0$.*

Here, n_0 satisfies $k_0 - c(n_0) = 0$ and $\Delta \equiv u(n^*) - c(n^*) - u(n_0) + c(n_0) \geq 0$ (by definition of n^*).

The high disease cost ($\tau < h_c + h_w$) discourages a clan from practicing levirate marriage. When the child-rearing cost borne by a clan's female members is large (i.e., $\tau \geq \Delta$), a clan prefers a widow to take care of her children by relying on property bequeathed to her. However, since the amount of bequest is not large (i.e., $k = k_0 \leq c(n^*)$), she cannot afford many children. As a result, the clan reduces the number of children to the level of $n_0 \leq n^*$. When raising children of the deceased is not costly to a clan (i.e., $\tau < \Delta$), the clan encourages a widow to leave her husband's home alone.

In contrast with the second example of female empowerment (i.e., an increase in r), this HIV/AIDS-driven institutional change does not increase a widow's welfare because it keeps her equilibrium payoff at the level of $r_0 = 0$. Intuitively, even if levirate marriage disappears because of the spread of HIV/AIDS, widows' social status remains low both before and after its disappearance and therefore, there is no reason for them to experience welfare improvements.

To make matters worse, it is also possible that the infectious disease reduces widows' reservation payoffs. This is possible because widows who lose their husbands to HIV/AIDS may also be HIV positive and therefore, face difficulty in finding a new marital partner. This situation can be interpreted as $r = r_2 < 0$. As a corollary of the proposition 4, it is easy to expect that HIV/AIDS undermines levirate marriage while decreasing widows' welfare.

Kagera is one of the regions most seriously affected by HIV/AIDS in Tanzania. Owing to the government's great efforts to fully understand the disease situation in this region, as seen in the Kagera AIDS Research Project initiated in 1987 (Lugalla et al., 1999), people's awareness of AIDS had already been raised by the early 1990s (e.g., Killewo et al., 1997; Killewo et al., 1998). In the KHDS data set, approximately 90% of 30 sample villages that had practiced levirate marriage in the early 1980s made this practice less customary by 2004. The spread of HIV/AIDS might have contributed to the disappearance of levirate marriage.

2.2.4 HIV/AIDS-induced female empowerment

In reality, the two mechanisms of female empowerment and of HIV/AIDS may not be mutually exclusive. One example is that HIV/AIDS established widows' de facto property rights. In other words, the shrinkage of the male labor force caused by HIV/AIDS enabled widows to obtain land rights in a family/village, as females had to control land owing to a greater number of male deaths.

This HIV/AIDS-driven female empowerment is possible, going by the findings provided by Goldstein and Udry (2008); according to them, a person's agricultural effort is often associated with establishing his/her land tenure in Africa. In addition, as will be delineated in subsection 6.1, this sort of female empowerment indeed appears to have arisen in Uganda (e.g., Mukiza-Gapere and Ntozi, 1995) and Zambia (e.g., Malungo, 2001). When this situation, reflected as $k = k_1 > c(n^*)$, occurs simultaneously with the aforementioned HIV/AIDS-induced decline in widows' reservation payoffs (i.e., $r = r_2 < 0$), it can be shown that

Proposition 5 *When $r = r_2 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_2 < h_w + h_c$, a strategy profile $(n_3, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_3 > n^*$ and a widow's* *payoff* $r_2 < 0$.

Here, n_3 satisfies $k_1 - c(n_3) = r_2$.

In this example, HIV/AIDS destroys the practice of levirate marriage owing to both mechanisms explained in subsection 2.2.1 and subsection 2.2.3. In this case, the disappearance of levirate marriage coincides with an increase in the number of children (i.e., $n_3 > n^*$) as well as a decrease in widows' welfare (i.e., $r_2 < 0$).[7]

2.3 Theoretical implication

This subsection summarizes important theoretical implications, along with a summary of the previous propositions provided in Table 1. First, while levirate marriage can be seen as a safety net for widows (as anecdotally argued), the material support such arrangements offer is minimal and only satisfies widows' subsistence needs.

Second, the disappearance of this practice may not necessarily mean that females are empowered. Given the intricate relationship among HIV/AIDS, female empowerment, and institutional change, it is possible that the deterioration of levirate marriage is associated with a range of (positive, negative, or no) changes in widows' welfare and women's fertility. It is also noted that in reality, the two factors of HIV/AIDS and female empowerment could simultaneously contribute to the disappearance of levirate marriage.

Third, in the preceding model, a husband's clan (resp., a widow) is institutionally advantaged (disadvantaged) in a traditional society sustaining levirate marriage. Thus, the mechanisms presented above imply that both the "positive" socioeconomic shocks (e.g., female empowerment) affecting the disadvantaged group (e.g., a widow) and "negative" shocks (e.g., HIV/AIDS) more pronouncedly affecting the advantaged group (e.g., a husband's clan) may disintegrate traditional institutions, with the former increasing the disadvantaged group's welfare, and the latter reducing the corresponding welfare.[8]

While the tendency of cultural institutions (i.e., the slow speed of institutional mobility) is not explicitly modeled in this study, intuitively, it is likely that institutional change occurs more slowly in the case of female empowerment compared with the case of HIV/AIDS, because the advantaged group that has historically benefited from the traditional scheme may resist the transformation (e.g., Luke and Munshi, 2011; Munshi and Rosenzweig, 2006). If so, the swift deterioration of levirate marriage in sub-Saharan Africa in recent years may be compatible with the case of HIV/AIDS.

[7] Admittedly, there are more women than men infected with HIV in sub-Saharan Africa (e.g., Anderson, 2018), which may, in principle, enable women to find a marital partner more easily than men because there are fewer women than men in marriage markets. However, this conjecture does not necessarily invalidate the aforementioned argument because men still tend to avoid marrying HIV-positive women (e.g., Ueyama and Yamauchi, 2009).

[8] Relatedly, Luke and Munshi (2011) and Munshi and Rosenzweig (2006) showed that "positive" economic shocks (e.g., English-education opportunities, income generating opportunities) affecting disadvantaged groups (e.g., girls, low-caste groups) could contribute to dissolving traditional institutions (e.g., caste) while improving their welfare.

In addition, as seen from Table 1, the sum of a clan's and a widow's equilibrium payoffs is the greatest at the level of $u(n^*) - c(n^*) + r_1 - \tau$ when a widow leaves her husband's home and receives a considerable amount of reservation utility (i.e., $r = r_1 > \tau$), followed by the levirate marriage equilibrium yielding $u(n^*) - c(n^*)$. Note that simply making it possible for a widow to inherit her husband's property (i.e., an increase in k) would reduce this total welfare to the level of $u(n_1) - c(n_1)$, compared with the case of the levirate marriage equilibrium.[9] This total welfare cannot necessarily be seen as social welfare, as it does not include the welfare accruing to a widow's children. Nevertheless, these findings may still suggest that the relationship between traditional institutions (apparently) violating women's human rights and social welfare is not so simple.

Admittedly, the above theoretical model is a crude attempt to understand the practice of levirate marriage, which has recently been disappearing in African societies. As seen from the analyses detailed in Section S.1 in the supplemental appendix, however, the main theoretical implications are robust to several model extensions that consider a widow's option to leave together with her own children, uncertainty about a couple's death, female (limited) power to control fertility (moral hazard), and so on. As discussed in subsection 6.3 (and subsection S.1.4 in the supplemental appendix in more detail), the analysis of female fertility control enables this study to consider the case that the number of children would increase because of women's fertility effort. In addition, HIV/AIDS may also increase the probability that a husband dies before he produces the optimal number of children, whose consequences are also analyzed in subsection S.1.5 in the supplemental appendix.

[Here, Table 1]

3 An association test

Data exploited in this study is drawn from the KHDS, a longitudinal household panel survey comprising six waves, with the first four waves carried out between 1991 and 1994, and the remaining two waves conducted in 2004 and 2010, respectively. The empirical analysis is based on data drawn from the first five waves pertaining to all of the 51 KHDS villages.[10] In wave 5, the survey team asked a group of village leaders whether it was common for a widow to be inherited as a wife by the brother or other male relatives of the deceased currently, (approximately) 10 years earlier, and 20 years earlier. Over 20 years, the number of villages commonly practicing levirate marriage significantly decreased from 31 to 17 (10 years ago) and 3 (wave 5). In this section, a strategy to explore the underlying mechanisms

[9] The improvement of widows' property rights is seen as a constraint which prevents a clan from choosing the desired number of children, n^*. Given no change in widows' reservation utility, this type of female empowerment reduces a clan's utility from the levirate marriage equilibrium without increasing widows' one.

[10] More precisely, the KHDS sample covers 51 communities located in 49 villages. However, this study uses "villages" and "communities" interchangeably.

responsible for the recent deterioration of levirate marriage based on this information is discussed.

3.1 Hypothesis building

Given the aforementioned theoretical model, a simple way to examine why levirate marriage has been disappearing is to estimate the (reduced-form) impacts of HIV/AIDS and female empowerment on the likelihood that a widow enters into a levirate marriage. However, this approach cannot be adopted in the current study because the KHDS data does not have information on widows' engagement in such traditional marriages at the individual level. To the best of my knowledge, it is difficult to find alternative data sets that provide such information (and even the community-level prevalence of levirate marriage) that lends itself to the current empirical investigation.

As an alternative, the mechanisms driving the dissolution of levirate marriage are tested by investigating a "correlation" between institutional change, as discerned from the aforementioned community-level information included in the KHDS, and changes in welfare outcomes (i.e., widows' welfare and married women's fertility) recorded at the individual level. The relevant equilibrium predictions are summarized in Table 2, whereby changes in a widow's equilibrium payoffs and women's fertility from the levirate marriage equilibrium are denoted as Δv_w and Δn, respectively. For example, if the disappearance of levirate marriage is associated with not only a decrease in widows' welfare but also an increase in women's fertility, which is actually the case demonstrated in the subsequent empirical analysis, this data pattern is compatible with the view (i.e., the proposition 5) that HIV/AIDS triggered the institutional change while establishing widows' de facto property rights.

However, exploring a simple correlation across the relevant variables is not useful, because such a correlation is attributable to many other factors.[11] Therefore, the proposed testing method still requires an appropriate strategy to identify a correlation stemming "only" from the mechanisms considered in the previous theoretical analysis. This identification strategy is discussed in the following subsections. Unlike standard empirical studies, hereinafter, it is said that the estimates are "biased" if the estimated correlation between the institutional change and welfare outcomes arises from factors not relevant to the theoretical mechanisms that this study focuses on.

[Here, Table 2]

[11] For example, being infected with HIV/AIDS (that may correlate with the prevalence of HIV/AIDS and therefore of levirate marriage in a community) may reduce a widow's welfare by deteriorating her health and thus, preventing her from engaging in any income-generating activities. Or, women exposed to urban lifestyles and values may prefer to reduce the number of children as well as to avoid the practice of levirate marriage simply because of the preference for modernity.

3.2 Identification strategy

3.2.1 Institutional change and widows' welfare

Pooling data pertaining to females of reproductive age (15—50) in wave 1 and wave 5 of the KHDS, this study first estimates the log of per capita annual consumption y_{ijt} (i.e., a household's consumption divided by the number of its members) of a female i in a period t (wave 1 or wave 5) as[12]

$$y_{ijt} = \alpha_1 + \alpha_2 D_{jt} \cdot w_{ijt} + \alpha_3 w_{ijt} + \alpha_4 \mathbf{x_{ijt}} + v_{jt} + \epsilon_{ijt}, \tag{7}$$

whereby D_{jt} takes the value one if levirate marriage is no longer a customary practice in a KHDS village j in the period t; w_{ijt} is a dummy variable, equal to one if the female i is widowed in the period t and zero otherwise; the vector $\mathbf{x_{ijt}}$ contains other determinants of consumption specific to the female and her household in the period t (e.g., age, education, and land and household size, which are expected to measure the household's financial capacity); v_{jt} represents a linear time trend specific to the KHDS village j; and ϵ_{ijt} is a stochastic error. As noted above, existence of levirate marriage in the past is only discerned from recall information provided by the wave 5 survey. Thus, it is assumed that the D_{jt} takes zero in wave 1, provided that the village leaders of the wave 5 survey had accepted that levirate marriage had commonly been practiced (approximately) 10 years earlier in a surveyed village j. Throughout the paper, the standard errors in equation (7) (and equation (8) explained below) are robust to heteroskedasticity and clustered to allow for arbitrary correlations across individuals within a village.

Importantly, the coefficient of interest, α_2, should be interpreted as a correlation induced only by the theoretical mechanisms that this study has in its scope (i.e., either HIV/AIDS, female empowerment, or the combination). In fact, based on the proposition 1 in Section 2, it is likely that widows obtain reservation utility from the relationship of levirate marriage. In this case, no causal impact of levirate marriage on widows' welfare is expected.

While the α_2 should not be given a causal interpretation, as described above, it is still necessary to remove any confounding factors that prevent this study from identifying the correlation resulting only from the aforementioned theoretical mechanisms. For this, the specification (7) compares changes in consumption patterns of the relevant females from wave 1 to wave 5 between villages where levirate marriage grew less customary during the sample periods (16 villages) and all other villages (which means, difference-in-differences).[13] Since this study exploits all the

[12] A household's consumption includes food consumption (seasonal and non-seasonal) and non-food consumption (e.g., education and health expenditures, miscellaneous non-food expenditures). The consumption data has been cleaned by the KHDS team and the resulting dataset is publicly available. See *Kagera Health and Development Survey – Consumption Expenditure Data* for the details at `http://edi-global.com/publications/`.

[13] More precisely, the former group consists of 16 communities located in 14 villages. See also footnote 10.

KHDS villages, the latter group includes those with either $D_{jt} = 0$ (one village) or $D_{jt} = 1$ (32 villages) in both wave 1 and wave 5 as well as two villages with $D_{jt} = 1$ in wave 1 and $D_{jt} = 0$ in wave 5. While it is possible to separate this group further, this was not done in this study to simplify the analysis.[14] However, this difference-in-differences (DID) approach is still effective, as long as the consumption patterns in these different types of villages, as one group, followed a similar trend. Analyzing data pertaining to only the aforementioned 16 villages (i.e., $D_{jt} = 0$ in wave 1 and $D_{jt} = 1$ in wave 5) and the 32 villages (i.e., $D_{jt} = 1$ in both wave 1 and wave 5) did not affect the key implications obtained in this study, either.[15] Furthermore, by focusing on a comparison of consumption between widows and others (which implies triple difference), this study eliminates the influence of time-varying unobserved village-level characteristics that affected these villages over time in a different manner.

While the KHDS is a panel survey, the above empirical approach exploits the data as if it were pooled cross-sectional data sourced from two different points in time (i.e., wave 1 or wave 5). This approach is identical to that adopted in Kudo (2015). This strategy allows the current study to exploit data variations fully while avoiding the unnecessary selection of the sample as well as the associated potential "bias." To facilitate an interpretation of the identification strategy, more detailed discussion is provided in Section S.2 in the supplemental appendix.

3.2.2 Institutional change and fertility

In its analysis of fertility, this study exploits data on reproductive-age women whose husbands are household heads, because fertility-related information available in the data consists only of the number of a head's (biological) co-resident children f_{ijt}. The model presented in Section 2 implicitly assumes that a clan of husbands having "wives of reproductive age" chooses the number of children. Thus, the selection of this female sample as a unit of observation is still consistent with the theoretical framework, which encourages to estimate the following empirical model

$$f_{ijt} = \beta_1 + \sum_k \beta_2^k \cdot D_{jt} \cdot o_{ijt}^k + \sum_k \beta_3^k \cdot o_{ijt}^k + \beta_4 \mathbf{x_{ijt}} + v_{jt} + u_{ijt}, \tag{8}$$

where o_{ijt}^k is an indicator that equals one if the respondent belongs to age group k and zero otherwise. The reference group is the oldest group, i.e., those aged 41 to 50. Assuming that the disappearance of levirate marriage is associated with fertility decisions, this institutional mobility may have a more evident correlation with the number of children born to young (thus, fecund) females. Interacting D_{jt} with o_{ijt}^k enables this study to examine this prediction while

[14] Regarding the two villages reporting $D_{jt} = 1$ in wave 1 and $D_{jt} = 0$ in wave 5, its pattern is somewhat difficult to interpret given the declining tendency of levirate marriage. Once these two villages are excluded, 32 of 33 villages were recorded as $D_{jt} = 1$ in both wave 1 and wave 5. Therefore, this separation is likely to have limited impacts on the current analysis.

[15] The relevant results are available upon request.

again allowing controlling for time trends specific to the original KHDS villages. As before, the β_2^k should be interpreted as a correlation driven by either HIV/AIDS, female empowerment, or their combination.

4 Data

The World Bank launched the KHDS in Kagera, a rural region in northwest Tanzania, as a part of a research project on adult mortality and morbidity in 1991. The KHDS is a long-term household panel survey that includes six waves, as of now. This survey provides a range of information related to households, as well as their members and community, thus enabling the current study to construct unbalanced panel data at the individual level (although as discussed in Section 3, the empirical strategy exploited in this study utilizes the data as if it were pooled cross-sectional). The first four waves were carried out six to seven months apart between 1991 and 1994, with the remaining two waves taking place in 2004 and 2010, respectively. Since this project used a standardized survey questionnaire, highly comparable information is available across the waves. This study uses the data drawn from the first five waves. This is because a community survey was not implemented in wave 6 and, therefore, the data set in the final wave has no information on local customary practices.

With stratifications based on geography and mortality, the initial 912 households were randomly selected from the 1988 Tanzanian Census. In wave 5, approximately 91% of these baseline households were re-contacted. Owing to the long-term nature of the project, a significant proportion of the family members surveyed earlier had moved out of their original households/villages between wave 1 and wave 5. One of the many contributions of this longitudinal survey was the survey team's success in tracing new households. This strenuous effort resulted in 2,719 household interviews in wave 5, including those done with the original households. Consequently, this survey shows a significantly low rate of sample attrition at both the individual and household levels. Excluding individuals that died, approximately 82% of the 5,394 original respondents who were interviewed in the first four waves were successfully re-contacted in wave 5 (Beegle et al., 2011). The analysis in this study uses data pertaining to only panel respondents originating from all of the 51 KHDS villages. This sample includes those who resided in different places from their original villages in wave 5 (i.e., migrants). As explained in Section S.2 in the supplemental appendix, inclusion of the migrants would not invalidate the analysis. Information on new respondents in the wave 5 survey is not exploited. Table 3 provides a description of several variables pertaining to the sample females of reproductive age. In this table, group A refers to villages that made the traditional safety net less prevalent during the sample periods (16 villages), with group B consisting of all the remaining villages, and the equality of the mean between these two groups was checked.

By controlling for the village-specific linear time trend, the key identification assumption underlying the triple-difference approach is that in the absence of the deterioration of levirate marriage, a difference in the consumption levels between widows and the remaining females within the same village would have followed parallel trends (both before and during the institutional change) between the two groups A and B. A similar assumption is also needed in estimating fertility when comparing the outcome of the young cohort with that of the elderly one.

Unfortunately, as the data prior to wave 1 is not available, it is difficult to ascertain the parallel trends during the pre-survey periods. However, it is still possible to examine the relevant welfare outcomes of respondents in wave 1 across different age cohorts. As revealed from the estimation result of consumption in column (a) in Table S.1 in the supplemental appendix, a coefficient on the tripe-interaction term between the group A indicator, a widow dummy, and age (years) is insignificantly different from zero. While it is only possible to estimate the DID specification for fertility, the interaction term between the group A indicator and age yielded an insignificant coefficient in column (c). These findings are robust to the inclusion of the squared age terms, as shown in the remaining columns.

This study also assessed whether changes from wave 1 to wave 5 in the mean value of variables reported in Table 3 were statistically equal between the two groups, and the DID estimates are demonstrated in Table S.2 in the supplemental appendix. The DID estimates revealed few significant differences in the changes of all reported variables. While these checks undoubtedly fall short of providing strong evidence in support of the parallel trend assumption, the yielded findings may still offer some comfort to the triple-difference approach exploited in this study.

[Here, Table 3]

5 Empirical findings

5.1 Widows' welfare

The estimation results of consumption are presented in Table 4. For each outcome reported in this table (and Table 5), the analysis in the first column controls for time-varying characteristics that affected the KHDS villages over time in a "similar" manner, in addition to fixed effects of the (original) KHDS villages. The estimations in the second column additionally include regressors for age, years of living in a village, and gender of the person responsible for providing information on customary practices in community surveys. These controls are expected to mitigate concerns over the potential noise in the measurements of levirate marriage. In the remaining columns, the village-fixed effects and region-wise time trend exploited in the first two columns are replaced by a village-specific linear time trend. The influence of changes in general marriage (and/or other) market conditions, population, and any other factors (e.g., economic hardship, religiosity, raising awareness, legal framework) operating at the village level can be absorbed by this time trend.

The estimated correlation between the disappearance of levirate marriage and widows' welfare displays a relatively stable pattern across the columns in Table 4. First, based on the results in columns (a) to (c), on average, the deterioration of the traditional safety net had a negative correlation with widows' per capita consumption, but the correlation is insignificantly different from zero. Applying the methodology proposed by Collier et al. (1986) (pp. 70—73) for Tanzania, this study also estimates consumption per adult equivalent as well as that per adjusted adult equivalent, the results of which are presented in columns (d) to (f) and (g) to (i), respectively. The former measure reflects nutritional requirements that vary by gender and age of typical individuals, whereas the latter additionally takes into account the effects of economies of scale attributed to household size. The results suggest that widows' consumption declined in step with the dissolution of levirate marriage.

While the statistical significance is not always strong, the estimations in Table 4 reveal the negative relationships between widows' consumption and the deterioration of levirate marriage. As will be discussed more carefully in Section 6, this finding highlights the role of HIV/AIDS as a factor facilitating this institutional change. If this infectious disease indeed plays a significant role, this correlation is expected to be more pronounced for young females having prime-age husbands. This is because HIV/AIDS primarily increased prime-age adult mortality in Kagera (Beegle, 2005; Beegle et al., 2008). Based on a population-based follow-up survey that Killewo et al. (1993) conducted in Kagera in 1988, for example, among males aged above 15 years, incidence of HIV infection was highest in the age group of 25 to 34.

To explore this possibility, this study re-estimated equation (7). While data on female respondents aged 15 to 50 were exploited in the previous estimations, the analysis here utilized different female samples by varying the upper bound of respondents' age. The estimated α_2 and its 95% confidence interval are graphically reported in Figure 2 (see Table S.4 in the supplemental appendix for the precise estimates).[16] In this figure, the estimate corresponding to age m in the horizontal axis stems from the regression using data pertaining to females aged 15 to $m-1$ years.

As the figure shows, when the upper bound on age is less than 21 years ($m \leq 21$), the estimates appear to be imprecise. This could reflect the fact that only a few females are widowed in this age cohort. For example, in the estimation using 805 females aged 15 to 20, only four respondents are widowed. However, as the estimated sample includes females in their late-20s and early-30s (and more widows), the deterioration of levirate marriage comes to have increasingly negative correlations with widows' consumption at conventional levels of statistical significance. Moreover, if data relevant to much older females are exploited in the analysis, then the estimates gradually tend toward zero.

[16]Instead of age-cohort dummies, these estimations exploited age and age squared as regressors.

This finding suggests that the disappearance of levirate marriage relates to a decline in welfare obtained by widows belonging to young age cohorts.[17]

[Here, Table 4 and Figure 2]

5.2 Fertility

Table 5 reports the estimation results of equation (8). Based on the results in columns (a) to (d), females aged 21 to 40 increased their number of children compared to those aged 41 to 50 (reference group) in association with loss of the informal safety net. Owing to this significant association, pooling all those aged below 41 years into one category and estimating the same equation still yielded a significantly positive correlation between the institutional change and fertility in column (e). Utilizing the continuous measure of age (years) in column (f) also confirmed the positive correlation between the deterioration of levirate marriage and fertility of young wives.

The correlation evidently observed in that 21—40 age cohort is quite reasonable because female respondents aged 21 to 40 in wave 5 were aged 8 to 27 years in wave 1, and were likely to show higher fecundity during the sample periods than those in any other cohorts. On the other hand, females aged below 15 (resp., aged 41 to 50 years) in wave 5 might have been too young (old) to adjust their number of children during the investigation period in parallel with the dissolution of levirate marriage.

Despite the plausible empirical findings, several concerns should be addressed. First, as the estimated outcome is the number of children born to a household's head, the estimation results may also be consistent with the view that in villages where the practice of levirate marriage became less common, young females who lost a husband entered into polygynous relationships with male heads having multiple wives and thus many children. Second, the estimated number of children does not include children residing elsewhere. As parents grow older, co-residence with their children is less likely because most adult children leave their natal home to form their own family. Consequently, the elder cohorts of wives tend to have a smaller number of co-resident children. Third, given the presumed non-normal distribution of the fertility outcome, the OLS estimations might not provide adequate implications. Robustness checks conducted in Section S.3 in the supplemental appendix may mitigate these concerns (while if any, providing statistically stronger evidence for the positive correlation between the disappearance of levirate marriage and young women's fertility).

Thus far, this study has demonstrated that the deterioration of levirate marriage is negatively associated with young widows' consumption, while being positively correlated with the fertility of young wives (aged 21 to 40). The finding

[17]Figure S.4 and Figure S.5 in the supplemental appendix also report correlation of the institutional change with widows' consumptions per adult equivalent and per adjusted adult equivalent, respectively (see Table S.4 in the supplemental appendix for the precise estimates). The implications remain unchanged.

that the estimated correlations are more pronounced for the young cohort is plausible, presuming that HIV/AIDS primarily affected the young population and that young respondents show higher fecundity; therefore, it may mitigate the concern that the identified correlations are entirely attributed to confounding factors unrelated to the theoretical mechanisms that this study focuses on. In addition, note that the R-squared values shown in the previous estimations of consumption and fertility are relatively large. This may suggest that there is little variation of the outcomes left to "bias" the coefficients of interest (Oster, forthcoming). Nevertheless, several threats to the finding are carefully discussed in Section S.4 in the supplemental appendix.

[Here, Table 5]

6 HIV/AIDS as an agent of institutional change

The main finding of this study is compatible with the proposition 5 in Section 2; HIV/AIDS reduced widows' reservation utility as well as established their de facto property rights, while also discouraging a husband's clan from providing this traditional safety net. It should also be recalled that based on the KHDS data, this centuries-long practice has started to disappear only during the past 20 years in the area studied. As argued in subsection 2.3, this swift transformation may be consistent with the influence of HIV/AIDS, especially considering that in Tanzania, the first case of AIDS was reported in Kagera in 1983 (e.g., Ainsworth et al., 1998; Lugalla et al., 1999), and the primary purpose of the KHDS was to examine the economic impact of prime-age adult deaths on surviving household members owing to the high HIV infection rates in this region (e.g., Beegle, 2005; Beegle et al., 2008). Nevertheless, the aforementioned interpretation of the estimation results requires more careful discussion, as demonstrated in this section.

6.1 Anecdotal support for the influence of HIV/AIDS

A non-negligible amount of case studies support the claim that HIV/AIDS has contributed to the disappearance of levirate marriage in Africa, as studied in Kenya (e.g., Luke, 2002; Perry et al., 2014), Uganda (e.g., Berger, 1994; Mukiza-Gapere and Ntozi, 1995; Ntozi, 1997), and Zambia (e.g., Malungo, 2001). Consistent with the assumption of the theoretical model in Section 2, this institutional change is taking place because both the inheritors and widows fear infection with HIV/AIDS stemming from practicing this customary marriage (and the associated sexual cleansing). For instance, I, specifically for the purpose of this research, conducted an original (cross-sectional) household survey (810 respondents) relevant to the Luo's customary practices in Rorya, a district in the Mara region of northeast Tanzania in November—December 2015 using a structured questionnaire.[18] The Luo is an ethnic group that has received much publicity for its practice of levirate marriage. In this survey, 80% (resp., 83%) of the interviewed females and 84% (90%) of their husbands "strongly agreed" (or "agreed") to the view that levirate marriage increased the risk of people being infected with HIV, respectively. Similarly, according to 4,500 interviews that Doosuur and Arome (2013) conducted in Benue state of Nigeria, men more than women perceived the practice of levirate marriage as a mode of HIV transmission. In Zambia, a lobby group asked for legislation banning sex cleansing typically followed by levirate marriage because of the fear of spreading HIV/AIDS (Kunda, 1995). The chiefs in Chikankata Hospital catchment area of Zambia also enacted a law to abolish sexual cleansing in the early 1990s for a similar reason (Malungo, 2001).

It appears that the socioeconomic consequences of the break down of levirate marriage triggered by HIV/AIDS vary across societies and/or widowhood cases within a society. For example, some Luo widows in Kenya refused levirate marriage and moved to the urban center to look for a new means of livelihood (Luke, 2002). According to a case study of widowhood rites in Slaya district in Kenya, young widows who refrained from observing sexual cleansing, also migrated to towns and to make ends meet, engaged in petty trade and sometimes secret sexual liaisons (Ambasa-Shisanya, 2007). Based on the focus-group discussion facilitated by Ntozi (1997), widows' migration to other parts of the country was also observed in Uganda. Recalling the theoretical model in Section 2, this sort of relocation of widows may be seen as a strategy l accompanied by their reservation utility r, which was possibly lowered by HIV/AIDS.

As Mukiza-Gapere and Ntozi (1995) found in Uganda, another scenario also emerged, whereby property was increasingly left to wives and children of the deceased, even though clan members of the deceased used to take over the property from the widows in the past. Similarly, in present-day Zambia, family members of the deceased are sometimes expected to provide financial, material, and social support for the remaining widow and children, as the practice of levirate marriage is no longer offered to the widow (Malungo, 2001). This necessary care of the remaining household members generated a long policy debate in this country, which resulted in the enactment of the 1989 Intestate Succession Act, which allowed widows (resp., children) to inherit 20% (50%) of property left by the deceased. While this act may not be strictly enforced at the grassroots level in a society, these social movements suggest that HIV/AIDS could possibly establish widows' (whether de jure or de facto) property rights (i.e., an increase in k), which may enable them to afford many children and thus, explain why a positive correlation between the disappearance of

[18] The target population of this survey was young married females who may be inherited by male relatives of their husbands in the future as well as their husbands who may inherit widowed relatives in the future (or who have inherited widowed relatives). To reach a random sample of this population, from July to September 2015, I first attempted to make a list of married females aged 20 to 40 residing in all the villages in Rorya. This work encouraged the survey team to actually visit 82 villages (approximately 93% of the total villages in Rorya) based on Tanzania Population and Housing Census 2012, while enabling the team to list 9,900 eligible females in total. In each of the 82 villages, barring one village used for training the survey enumerators, five females and their husbands were randomly selected from the list, yielding 405 couples individually interviewed in the household survey in the end. Before starting this survey, I obtained a research permit from Tanzania Commission for Science and Technology (COSTECH) in July 2015.

levirate marriage and fertility was observed in the preceding empirical analyses.[19]

6.2 Analyses exploiting data on HIV/AIDS

To provide further evidence of the influence of HIV/AIDS as a factor driving the deterioration of levirate marriage, in this subsection, additional exercises are conducted based on HIV/AIDS-related information available to this study. In each wave of the KHDS, the survey team asked a group of village leaders about the health situation in a community. The number of villages that referred to HIV/AIDS as the most or second-most important health problem in a community increased from 18 in wave 1 to 32 in wave 5, with the corresponding in-between figures summarized as 25, 24, and 35 in wave 2, 3, and 4, respectively.

While the available data is highly limited, this study also attempted to collect estimates of the biomarker-based prevalence of HIV/AIDS from the following two information sources: 2003—04 Tanzania HIV/AIDS Indicator Survey (2003—04 THIS) and Killewo et al. (1990). The THIS is the first population-based comprehensive survey carried out on HIV/AIDS in Tanzania from December 2003 to March 2004 (see Section S.5 in the supplemental appendix for more details), whereas Killewo et al. (1990) estimated the district-level infection rate based on a population-based survey conducted in Kagera in 1987. Owing to the difficulty in estimating HIV/AIDS prevalence in general, however, the estimates provided by two "independent" data sources may not be temporally comparable. In addition, Killewo et al. (1990)'s estimates, which vary only by the number of districts (six districts), also have little data variation to allow for a rigorous empirical analysis.

Nevertheless, these estimates are still useful in reflecting the disease situation across space at each point in time and thus, in assessing the accuracy of the aforementioned HIV/AIDS-related information collected in the respective waves of the KHDS. As reported in Section S.5 in the supplemental appendix, the above subjective information in wave 5 (resp., wave 1 to wave 4) was consistent with the estimated disease prevalence based on the THIS (Killewo et al., 1990). This finding facilitates utilization of this subjective information in the empirical analysis that follows.[20]

In the current context, one way to proceed with this community-level information on HIV/AIDS collected in the KHDS is to regress the village-level prevalence of levirate marriage (i.e., D_{jt}) on the indicator for the villages that identified HIV/AIDS as the most or second-most important health problem in a community.[21] However, it is difficult

[19] In addition, the socioeconomic consequences of the HIV/AIDS-induced deterioration of levirate marriage also include development of alternative cleansing methods that do not involve sexual intercourse (e.g., Malungo, 2001), although such alternative cleansing may not always be accepted. Moreover, in some societies, clan members of the deceased are refusing to cleanse and inherit widows, instead handing over the task to some professional people (e.g., Ambasa-Shisanya, 2007; Luke, 2002; Nyanzi et al., 2009). It is also argued that these professional cleansers/inheritors are spreading HIV/AIDS, as they are quite likely to be HIV positive specifically owing to this business.

[20] The estimates provided by the THIS and Killewo et al. (1990) may also not necessarily have an advantage over this subjective information in accurately estimating the prevalence of the disease. For example, a measurement concern still arises, because the infection rate among those that did not test for HIV is unknown in the THIS.

[21] The DID estimation exploiting the village-level 102 observations (i.e., $102 = 51 \times 2$) in waves 1 and 5 as well as controlling for the

to interpret this estimate in a causal manner, because the practice of levirate marriage is often blamed for facilitating the sexual transmission of HIV/AIDS (e.g., Malungo, 2001; Okeyo and Allen, 1994).[22]

6.2.1 HIV/AIDS-related heterogeneity of the correlation

Alternatively, if levirate marriage has disappeared largely because of the influence of HIV/AIDS, the previously identified correlations between the institutional change and welfare outcomes might have been more pronounced in communities where this communicable disease had increasingly deteriorated the local health during the sample periods.

This prediction was checked for consumption and fertility in Table 6. Of the 51 KHDS communities, 17 did not refer to HIV/AIDS as the most or second-most important health problem in wave 1 but did so in wave 5.[23][24] Of the remaining 34 (= 51-17) communities, 31 communities did not identify HIV/AIDS as the most or second-most important health problem in both wave 1 and wave 5, whereas the other three communities did so only in wave 1.

For each outcome and specification demonstrated in Table 6, the estimation results exploiting data relevant to the 17 communities are reported in the first column, whereas those in the second column are relevant to the remaining 34 communities. First, the estimation results of consumption per capita, per adult equivalent, and per adjusted adult equivalent are reported in columns (a) to (f) for females of reproductive age. As seen from the results in columns (a) and (c), the negative correlation between the deterioration of levirate marriage and widows' welfare are more clearly observed in villages more severely affected by HIV/AIDS from 1991 (wave 1) to 2004 (wave 5). As Figure 2 showed, such a negative correlation is statistically the most distinct, if the analysis was limited to data pertaining to female respondents aged 15 to 28. In columns (k) to (p) in Table 6, the corresponding sub-sample is exploited. Compared with the estimation results using the full-sample in columns (a) to (f), the estimation results based on this sub-sample reveal that institutional change had a larger and statistically more pronounced negative correlation with widows' consumption in villages, whereby HIV/AIDS increasingly produced unfavorable consequences for the residents' health during the sample periods.

The relevant estimation results for fertility are reported in columns (g) to (j) in Table 6. In columns (g) and (i), the reduced sample size might have made the relevant estimates somewhat imprecise in the disease-stricken areas, as seen

region-wise time trend and village-fixed effects yielded an insignificant estimate (-0.052 with std. 0.171).

[22] However, there is also another view that the practice of levirate marriage impedes the spread of HIV/AIDS, because the infected widow is attached to a single inheritor and therefore, this practice contains the spread of the disease within an extended family of the deceased (Agot, 2001; Agot et al., 2010; Luke, 2002).

[23] It was also possible to construct an indicator for villages that referred to HIV/AIDS as the most important health problem in a community. While this number was 6, 13, 8, 22, and 4 in wave 1, 2, 3, 4, and 5, respectively, the decline in the number from wave 1 to wave 5 is somewhat difficult to interpret, given the likely influence of HIV/AIDS in Kagera (e.g., Beegle, 2005; Beegle et al., 2008). Therefore, in the analysis that follows, importance is given to the indicator for villages that identified HIV/AIDS as the most or second-most important health problem in a community.

[24] Note that the analysis in Table 6 is less likely to suffer from the aforementioned reverse causality from the practice of levirate marriage to the spread of HIV/AIDS, because it implicitly uses these pieces of information together as regressors.

from the increases in the associated standard errors. In particular, of the 374 observations exploited in the estimation of columns (g) and (i), only 9 (resp., 18) females were aged 15 to 20 in wave 1 (wave 5). This small sample size might by chance have made the correlation between institutional change and fertility statistically significant in this youngest cohort, as such a significant correlation was not observed in this cohort in the main estimation results presented in Table 5. Admitting this limitation, nevertheless, the magnitude of the positive correlation between institutional change and fertility in the cohorts aged 21 to 40 is greater in the HIV/AIDS-affected 17 communities than that in the remaining communities.

[Here, Table 6]

6.2.2 Reduced-form impact of HIV/AIDS on widows' welfare and fertility

If HIV/AIDS indeed brought about the deterioration of levirate marriage while establishing widows' de facto property rights, it is expected that this infectious disease causally reduced widows' welfare while increasing the number of children, as indicated in the proposition 5 in Section 2.

Accordingly, after replacing the D_{jt} in equation (7) and (8) with an indicator for the villages that referred to HIV/AIDS as the most or second-most important health problem in a community in the respective period, the impacts of HIV/AIDS on widows' welfare and parental fertility decisions are also investigated and the relevant estimation results are reported in Table 7. This impact, obtained using the triple-difference approach, may be seen as reduced-form effects of HIV/AIDS, as indicated in the theoretical model in Section 2. Unlike the information on D_{jt} that was recalled by a group of village leaders in the wave 5 survey, the community-level information relevant to HIV/AIDS was available in every wave of the KHDS. Therefore, in the estimations performed in Table 7, the relevant observations recorded in all the five waves were exploited. This treatment is expected to increase the precision of the estimates and power of the associated statistical test by increasing the sample size.

As the results in columns (a) to (c) show, HIV/AIDS reduced the per capita consumption of widows aged 15 to 50. However, the statistical significance is not always strong. As recalled from the analyses conducted in subsection 5.1, the negative welfare consequence of HIV/AIDS might have been more evident for widows belonging to a young age cohort. Taking a similar approach to that for the estimations performed in Figure 2, the impact of HIV/AIDS on consumption was estimated for females aged 15 to $m-1$ ($m \geq 16$), and the relevant estimates are reported in Figure 3 with 95% confidence intervals (see Table S.7 in the supplemental appendix for the precise estimates).[25] As the results show, HIV/AIDS reduced the consumption of young widows, and the magnitude and statistical significance of the

[25] Similar to the estimations reported in Figure 2, age and age squared are exploited as regressors in these estimations, instead of age-cohort dummies.

impact was more pronounced for widows aged 15 to 28. This finding is consistent with the fact that the negative correlation between institutional change and widows' welfare is more clearly observed for widows belonging to this particular age cohort, as seen in Figure 2.[26]

The impacts of HIV/AIDS on fertility are reported in columns (d) through (f) in Table 7 and the result suggests that females aged 21 to 40 increased their number of children during the sample periods as a result of this infectious disease than those aged 41 to 50 (reference group) did. Compared with those belonging to any other cohorts, females aged 21 to 40 in wave 5 were aged 8 to 27 years in wave 1 and thus, must have revealed great fecundity during the investigation period. Accordingly, the marked fertility response of this age cohort is quite reasonable. Moreover, this age cohort is exactly the same as the cohort in which the statistically significant positive correlation between the deterioration of levirate marriage and fertility were more pronouncedly observed in Table 5.[27]

Strictly speaking, the above estimates may be attenuated. For example, if relatively wealthy wives (whose husbands are active in the dating market or engage in polygyny) lost their husbands to HIV/AIDS in the disease-stricken areas, the aforementioned negative impact on widow's welfare would be biased upward. In addition, young women might have lost prime-age husbands (that were active in the dating market) in the HIV/AIDS-affected areas. Since the analysis of fertility limits attention to data on females whose husbands are alive and household heads, this study might have underestimated the number of children born to young, fecund wives in the disease-prone areas, while underestimating the positive fertility effects of HIV/AIDS in the young cohort. Additional exercises performed to evaluate the importance of omitted variables (required to explain the above HIV/AIDS impacts) based on Oster (forthcoming) supported the view of the possible attenuation and thus, kept the interpretation that HIV/AIDS decreased widows' consumption and encouraged the fertility of young wives.[28]

[Here, Table 7 and Figure 3]

[26] With 95% confidence intervals, Figure S.7 and Figure S.8 in the supplemental appendix also present the estimated effects of HIV/AIDS on consumption per adult equivalent and per adjusted adult equivalent, respectively (see Table S.7 in the supplemental appendix for the precise estimates). The implications are similar to those provided by Figure 3.

[27] Remember that the community-level prevalence of levirate marriage in wave 1 (i.e., D_{jt}) was estimated based on recall information provided by the wave 5 survey, whereas information on the measured prevalence of HIV/AIDS (i.e., indicator) was collected in all the waves of the KHDS. As detailed in Section S.5 in the supplemental appendix, the HIV/AIDS-relevant information in wave 1 was consistent with objective infection rates sourced from Killewo et al. (1990). Therefore, the remarkably similar heterogeneity based on respondents' age between Figure 2 and Figure 3 (for consumption) as well as between Table 5 and column (d) through (f) in Table 7 (for fertility) may mitigate a concern over measurement noise pertaining to the recalled prevalence of levirate marriage in wave 1.

[28] Following Oster (forthcoming), this study estimated a coefficient of proportionality on selection assumptions, as denoted as δ, for the significant coefficients on the interaction term between an indicator for widows [column (c) in Table 7] or a cohort aged 21 to 40 [column (f) in Table 7] and an indicator for HIV/AIDS-affected communities. Assuming that all the controls are proportional to unobservables, the estimated δ values for the column (c) was -1.548 when it is assumed that $R_{max} = 1.3\tilde{R}$, as heuristically suggested in Oster (forthcoming), and -0.492 when $R_{max} = 1$; whereby R_{max} refers to the value of R-squared obtained from a hypothetical regression of the outcome on the treatment, observed, and unobserved controls, whereas $\tilde{R}$ is the value of R-squared resulting from a regression on the treatment and observed controls. The corresponding values for the column (f) was -9.342 and -7.618, respectively. The negative δ values indicate that the aforementioned HIV/AIDS impacts appear to be attenuated if any (causality) bias exists.

6.3 Alternative interpretation

Each of the main findings of this study, i.e., negative (resp., positive) association of the disappearance of levirate marriage with young widows' welfare (young wives' fertility), may make sense on its own, if the causal interpretation is given to such relationships. First, widows might actually have lost welfare owing to the deterioration of the informal safety net that had benefited them previously. Second, considering the findings that an investment in childbearing may be an important strategy for young women to protect them in their old age in agrarian societies (e.g., Hoddinott, 1992; Jensen, 1990; Nugent, 1985), this institutional change might have encouraged a young woman to have more children, given the possibility that female (reproductive) rights are not entirely suppressed within a family. This is because children may protect her in the future instead of the traditional safety net.

However, if women had indeed previously gained from the practice of levirate marriage, it is necessary to explain why they agreed to stop this practice. One possibility is that since women found a better way to make a livelihood outside this customary marriage, they lost an interest in welfare services provided by levirate marriage. In this case, however, there is no theoretical reason to expect that young women attempt to increase the number of children. The aforementioned empirical findings also provide no support for such welfare improvement.

Alternatively, women could not resist the loss of the safety net, because they did not have a powerful voice in any matter to do with their husbands' families. In this case, it is less likely that married women had strong bargaining power over fertility decisions and that the positive fertility effect resulted from their behavioral response to protect their widowhood.

To increase the number of children, it may still be possible that married women reduced their use of concealable contraception in response to institutional change (e.g., Ashraf et al., 2014). Despite considerable increases in the use of injectables and pills for the period of 1991—2004, however, the respective prevalence rates were just 8.3% and 5.9% among married women in 2004—2005 (National Bureau of Statistics (NBS) [Tanzania] and ORC Macro, 2005, p. 74), and access to family planning was still limited, particularly in rural areas.[29][30]

Nevertheless, in subsection S.1.4 in the supplemental appendix, it was also attempted to interpret a woman's motive to substitute own children for levirate marriage in an extended theoretical model, whereby women expend fertility effort unobserved by a clan. As indicated in the discussion pertaining to the proposition S.7, if an increase in women's intrinsic motive for such substitution, which may be interpreted as a decline in an (extrinsic) incentive cost needed for

[29] The corresponding rate of male condom use was approximately 2.0% (resp., 3.0%) among the currently married women (all women).

[30] Related to this concern, additional exercises conducted in Table S.8 in the supplemental appendix provided no evidence suggesting that married women's bargaining power increased as a result of institutional change. In these exercises, this study replaced f_{ijt} in equation (8) with a proportion of mother-related expenditures relative to a household's total expenditures and estimated the equation with or without additional control of the total expenditures. Three different types of mother-related expenditures were attempted, namely just jewelry and perfume, additionally expenditures on fabric, clothing, and shoes, and further, expenditures on children's education.

a clan to elicit women's fertility effort, takes places together with the spread of HIV/AIDS, the equilibrium number of children may increase due to women's fertility effort even if HIV/AIDS does "not" improve widows' property rights; nonetheless, this fertility increase is, along with a decline in widows' welfare, still consistent with the disappearance of levirate marriage driven by HIV/AIDS.

7 Conclusion

To better understand the mechanisms that facilitate cultural change, this study examines why levirate marriage is disappearing in sub-Saharan Africa, which has, thus far, not been a subject of economic research despite its popularity and economic significance. To address this question, this study first developed a simple theoretical model that explained the mechanisms maintaining levirate marriage based on the findings provided by relevant anthropological and ethnographic studies as well as my field surveys in the Kagera and Mara regions in Tanzania. In an empirical analysis, it exploited one novel setting observed in the survey data collected in rural Tanzania for 1991—2004; during this period, this customary marriage practice became less common in several communities.

Since widows' engagement in levirate marriage is not observed at the individual level in the survey data, the current study attempted to infer the mechanisms underlying its deterioration by testing multiple theoretical predictions.[31][32] Notably, this study has reasoned the mechanisms by a sort of syllogism. As the HIV/AIDS reduced (resp., encouraged) young widows' consumption (young wives' fertility), which is associated with the community-level disappearance of levirate marriage, it is likely that HIV/AIDS deteriorated levirate marriage.

To refute this interpretation, alternative hypotheses would have to simultaneously explain why the dissolution of levirate marriage had a negative correlation with young widows' consumption; why this institutional change positively correlated with fertility of young wives (aged 21 to 40); why these correlations are more pronounced in HIV/AIDS-affected communities; why HIV/AIDS reduced young widows' consumption; why HIV/AIDS encouraged the fertility of young wives (aged 21 to 40); and most importantly, why levirate marriage is fast disappearing. While the fertility response to HIV/AIDS might have resulted from other channels not considered in this study (see Section S.6 in the supplemental appendix for the relevant literature), these channels do not necessarily explain the positive relationship

[31] Even if such individual-level information had been available, it might also have been difficult to identify the relevant causal effects, given the possible impact of levirate marriage on the spread of HIV/AIDS (Agot, 2001; Agot et al., 2010; Luke, 2002; Malungo, 2001; Okeyo and Allen, 1994) as well as difficulty in finding an appropriate instrumental variable.

[32] Developing the relevant testing strategy despite the lack of such crucial information may be seen as one contribution of the present paper, given that there is little empirical evidence of this marriage practice. Indeed, exploitation of the data drawn from the KHDS makes the empirical analyses and findings presented in this study invaluable. This is because empirical research of the kind presented here requires not only a setting, where the practice of levirate marriage is deteriorating, but also panel data that "records" the institutional transformation in the "long term." Collecting information on levirate marriage is extremely unusual (even if it is at the community-level) in standard household surveys, much less in the long term.

between the disappearance of levirate marriage and fertility. Moreover, the empirical exploration of widows' welfare is still helpful in interpreting mechanisms responsible for the deterioration of levirate marriage, because likely, a husband's clan always attempts to keep a widow's equilibrium payoff at the minimum. In the absence of strong candidates for an alternate hypothesis, all the relevant results demonstrated in this study may collectively provide support for the claim that a primary factor responsible for the deterioration of levirate marriage is HIV/AIDS, at least in the studied area. This claim is also consistent with the findings of prior case studies conducted in other areas.

The implication of the present investigation serves as an important caution for those who propose an outright ban on an anti-social practice that is seen as violating women's human rights and who interpret the disappearance of levirate marriage as a sign of female empowerment. As a result of HIV/AIDS, young widows may need a form of social protection (e.g., formal insurance, access to income-generating opportunities). As indicated in the theoretical model presented in Section 2 (see also Table 1), providing such protection (i.e., an increase in $r > \tau$) may also improve the total welfare enjoyed by a clan and by widows. Owing to the absence of solid data, however, further empirical research is still required to prove or disprove the plausibility of the asserted mechanisms in a strict sense. Since this study's assertion comes from the examination of one particular setting, its external validity also needs to be confirmed. Along with the relevant future studies, the current research must improve the general understanding of the mechanisms responsible for the transformation of cultural institutions that have been rooted in societies.

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Table 1: Summary of the propositions

Proposition	Strategy profile at equilibrium	Fertility at equilibrium	A clan's payoffs at equilibrium	A widow's payoffs at equilibrium
1. Levirate marriage	$(n^*, c(n^*), a)$	n^*	$u(n^*) - c(n^*)$	$r_0 = 0$
2. Female empowerment ($k \uparrow$)	$(n_1, c(n_1), a)$ or $(n_1, 0, z)$	$n_1 > n^*$	$u(n_1) - c(n_1)$	$r_0 = 0$
3. Female empowerment ($r \uparrow$)				
$\tau \geq r_1$	$(n^*, c(n^*) + r_1, a)$	n^*	$u(n^*) - c(n^*) - r_1$	$r_1 > 0$
$\tau < r_1$	$(n^*, 0, l)$	n^*	$u(n^*) - c(n^*) - \tau$	$r_1 > 0$
4. HIV/AIDS				
$\tau \geq \Delta$	$(n_0, 0, z)$	$n_0 \leq n^*$	$u(n_0) - c(n_0)$	$r_0 = 0$
$\tau < \Delta$	$(n^*, 0, l)$	n^*	$u(n^*) - c(n^*) - \tau$	$r_0 = 0$
5. HIV/AIDS-induced female empowerment ($k \uparrow$ & $r \downarrow$)	$(n_3, 0, z)$	$n_3 > n^*$	$u(n_3) - c(n_3) - r_2$	$r_2 < 0$

Note: $\Delta \equiv u(n^*) - c(n^*) - u(n_0) + c(n_0)$.

Table 2: Relationship with the deterioration of levirate marriage

A change in a widow's payoffs at equilibrium	A change in fertility at equilibrium	Underlying mechanisms (proposition)
$\Delta v_w > 0$	$\Delta n > 0$	Not possible
	$\Delta n = 0$	3. Female empowerment ($r \uparrow$)
	$\Delta n < 0$	Not possible
$\Delta v_w = 0$	$\Delta n > 0$	2. Female empowerment ($k \uparrow$)
	$\Delta n = 0$	4. HIV/AIDS ($\tau < \Delta$ & $\tau \geq \Delta$)
	$\Delta n < 0$	4. HIV/AIDS ($\tau \geq \Delta$)
$\Delta v_w < 0$	$\Delta n > 0$	5. HIV/AIDS-induced female empowerment ($k \uparrow$ & $r \downarrow$)
	$\Delta n = 0$	Not possible
	$\Delta n < 0$	Not possible

Table 3: Summary statistics (females aged 15 to 50 years)

	Group A			Group B		
	Mean	Std.	No. of obs.	Mean	Std.	No. of obs.
(1) Wave 1						
Per capita consumption (TSH)	53517.16	45253.82	400	52812.96	35915.54	800
No. of biological children	2.63**	2.66	402	2.28	2.23	802
No. of biological sons	1.28**	1.37	402	1.11	1.32	802
No. of biological daughters	1.35*	1.76	402	1.16	1.34	802
Education (years)	4.55**	3.31	394	5.05	3.06	786
Widow (dummy)	0.08	0.28	402	0.10	0.30	802
Age (years)	27.07	9.80	402	27.46	10.42	802
Head's age (years)	46.10*	16.03	402	47.90	16.16	802
Head male (dummy)	0.78*	0.41	402	0.73	0.43	802
HH size	7.70	5.14	400	7.33	3.07	800
HH land (acre)	6.67***	6.70	388	5.19	4.78	793
(2) Wave 5						
Per capita consumption (TSH)	48143.06***	39185.11	526	58488.40	54943.67	1190
No. of biological children	2.32***	2.22	526	1.82	1.72	1190
No. of biological sons	1.15***	1.37	526	0.88	1.06	1190
No. of biological daughters	1.17***	1.41	526	0.94	1.14	1190
Education (years)	5.18***	3.37	524	5.89	3.14	1171
Widow (dummy)	0.05	0.22	524	0.05	0.22	1189
Age (years)	27.89**	9.20	526	26.80	8.56	1190
Head's age (years)	41.67	14.99	525	42.35	15.48	1180
Head male (dummy)	0.80***	0.40	525	0.69	0.45	1180
HH size	5.97***	3.59	526	5.39	2.63	1190
HH land (acre)	4.50**	4.63	468	3.86	4.12	1008

Notes: (1) Group A refers to villages that made levirate marriage less customary during the sample periods, with group B consisting of all the remaining villages. (2) In each wave, the equality of means between the group A and group B is examined. *** denotes significance at 1%, ** at 5%, and * at 10%.

Table 4: Institutional change and widows' welfare (OLS)

Dependent variables:	Log of consumption per capita (TSH)			Log of consumption per adult equivalent (TSH)			Log of consumption per adjusted adult equivalent (TSH)		
Sample:	Females aged 15 to 50			Females aged 15 to 50			Females aged 15 to 50		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
No levirate marriage									
× Widow	-0.054	-0.066	-0.044	-0.116	-0.129	-0.102	-0.187	-0.202*	-0.195*
	(0.095)	(0.093)	(0.075)	(0.094)	(0.092)	(0.074)	(0.118)	(0.116)	(0.106)
No levirate marriage	-0.020	-0.023	-	-0.031	-0.041	-	-0.026	-0.046	-
	(0.082)	(0.077)		(0.082)	(0.078)		(0.097)	(0.092)	
Widow	-0.075	-0.062	-0.090	-0.024	-0.011	-0.043	0.096	0.107	0.103
	(0.089)	(0.088)	(0.071)	(0.087)	(0.086)	(0.068)	(0.102)	(0.100)	(0.086)
Aged 15 to 20	-0.134***	-0.137***	-0.147***	-0.114***	-0.117***	-0.125***	-0.151***	-0.151***	-0.164***
	(0.037)	(0.038)	(0.037)	(0.036)	(0.036)	(0.035)	(0.039)	(0.039)	(0.040)
Aged 21 to 30	-0.183***	-0.187***	-0.204***	-0.054	-0.058	-0.076*	0.039	0.035	0.012
	(0.041)	(0.041)	(0.042)	(0.038)	(0.038)	(0.039)	(0.037)	(0.037)	(0.040)
Aged 31 to 40	-0.160***	-0.167***	-0.164***	-0.081**	-0.087**	-0.087**	0.084*	0.078*	0.065
	(0.038)	(0.037)	(0.037)	(0.038)	(0.037)	(0.037)	(0.044)	(0.043)	(0.044)
Education (years)	0.035***	0.035***	0.036***	0.031***	0.031***	0.032***	0.023***	0.022***	0.023***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)
Head's age (years)	-0.000	-0.000	-0.000	-0.002**	-0.002**	-0.002*	-0.008***	-0.008***	-0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head male	0.105***	0.106***	0.105***	0.112***	0.115***	0.113***	0.027	0.027	0.032
	(0.033)	(0.034)	(0.034)	(0.036)	(0.036)	(0.037)	(0.045)	(0.046)	(0.045)
HH size	-0.056***	-0.055***	-0.055***	-0.047***	-0.047***	-0.047***	-0.131***	-0.130***	-0.132***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.014)	(0.013)	(0.013)
HH land (acre)	0.023***	0.022***	0.023***	0.020***	0.019***	0.020***	0.013***	0.011***	0.011**
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.005)
Head's ethnicity	YES	YES	YES	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village leader char.	NO	YES	NO	NO	YES	NO	NO	YES	NO
Village FE	YES	YES	NO	YES	YES	NO	YES	YES	NO
Region-time trend	YES	YES	NO	YES	YES	NO	YES	YES	NO
Village-time trend	NO	NO	YES	NO	NO	YES	NO	NO	YES
R-squared	0.330	0.335	0.370	0.315	0.320	0.357	0.462	0.466	0.489
No. of obs.	2616	2564	2616	2616	2564	2616	2616	2564	2616

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table 5: Institutional change and fertility (OLS)

Dependent variable:	No. of children					
Sample:	Head's wives aged 15 to 50					
	(a)	(b)	(c)	(d)	(e)	(f)
No levirate marriage						
× Aged 15 to 20	0.002	-0.052	0.052	0.056	-	-
	(0.322)	(0.331)	(0.351)	(0.350)		
× Aged 21 to 30	0.524**	0.469*	0.444	-	-	-
	(0.246)	(0.265)	(0.273)			
× Aged 31 to 40	0.642*	0.607*	0.719*	-	-	-
	(0.323)	(0.337)	(0.368)			
× Aged 21 to 40	-	-	-	0.561*	-	-
				(0.293)		
× Aged 15 to 40	-	-	-	-	0.482*	-
					(0.277)	
× Age	-	-	-	-	-	0.247**
						(0.107)
× Age squared	-	-	-	-	-	-0.004**
						(0.002)
No levirate marriage	-0.479*	-0.452	-	-	-	-
	(0.270)	(0.279)				
Aged 15 to 20	-0.380	-0.375	-0.416	-0.419	-0.743**	-
	(0.351)	(0.358)	(0.382)	(0.382)	(0.348)	
Aged 21 to 30	0.299	0.314	0.342	0.245	0.311	-
	(0.242)	(0.250)	(0.268)	(0.294)	(0.281)	
Aged 31 to 40	0.605**	0.607*	0.479	0.604**	0.665**	-
	(0.295)	(0.312)	(0.356)	(0.292)	(0.279)	
Age (years)	-	-	-	-	-	0.289***
						(0.097)
Age squared	-	-	-	-	-	-0.004***
						(0.001)
Education (years)	-0.004	-0.004	-0.001	-0.001	0.002	-0.013
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Head's age (years)	-0.010	-0.011*	-0.010*	-0.010*	-0.010*	-0.014**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Head male	-0.444	-0.472	-0.352	-0.342	-0.301	-0.332
	(0.435)	(0.468)	(0.542)	(0.533)	(0.586)	(0.415)
HH size	0.553***	0.552***	0.554***	0.554***	0.554***	0.536***
	(0.029)	(0.030)	(0.030)	(0.031)	(0.031)	(0.030)
HH land (acre)	0.001	-0.004	-0.002	-0.002	-0.002	-0.000
	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)
Head's ethnicity	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES
Village leader char.	NO	YES	NO	NO	NO	NO
Village FE	YES	YES	NO	NO	NO	NO
Region time-trend	YES	YES	NO	NO	NO	NO
Village time-trend	NO	NO	YES	YES	YES	YES
R-squared	0.716	0.722	0.730	0.730	0.729	0.745
No. of obs.	1217	1191	1217	1217	1217	1217

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table 6: HIV/AIDS-related heterogeneity: Institutional change and welfare outcomes (OLS)

Dependent variables:	Log of consumption (TSH) per						No. of children			
	capita		adult equivalent		adusted adult equivalent					
Sample:	Females aged 15 to 50		Females aged 15 to 50		Females aged 15 to 50		Head's wives aged 15 to 50			
Did HIV/AIDS become a more important health problem from wave 1 to 5?	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
No levirate marriage										
× widow	-0.201**	0.026	-0.194**	-0.059	-0.102	-0.220	-	-	-	-
	(0.083)	(0.091)	(0.079)	(0.093)	(0.165)	(0.131)				
× Aged 15 to 20	-	-	-	-	-	-	1.662*	-0.298	1.658*	-0.297
							(0.925)	(0.344)	(0.918)	(0.343)
× Aged 21 to 30	-	-	-	-	-	-	0.720	0.329	-	-
							(1.006)	(0.278)		
× Aged 31 to 40	-	-	-	-	-	-	1.182	0.607	-	-
							(1.281)	(0.362)		
× Aged 21 to 40	-	-	-	-	-	-	-	-	0.950	0.438
									(1.090)	(0.287)
R-squared	0.310	0.402	0.299	0.389	0.460	0.507	0.701	0.745	0.700	0.744
No. of obs.	867	1749	867	1749	867	1749	374	843	374	843
Sample:	Females aged 15 to 28		Females aged 15 to 28		Females aged 15 to 28					
Did HIV/AIDS become a more important health problem from wave 1 to 5?	YES	NO	YES	NO	YES	NO				
	(k)	(l)	(m)	(n)	(o)	(p)				
No levirate marriage										
× widow	-1.135***	-0.213	-1.285***	-0.210	-1.894***	-0.171				
	(0.249)	(0.147)	(0.226)	(0.149)	(0.258)	(0.222)				
R-squared	0.355	0.417	0.355	0.405	0.507	0.537				
No. of obs.	520	1033	520	1033	520	1033				
Individual controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village-time trend	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) Individual controls include all regressors used in the analysis in Table 4 and Table 5, but the corresponding estimates are not reported here.

Table 7: Reduced-form impacts of HIV/AIDS on widows' welfare and fertility (OLS)

Dependent variables:	Log of consumption (TSH) per			No. of children		
	capita	adult equivalent	adjusted adult equivalent			
Sample:	Females aged 15 to 50	Females aged 15 to 50	Females aged 15 to 50	Head's wives aged 15 o 50		
	(a)	(b)	(c)	(d)	(e)	(f)
One if HIV/AIDS is the most or second most important health problem in a community						
× Widow	-0.040	-0.048	-0.148*	-	-	-
	(0.055)	(0.054)	(0.079)			
× Aged 15 to 20	-	-	-	-0.155	-0.150	-
				(0.363)	(0.363)	
× Aged 21 to 30	-	-	-	0.348*	-	-
				(0.183)		
× Aged 31 to 40	-	-	-	0.518**	-	-
				(0.223)		
× Aged 21 to 40	-	-	-	-	0.425**	0.476***
					(0.192)	(0.149)
Widow	-0.145***	-0.142***	0.001	-	-	-
	(0.046)	(0.046)	(0.058)			
Aged 15 to 20	-0.175***	-0.159***	-0.167***	-0.534*	-0.539*	-0.605**
	(0.026)	(0.025)	(0.031)	(0.308)	(0.308)	(0.270)
Aged 21 to 30	-0.209***	-0.101***	0.010	0.407**	0.367**	0.344**
	(0.033)	(0.031)	(0.034)	(0.166)	(0.166)	(0.157)
Aged 31 to 40	-0.176***	-0.111***	0.065*	0.807***	0.851***	0.829***
	(0.031)	(0.029)	(0.036)	(0.186)	(0.180)	(0.163)
Education (years)	0.038***	0.035***	0.024***	0.009	0.009	0.009
	(0.004)	(0.004)	(0.004)	(0.015)	(0.015)	(0.015)
Head's age (years)	0.001	-0.001	-0.006***	-0.014**	-0.014**	-0.014**
	(0.001)	(0.001)	(0.001)	(0.006)	(0.006)	(0.006)
Head male	0.131***	0.116***	0.018	-0.616	-0.637	-0.606
	(0.033)	(0.034)	(0.042)	(0.445)	(0.457)	(0.462)
HH size	-0.047***	-0.041***	-0.116***	0.531***	0.530***	0.530***
	(0.004)	(0.004)	(0.010)	(0.033)	(0.033)	(0.033)
HH land (acre)	0.002	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head's ethnicity	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES
Village-time trend	YES	YES	YES	YES	YES	YES
R-squared	0.365	0.357	0.514	0.731	0.731	0.731
No. of obs.	5688	5688	5688	2327	2327	2327

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

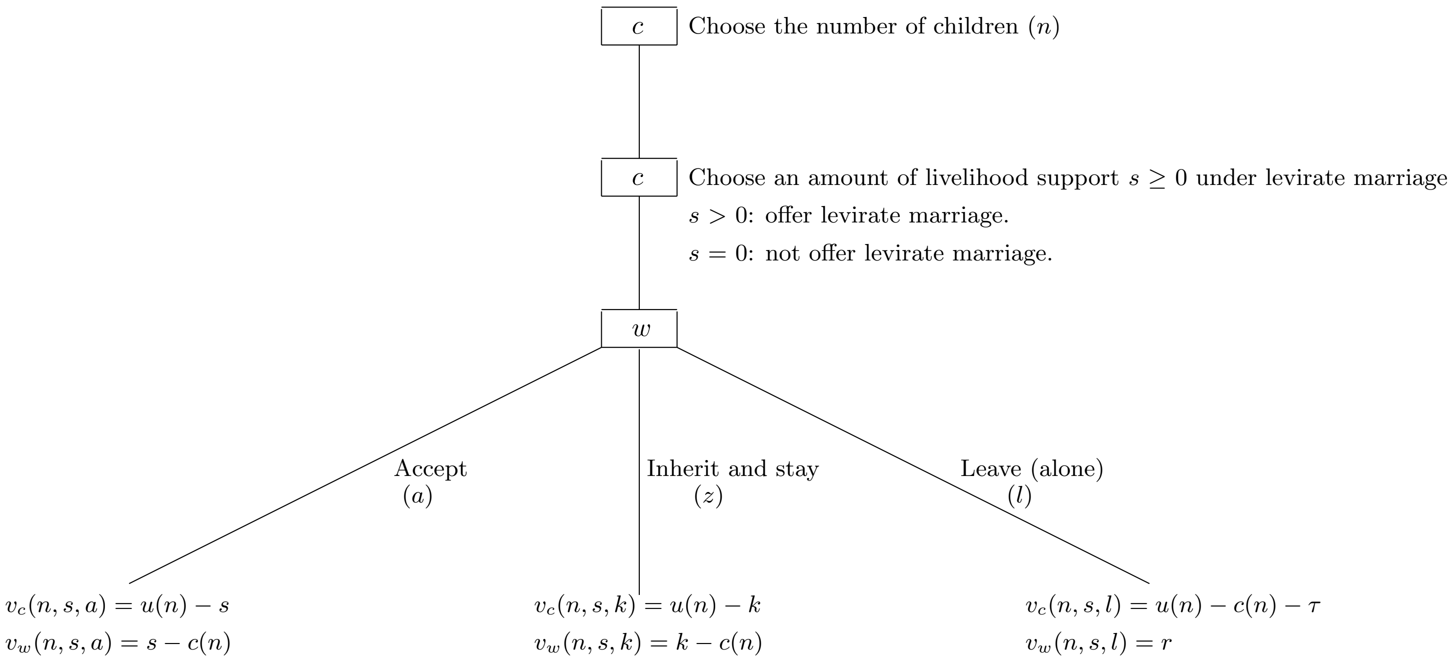

Figure 1: Game tree

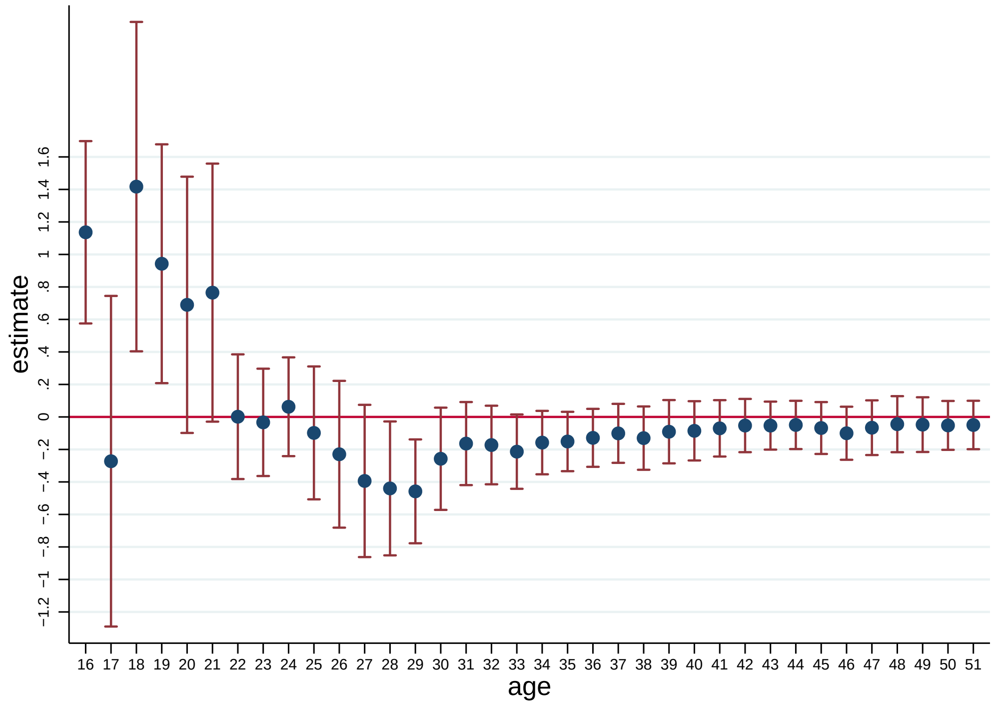

Figure 2: Age heterogeneity: Institutional change and widows' welfare (consumption per capita) (OLS)

Notes: (1) This figure reports the estimated α_2 in equation (7) with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.4 in the supplemental appendix.

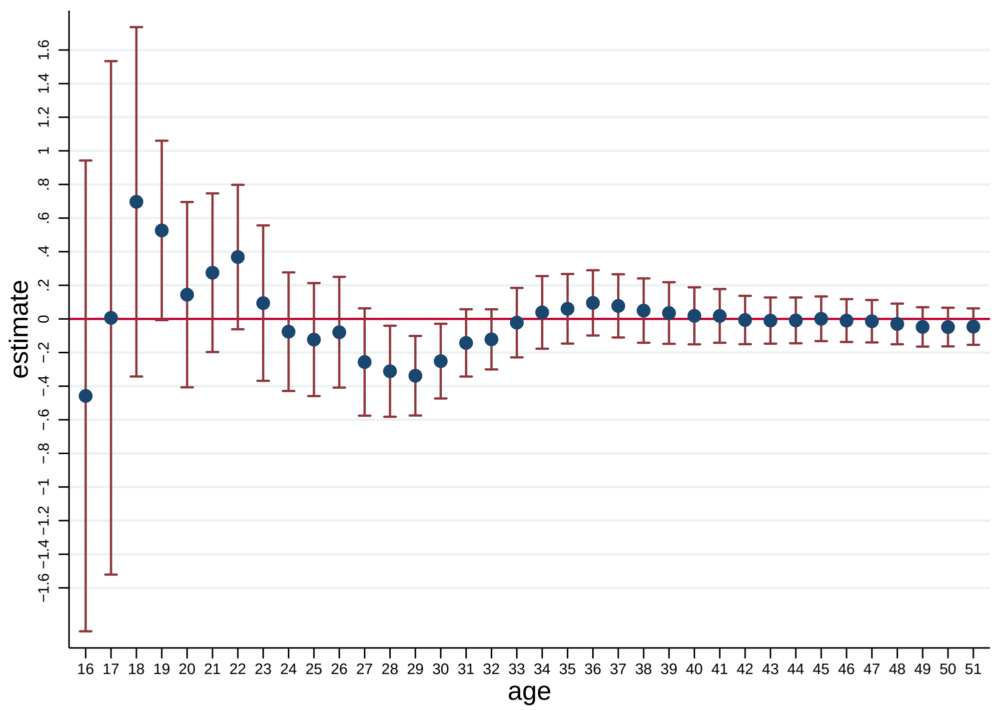

Figure 3: Age heterogeneity: Reduced-form impacts of HIV/AIDS on widows' welfare (consumption per capita) (OLS)

Notes: (1) After replacing D_{jt} in equation (7) with an indicator for villages that referred to HIV/AIDS as the most or second most important health problem in a community in each wave, this figure reports the estimated impacts of HIV/AIDS on widows' consumption with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.7 in the supplemental appendix.

Supplemental appendix

S.1 Robustness to model extension

In this section, an attempt is made to ensure that the key theoretical implications are robust to several model extensions.

S.1.1 Relocation cost and punishment

In the real world, several additional costs affect players' payoffs, which can easily be considered in the model. For example, it is possible to include the cost that may be imposed by community members on widows not following the traditional custom. Similarly, a widow's relocation cost associated with the action l can also be analyzed in the model. However, inclusion of these additional costs would not change the model predictions, because these costs only reduce widows' reservation utility.

S.1.2 A widow's option to leave with her own children

In this subsection, a widow's choice to leave with her own children is additionally included in her action set, namely, a widow may leave alone (m = action l_1) or leave with her own children (m = action l_2). Presuming that a widow taking the action l_2 (or her parents) usually has to return bridewealth payments (given at the time of marriage from a groom to a bride's family) to the clan, the relevant payoff profiles can be summarized as

$$v_c(n,s,a) = u(n) - s, \tag{S.1.1}$$

$$v_w(n,s,a) = s - c(n), \tag{S.1.2}$$

$$v_c(n,s,l_1) = u(n) - c(n) - \tau, \tag{S.1.3}$$

$$v_w(n,s,l_1) = r - g, \tag{S.1.4}$$

$$v_c(n,s,l_2) = b, \tag{S.1.5}$$

$$v_w(n,s,l_2) = r - c(n) - b, \tag{S.1.6}$$

$$v_c(n,s,z) = u(n) - k, \tag{S.1.7}$$

$$v_w(n,s,z) = k - c(n), \tag{S.1.8}$$

whereby $b \geq 0$ is bridewealth payments and $g \geq 0$ is the cost borne by widows leaving alone (e.g., emotional cost arising from separation from children), both of which are assumed to be exogenously determined.[33] As seen from the

[33] As the amount of bride price is agreed on at the time of marriage, it is pre-determined when this extensive-form game begins.

payoff profiles, when a widow leaves with her own children, she has to repay bride prices to the clan, which benefits a clan but is detrimental to the widow. In addition, when a widow leaves alone, she bears the separation cost. To allow for the case that a widow prefers to leave with her children to leaving alone, it is assumed that the separation cost is reasonably large, i.e., $g \geq b$.

However, note that when widows' independent livelihood means are limited (i.e., $r \leq 0$) (and given $k \geq 0$), a widow never chooses the action l_2. This is because a widow prefers to exploit her husband's property bequeathed to her, rather than starting a new life with children taken away from a husband's family (i.e., $r - c(n) - b < k - c(n)$). Therefore, this observation makes the theoretical analysis of the present concern fundamentally the same as that considered in the benchmark model.

Consequently, when widows have limited independent livelihood means so that $r = r_0 = 0$ and $k = \hat{k}_0 \leq c(n^*) - g$, it turns out that

Proposition S.1 *When $r = r_0 = 0$ and $k = \hat{k}_0 \leq c(n^*) - g$, the strategy profile $(n^*, c(n^*) - g, a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_0 - g = -g$.*

In addition, assume that HIV/AIDS strikes a society sustaining the traditional marriage practice, while establishing widows' de facto property rights $k = \hat{k}_1 > c(n^*) - g$ as well as reducing r to the level of $r_2 < 0$. Now, $v_c(n, s, a) = u(n) - s - h_c$ and $v_w(n, s, a) = s - c(n) - h_w$. Then, the following proposition holds:

Proposition S.2 *When $r = r_2 < 0$, $k = \hat{k}_1 > c(n^*) - g$, and the disease cost is high enough such that $\tau - r_2 + g < h_w + h_c$, the strategy profile $(\hat{n}_1, 0, z)$ is subgame perfect, along with the equilibrium number of children $\hat{n}_1 > n^*$ and a widow's payoff $r_2 - g < -g$.*

Here, $\hat{n}_1$ satisfies $\hat{k}_1 - c(\hat{n}_1) = r_2 - g$.

In the case of HIV/AIDS-induced female empowerment, the deterioration of levirate marriage is associated with an increase in the number of children (i.e., $\hat{n}_1 > n^*$) as well as a decline in widows' welfare (i.e., $r_2 - g < -g$), which is a similar finding to that obtained from analyses of the benchmark model.

S.1.3 Uncertainty about a couple's death

While it was presumed in the benchmark model that a husband surely dies before a wife does, this assumption is relaxed in this subsection, as it is possible that this is not the case in the real world. Defining a probability that a husband's dies first as $p \in (0,1)$, the agents' expected payoffs can be characterized as

$$\begin{aligned} v_c(n,s,a) &= u(n) - ps - (1-p)(c(n)+\tau), && \text{(S.1.9)} \\ v_w(n,s,a) &= p(s - c(n)), && \text{(S.1.10)} \\ v_c(n,s,l) &= u(n) - c(n) - \tau, && \text{(S.1.11)} \\ v_w(n,s,l) &= pr, && \text{(S.1.12)} \\ v_c(n,s,z) &= u(n) - pk - (1-p)(c(n)+\tau), && \text{(S.1.13)} \\ v_w(n,s,z) &= p(k - c(n)), && \text{(S.1.14)} \end{aligned}$$

whereby it is assumed that when a wife dies first, a husband's clan will take care of the children left behind.

First, consider a case that widows have limited independent livelihood means so that $r = r_0 = 0$ and $k = k_0 \leq c(n^*)$. Then, it is easy to show that

Proposition S.3 *When $r = r_0 = 0$ and $k = k_0 \leq c(n^*)$, the strategy profile $(n^*, c(n^*), a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $pr_0 = 0$.*

Next, assume that HIV/AIDS hits a society that practices levirate marriage, while establishing widows' de facto property rights $k = k_1 > c(n^*)$ as well as reducing r to the level of $r_2 < 0$. Now, $v_c(n,s,a) = u(n) - ps - (1-p)(c(n)+\tau) - ph_c$ and $v_w(n,s,a) = p(s - c(n) - h_w)$. Then, the following proposition holds:

Proposition S.4 *Assume that $r = r_2 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_2 < h_w + h_c$. Then,*

1. *When $k_1 \leq c(n_p) + r_2$ (in this case, $n^* < n_3 \leq n_p$), the strategy profile $(n_3, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_3 > n^*$ and a widow's payoff $pr_2 < 0$ (Case 1).*

2. *When $c(n_p) + r_2 < k_1 < c(n_p)$ (in this case, $n^* \leq n_p < n_3$), the strategy profile $(n_p, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_p \geq n^*$ and a widow's payoff $p(k_1 - c(n_p)) < 0$ (Case 2).*

3. *When $k_1 \geq c(n_p)$ (in this case, $n^* \leq n_p < n_3$), the strategy profile $(n_p, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_p \geq n^*$ and a widow's a payoff $p(k_1 - c(n_p)) \geq 0$ (Case 3).*

Here, n_p satisfies $u'(n_p) = (1-p)c'(n_p)$.

When there is a possibility that a wife dies first, the disappearance of levirate marriage coincides with an increase in the number of children (i.e., $n_3 > n^*$ or $n_p \geq n^*$) as well as "either" a decrease or increase in widows' welfare.

The possible increase in widows' welfare (i.e., Case 3) is a prediction that was not provided in the benchmark model. Several points deserve highlighting.

First, as the likelihood that a husband dies first goes up, n_p increases.[34] Then, given the values of r_0 $(= 0)$, r_2, and k_1, Case 1 (i.e., $c(n^*) < k_1 \leq c(n_p) + r_2$) is more likely to occur, as p increases. Consequently, when the value of p is large, the strategy profile $(n_3, 0, z)$ would arise at equilibrium. In fact, this is exactly the equilibrium strategy profile achieved when a husband surely dies first, as seen from proposition 5.

Second, as discussed in subsection 2.2.1, an increase in the amount of a husband's property bequeathed to widows provides a clan with an incentive to increase the number of offspring, because widows can now afford many children when choosing action z. However, when the probability that a husband dies first decreases (i.e., small p), which tends to result in Case 2 or Case 3 because of the decreasing n_p (i.e., $k_1 > c(n_p) + r_2$),[35] a clan's expected cost of taking care of children left by a wife (that dies first) would increase. Owing to this increase in the expected child-rearing cost, a clan would hesitate to increase the number of children to the level of n_3 and eventually choose $n_p < n_3$. In this case, it is possible that widows' welfare increases (i.e., Case 3) as a result of HIV/AIDS, if they can inherit a significant amount of a husband's property (i.e., $k_1 \geq c(n_p)$). Otherwise (i.e., $k_1 < c(n_p)$), widows' welfare decreases (i.e., Case 2).

Third, even if uncertainty exists about a couple's death, widows' welfare would still decline and the number of children would increase, as long as a husband is more likely to die first (i.e., Case 1) and the amount of bequest provided for widows is not remarkably large (i.e., Case 2), both of which seem to be the case in reality.

S.1.4 Female fertility control: Moral hazard

In the benchmark model, a husband's clan had a deterministic influence on the number of children. However, it may be more realistic to assume that married women can also influence their fertility, which is what is considered in this subsection.

Now, assume that during her married life, a woman can either expend effort e, which is unobserved by a husband's clan, to produce children or not. If such effort is expended $(e = \bar{e})$, n children would be produced with certainty, otherwise $(e = \underline{e})$ with probability $q \in (0, 1)$, where the cost of fertility effort is denoted as $d > 0$.[36] The strategy profile now includes women's fertility effort, as characterized by (n, s, m, e). Then, a clan's and a widow's payoffs can

[34] This means that if $p_1 > p_2$, $n_p^1 > n_p^2$, whereby $u'(n_p^1) = (1 - p_1)c'(n_p^1)$ and $u'(n_p^2) = (1 - p_2)c'(n_p^2)$. This can be proved as follows; suppose $n_p^1 \leq n_p^2$ when $p_1 > p_2$, $c'(n_p^1) \leq c'(n_p^2)$, which results in $(1 - p_1)c'(n_p^1) \leq (1 - p_1)c'(n_p^2) < (1 - p_2)c'(n_p^2)$ and so, $u'(n_p^1) < u'(n_p^2)$. This implies that $n_p^1 > n_p^2$, which is a contradiction of $n_p^1 \leq n_p^2$.

[35] For example, when $p \approx 0$, $n^* \approx n_p$ and so, $c(n_p) + r_2 \approx c(n^*) + r_2 < c(n^*) < k_1$.

[36] Thus, the analysis of female fertility control enables this study to consider the case that married women eventually produce no children, which is sometimes observed in reality.

be written as

$$v_c(n,s,a,\bar{e}) = u(n) - s, \tag{S.1.15}$$

$$v_c(n,s,a,\underline{e}) = q(u(n) - s), \tag{S.1.16}$$

$$v_w(n,s,a,\bar{e}) = s - c(n) - d, \tag{S.1.17}$$

$$v_w(n,s,a,\underline{e}) = q(s - c(n)) + (1-q)r, \tag{S.1.18}$$

$$v_c(n,s,l,\bar{e}) = u(n) - c(n) - \tau, \tag{S.1.19}$$

$$v_c(n,s,l,\underline{e}) = q(u(n) - c(n) - \tau), \tag{S.1.20}$$

$$v_w(n,s,l,\bar{e}) = r - d, \tag{S.1.21}$$

$$v_w(n,s,l,\underline{e}) = r, \tag{S.1.22}$$

$$v_c(n,s,z,\bar{e}) = u(n) - k, \tag{S.1.23}$$

$$v_c(n,s,z,\underline{e}) = q(u(n) - k), \tag{S.1.24}$$

$$v_w(n,s,z,\bar{e}) = k - c(n) - d, \tag{S.1.25}$$

$$v_w(n,s,z,\underline{e}) = q(k - c(n)) + (1-q)r. \tag{S.1.26}$$

Here, it is assumed that when a woman does not expend effort and produces no children, she has to leave her husband's home when he dies. In addition, note that when a woman takes action l, she always prefers not to expend effort. This is because doing so results in utility $r - d$, which is lower than utility r achieved with no effort expended.

First, consider a case where widows have limited independent means to support themselves such that $r = r_0 = 0$ and $k = k_0 \leq c(n^*)$. Then, it can be shown that

Proposition S.5 *When $r = r_0 = 0$, $k = k_0 \leq c(n^*)$, and $(1-q)(u(n^*) - c(n^*)) \geq \frac{d}{1-q}$, the strategy profile $(n^*, c(n^*) + \frac{d}{1-q}, a, \bar{e})$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $\frac{qd}{1-q}$. When $r = r_0 = 0$, $k = k_0 \leq c(n^*)$, and $(1-q)(u(n^*) - c(n^*)) < \frac{d}{1-q}$, the strategy profile $(n^*, c(n^*), a, \underline{e})$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_0 = 0$.*

Note that $\frac{d}{1-q}$ is an incentive cost needed for a clan to encourage a woman's fertility effort. As this incentive cost increases, the "no-effort equilibrium" $(n^*, c(n^*), a, \underline{e})$ tends to arise at equilibrium. The large effort cost d increases this incentive cost. This incentive cost also becomes larger as a woman's power to control fertility becomes more limited (i.e., large q), because her limited power enables a clan to achieve its desired fertility without inducing a marked fertility effort. Notably, when a clan decides to prompt a woman's fertility effort, she obtains a payoff greater than her reservation utility by an amount of (net) information rent, $\frac{qd}{1-q} = \frac{d}{1-q} - d$.

Next, consider the case where HIV/AIDS became a serious health problem in a society. Owing to its influence, widows' de facto property rights are established as $k = k_1 > c(n^*)$ and their reservation utility is reduced such that $r = r_2 < 0$. Now, a clan and a widow obtain the following utility $v_c(n, s, a, \bar{e}) = u(n) - s - h_c$ and $v_w(n, s, a, \bar{e}) = s - c(n) - d - h_w$, along with $v_c(n, s, a, \underline{e}) = q(u(n) - s - h_c)$ and $v_w(n, s, a, \underline{e}) = q(s - c(n) - h_w) + (1 - q)r$. Then, the following proposition holds:

Proposition S.6 *Assume that $r = r_2 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_2 < h_c + h_w \approx \infty$. Then,*

1. *When $k_1 - c(n^*) < k_1 < \frac{d}{1-q} + r_2$ (in this case, $n_6 < 0 < n^* < n_8$), the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$ (Case 1).*

2. *When $k_1 - c(n^*) \leq \frac{d}{1-q} + r_2 \leq k_1$ (in this case, $0 \leq n_6 \leq n^* < n_8$)*

   (a) and $u(n_8) - k_1 \leq \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$ (Case 2).

   (b) and $u(n_8) - k_1 > \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_6 \leq n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} = r_2 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ (Case 3).

3. *When $\frac{d}{1-q} + r_2 < k_1 - c(n^*) < k_1$ (in this case, $0 < n^* < n_6 < n_8$)*

   (a) and $u(n_8) - k_1 \leq \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$ (Case 4).

   (b) and $u(n_8) - k_1 > \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_6 > n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} = r_2 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ (Case 5).

Here, n_6 and n_8 satisfy $k_1 - c(n_6) = \frac{d}{1-q} + r_2$ and $k_1 - c(n_8) = r_2$.

The proposition S.6 suggests that as a result of HIV/AIDS, levirate marriage disappears and a widow makes a living with her children by inheriting her husband's property. Note that in this example, an incentive cost needed for a clan to induce a woman's fertility effort is $\frac{d}{1-q} + r_2$.

When this incentive cost is very large (i.e., $k_1 < \frac{d}{1-q} + r_2$), a clan does not encourage a woman's fertility effort and attempts to raise the number of children to the level of $n_8 > n^*$ in response to the increasing amount of a husband's property bequeathed to her (i.e., Case 1). As this incentive cost decreases (i.e., $k_1 \geq \frac{d}{1-q} + r_2$), a clan has some incentive to elicit a woman's fertility effort. If a clan eventually decides not to induce such effort, it encourages her to increase fertility to the level of $n_8 > n^*$, because a clan believes that she does not incur the cost of effort and thus, can afford many children by exploiting a husband's bequest (i.e., Case 2 and Case 4). In all these cases, HIV/AIDS would raise the equilibrium number of children while decreasing widows' welfare. This prediction follows that implied by the proposition 5.

On the other hand, when a clan decides to encourage a woman to make a fertility effort, whether or not the equilibrium number of children increases depends upon the amount of her husband's property bequeathed to her. If the amount is remarkably large (i.e., $k_1 - c(n^*) > \frac{d}{1-q} + r_2$), a clan encourages fertility to the level of $n_6 > n^*$ (i.e., Case 5). In contrast, if the amount of bequest is small (i.e., $k_1 - c(n^*) \leq \frac{d}{1-q} + r_2$), the clan decides to reduce the number of children to the level of $n_6 \leq n^*$ (i.e., Case 3).

In Case 3 and Case 5, a widow obtains reservation utility plus (net) information rent (i.e., $r_2 + \frac{qd}{1-q}$) because of a clan's compensation for her fertility effort. However, whether her welfare increases or not depends upon her payoff realized in the previous levirate marriage equilibrium. If a woman expended marked fertility effort before, her utility surely declines from $\frac{qd}{1-q}$ to $r_2 + \frac{qd}{1-q}$. Otherwise, her welfare may increase or decrease from $r_0 = 0$ to $r_2 + \frac{qd}{1-q} = r_2 + \frac{d}{1-q} - d$. When $r_2 + \frac{d}{1-q} < d$ (i.e., very low incentive cost), widows' welfare decreases. When $r_2 + \frac{d}{1-q} \geq d$, widows' welfare may improve. This welfare improvement is possible despite the induced fertility effort, owing to the significant amount of the husband's property inherited by her (i.e., $k_1 \geq r_2 + \frac{d}{1-q}$) and particularly in Case 3, the reduced child-rearing cost.

In sum, when a wife has power over fertility by altering her effort unobserved by a clan, the equilibrium number of children may decrease in Case 3 and widows' welfare may improve in particular cases of Case 3 and Case 5. In all the remaining cases, the predictions remained unchanged from those provided by the benchmark analysis. Importantly, in traditional agrarian societies, women are still expected to have limited power to control fertility (i.e., large q). In addition, recall from subsection 6.3 that women's access to family planning methods was also limited during the investigation periods (i.e., large d). Both these factors result in a large incentive cost expended by a clan to encourage a woman's fertility effort. In this case, the strategy profiles $(n^*, c(n^*), a, \underline{e})$ and $(n_8, 0, z, \underline{e})$ (more precisely, Case 1) tend to arise before and after the deterioration of levirate marriage induced by HIV/AIDS. Consequently, the equilibrium number of children would increase and widows' welfare would decline.[37] Therefore, the equilibrium prediction in the

[37] More precisely, under the "no-effort equilibrium," the equilibrium number of children that a clan desires may differ from the actual number of children. However, the expected number of children would still increase from qn^* to qn_8 when the equilibrium shifts from the profile $(n^*, c(n^*), a, \underline{e})$ to $(n_8, 0, z, \underline{e})$. In empirical analyses focusing on "average," changes in the number of children explored in data would correspond to changes in this expected number.

benchmark model is still robust to consideration of a woman's limited power to control fertility.

Finally, as discussed in subsection 6.3, a woman may respond to the disappearance of levirate marriage by making more effort to produce children because they may protect her widowhood in the absence of the traditional safety net. In the current model, it may be possible to interpret this increase in women's intrinsic motive to substitute own children for levirate marriage as a reduction in an (extrinsic) incentive cost $\frac{d}{1-q}+r_2$ needed for a clan to induce women's fertility effort (more precisely, $\frac{d}{1-q}$ given r_2). If making fertility effort and having more children may allow a woman to claim access to the deceased's property (see the relevant discussion in subsection S.1.5), the disappearance of levirate marriage may decrease her perceived cost of fertility effort d relative to its benefits. Or, a woman may interpret the deterioration of levirate marriage as an increase in the probability that she has to leave her husband's home when her husband dies (i.e., decrease in q). Both the decreases in the values of d and q perceived by women would reduce a clan's incentive cost. If the reduction in this incentive cost takes place together with the spread of HIV/AIDS, it is possible to demonstrate that women's more fertility effort results in an increase in actual fertility in the present framework. In other words, when the incentive cost is small in a society hit by HIV/AIDS, as a corollary of Case 4 and Case 5 in the proposition S.6, it can be shown that

Proposition S.7 *Assume that $r = r_2 < 0$, $k = k_0 \leq c(n^*)$, and the disease cost is high enough such that $\tau - r_2 < h_c + h_w \approx \infty$. Then, when $\frac{d}{1-q}+r_2 < k_0 - c(n^*) \leq 0$ (in this case, $n^* < n_9 < n_{11}$)*

1. *and $u(n_{11}) - k_0 \leq \frac{u(n_{11})-u(n_9)}{1-q}$, the strategy profile $(n_{11}, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_{11} > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$ (Case 4b).*

2. *and $u(n_{11}) - k_0 > \frac{u(n_{11})-u(n_9)}{1-q}$, the strategy profile $(n_9, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_9 > n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} = r_2 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ (Case 5b).*

Here, n_9 and n_{11} satisfy $k_0 - c(n_9) = \frac{d}{1-q} + r_2$ and $k_0 - c(n_{11}) = r_2$.

Notably, the small $\frac{d}{1-q}$ makes $\frac{d}{1-q}+r_2 < k_0 - c(n^*)$ more likely as well as raises the levels of n_9 and n_{11} (by construction), thereby making $u(n_{11}) - u(n_9)$ small owing to concavity of a clan's utility function. Since this small difference between $u(n_{11})$ and $u(n_9)$ makes the case of $u(n_{11}) - k_0 > \frac{u(n_{11})-u(n_9)}{1-q}$ more likely, it is expected that a woman makes fertility effort at equilibrium (i.e., Case 5b); as a result, the equilibrium number of children increases from n^* to n_9 even if widows' property rights do not improve (i.e., $k_0 \leq c(n^*)$). When widows' property rights improve as a result of HIV/AIDS (i.e., $k_1 > c(n^*)$), Case 5 in the proposition S.6 applies for a similar reasoning. In Case 5 and Case 5b, widows' welfare unambiguously declines from the previous levirate-marriage equilibrium when a clan's incentive cost $r_2 + \frac{d}{1-q}$ decreases due to HIV/AIDS so that $r_2 + \frac{d}{1-q} < d$. Therefore, once again, both the decline in widows' welfare and the increase in women's fertility are consistent with the disappearance of levirate marriage driven by HIV/AIDS.

S.1.5 A widow's rights tied to her children's rights and the timing of a husband's death

Based on a customary rule in Africa, a widow's rights are often tied to her children's rights. Namely, having children (in particular, sons) allows her to remain a member of her husband's clan, and therefore to claim access to the deceased's property (Rwebangira, 1996). In 2012, I conducted a short questionnaire-based survey about local marital practices in Karagwe, a district in the Kagera region, with support from one supervisor of the KHDS project (wave 5) (Kudo, 2015). Based on my field interviews (made with rural females aged 30 to 40 years), the locals were prone to believe that widows could have access to a husband's property if they had children. This finding suggests that the de facto amount of k bequeathed to widows tends to be large for those having old children when they are widowed. Analyses in this subsection attempt to consider this perspective explicitly.

Assume that a woman loses her husband early with a probability $\rho \in (0,1) = \rho_0$ and late with the remaining probability. Before the spread of HIV/AIDS, the value of ρ_0 is assumed to be small in the sense that $n_\rho > n_1$, whereby n_ρ satisfies $u'(n_\rho) = \rho_0 c'(n_\rho)$.[38] The amount of bequest provided for a woman is $k = k_0 \leq c(n^*)$ when she loses her husband early (because her children are young) and otherwise, $k = k_1 > c(n^*)$ (because her children are adults). Now, the strategy profile can be written as $(n, (s_y, m_y), (s_o, m_o))$, whereby s_y (resp., s_o) is the amount of livelihood support provided for a widow who loses her husband early (late) in the form of levirate marriage, along with $m_y \in (a_y, z_y, l_y)$ ($m_o \in (a_o, z_o, l_o)$) referring to choices made by the widow. Below, a payoff enjoyed by a woman who loses her husband early (resp., late) is denoted as v_w^y (v_w^o).

Then, it can be shown that

Proposition S.8 *Assume that $\rho = \rho_0$, $r = r_0 = 0$, and $k = k_0 \leq c(n^*)$ (resp., $k = k_1 > c(n^*)$) for a woman who loses her husband early (late). Then,*

1. *When $u(n_1) - u(n_0) \geq \rho_0(c(n_1) - c(n_0))$, the strategy profiles $(n_1, (c(n_1), a_y), (0, z_o))$ and $(n_1, (c(n_1), a_y), (c(n_1), a_o))$ are subgame perfect, along with the equilibrium number of children n_1 and a widow's payoffs $v_w^y = v_w^o = r_0 = 0$ (Case 1).*

2. *When $u(n_1) - u(n_0) < \rho_0(c(n_1) - c(n_0))$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$,*

[38] The n_ρ increases as ρ_0 decreases, which means that if $\rho_0^1 > \rho_0^2$, $n_\rho^1 < n_\rho^2$, whereby $u'(n_\rho^1) = \rho_0^1 c'(n_\rho^1)$ and $u'(n_\rho^2) = \rho_0^2 c'(n_\rho^2)$. This can be proved as follows; suppose $n_\rho^1 \geq n_\rho^2$ when $\rho_0^1 > \rho_0^2$, $c'(n_\rho^1) \geq c'(n_\rho^2)$, which results in $\rho_0^1 c'(n_\rho^1) > \rho_0^2 c'(n_\rho^2)$ and so, $u'(n_\rho^1) > u'(n_\rho^2)$. This implies that $n_\rho^1 < n_\rho^2$, which is a contradiction of $n_\rho^1 \geq n_\rho^2$.

$(n_0, (0, z_y), (c(n_1), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_1), a_o))$ are subgame perfect, along with the equilibrium number of children n_0 and a widow's payoffs $v_w^y = r_0 = 0$ and $v_w^o = c(n_1) - c(n_0) > 0$ (Case 2).

To encourage a widow to accept levirate marriage, the amount of livelihood support must be equal to or greater than the amount of bequest, which influences the number of children she can afford. Thus, when a woman is less likely to lose her husband early (i.e., small ρ_0, so $u(n_1) - u(n_0) \geq \rho_0(c(n_1) - c(n_0))$), the amount k_1 $(= c(n_1))$ primarily determines the number of children and otherwise, k_0 $(= c(n_0))$ does. Note that, in the former equilibrium (i.e., Case 1), a widow can choose either z_o or a_o after she loses her husband late. On the other hand, a widow strictly prefers a_y to z_y when she loses her husband early because choosing z_y would reduce her utility from $r_0 = 0$ to $k_0 - c(n_1) < 0$. In my field survey in Rorya (see footnote 6 for the details), a widow tended to reject levirate marriage when her children were old, because adult children who inherit a clan's property can provide her with livelihood support. Similarly, elderly widows in Uganda also often seek protection from their adult children, rather than entering into a relationship of levirate marriage (Ntozi, 1997). These findings may indicate that the former equilibrium, which arises along with a small ρ_0, is often the case in reality.[39]

As before, (whether a woman loses her husband early or late) HIV/AIDS makes the practice of levirate marriage costly due to the infection risk (i.e., h_c and h_w) and reduces widows' reservation utility to the level of r_2 while establishing their de facto property rights (i.e., always $k = k_1$). In addition, since HIV/AIDS primarily affected prime-age males in Kagera (e.g., Killewo et al., 1993), the probability of losing husbands early may also increase from ρ_0 to ρ_1. Then,

Proposition S.9 *Assume that $\rho = \rho_1 > \rho_0$, $r = r_2 < 0$, $k = k_1 > c(n^*)$ for a widow, whether early or late, who loses her husband, and the disease cost is high enough such that $\tau - r_2 < h_w + h_c$. Then, the strategy profile $(n_3, (0, z_y), (0, z_o))$ is subgame perfect, along with the equilibrium number of children $n_3 > n_1 > n_0$ and a widow's payoffs $v_w^y = v_w^o = r_2 < 0$.*

Compare the proposition S.9 with (particularly Case 1 of) the proposition S.8. When levirate marriage is commonly practiced prior to the spread of HIV/AIDS, a widow's welfare declines and the equilibrium number of children increases in step with the deterioration of this practice.

On the other hand, a husband may die of HIV/AIDS before he produces the optimal number of children n_3. For example, it can be presumed that the couple produces children at the (exogenous) level of $n = \bar{n} < n_3$ when a woman loses her husband early. In this case,

[39] Note that the proposition 2 corresponds to Case 1 of the proposition S.8 when $\rho = 0$.

Proposition S.10 *Assume that $\rho = \rho_1 > \rho_0$, $r = r_2 < 0$, $k = k_1 > c(n^*)$ for a widow, whether early or late, who loses her husband, and the disease cost is high enough such that $\tau - r_2 < h_w + h_c$. Also, $n = \bar{n} < n_3$ when a woman loses her husband early. Then, the strategy profile $(n_3, (0, z_y), (0, z_o))$ is subgame perfect. In this case, the equilibrium number of children and a widow's payoff are $\bar{n}$ and $v_w^y = c(n_1) - c(\bar{n})$ when a woman loses her husband early, whereas the corresponding values are $n_3 > n_1 > n_0$ and $v_w^o = r_2 < 0$ when a woman loses her husband late.*

The disappearance of levirate marriage unambiguously coincides with a decline in a widow's welfare and an increase in the number of children when she loses her husband late. For a woman who loses her husband early, this finding holds true when $\bar{n} > n_1$.[40] On the one hand, the value of $\bar{n}$ can be small when a woman loses her husband early. On the other hand, a clan's incentive to increase the number of children to the level of n_3 may also raise the value of $\bar{n}$. Consequently, the resulting number of children is a priori ambiguous. Nevertheless, the empirical findings on widows' welfare and fertility are still consistent with the case of $\bar{n} > n_1$ and thus, highlight the significance of HIV/AIDS. In addition, when childbirths frequently occur during the immediate years following marriage (i.e., a woman loses her husband early but not early enough to fail to achieve n_3), the situation $\bar{n} > n_1$ may be plausible even if a woman loses her husband early.

S.2 Detailed explanation on the identification strategy

To facilitate an interpretation of the identification strategy explained in subsection 3.2.1, Figure S.3 provides a graphical representation of the data structure. While the KHDS is a panel survey, the empirical approach adopted in this study exploits the data as if it were pooled cross-sectional data sourced from two different points in time (i.e., wave 1 or wave 5). This approach is identical to that adopted in Kudo (2015). This strategy allows the current study to exploit data variations fully while avoiding the unnecessary selection of the sample as well as the associated potential "bias."

As the figure shows, in wave 1, all female respondents resided in the KHDS villages and some of them were widowed. On the other hand, as explained in more detail in Section 4, the wave 5 sample includes panel respondents who had moved out of the KHDS villages between wave 1 and wave 5 as well as those that remained, each of whom consisted of widows and other females. Defining Δy^{before} as the difference in consumption between widows and the remaining females in wave 1 and Δy^{after} as the corresponding difference between "all" widows and "all" other females in wave 5 (here, "all" means both the migrants and non-migrants), the specification (7) compares $\Delta y^{after} - \Delta y^{before}$ between the villages that made the practice of levirate marriage less common during the sample periods and the remaining

[40] Assuming that the previous levirare marriage equilibrium is Case 1 in the proposition S.8 and that the size of the relevant population is one, the overall number of children would increase when $\rho_1 \bar{n} + (1 - \rho_1) n_3 > \rho_0 n_1 + (1 - \rho_0) n_1$, i.e., $\frac{1-\rho_1}{\rho_1} > \frac{n_1 - \bar{n}}{n_3 - n_1}$.

villages (or triple difference).

Widows that were already in a levirate marriage in wave 1 are unlikely to have lost this traditional safety net during the sample periods. Given this presumption, therefore, the meaningful α_2 cannot be identified if no female respondents became widowed between wave 1 and wave 5. Of the reproductive-age female respondents in wave 5 who were in marital relationships in wave 1, approximately 15% were widowed by wave 5, which makes this concern less critical.

In addition, the estimations performed in this study include migrants in wave 5. Exploiting migrants in the estimations does not necessarily invalidate the analysis. For instance, a woman who has lost her husband during the sample periods might have left a KHDS village because his clan members did not offer levirate marriage to her. In this example, the widow is included in the group of migrants in wave 5 and should be considered in the empirical analysis because her welfare is greatly associated with the institutional change in the KHDS village. On the other hand, some migrants might have moved out of their original villages for reasons unrelated to the practice of levirate marriage.[41] Even in this case, the estimated α_2 can still be interpreted as the lower bound of the correlation of interest. Including migrants in the estimations can avoid any potential "bias" that may result from analyzing only the data pertaining to the non-migrants in wave 5. This migration issue will also be discussed more thoroughly in subsection S.4.1.

Partially related to the point of the lower bound estimate, it should also be noted that the measured institutional change based on group discussions with village leaders does not necessarily mean that all local households or individuals immediately avoided levirate marriage. Rather, it should be interpreted as reflecting an average tendency to stop the practice at the village level. In addition, by interacting D_{jt} with w_{ijt}, the specification (7) implicitly assumes that all widows in villages commonly practicing (resp., not practicing) levirate marriage are (are not) in this customary marriage-type of relationship. However, owing to the average nature of village rule, it is certainly possible that this is not the case. Thus, the assumption made here actually allows for flexibility in widows' engagement in this traditional safety net within each village which, however, is not strong enough to render the identification strategy invalid. Furthermore, in this study, it was also difficult to exactly identify the timing of the institutional change that occurred between wave 1 and wave 5. All these perspectives highlight the fact that the empirical approach exploited in this study tends to attenuate the correlation that the current investigation aims at identifying.

[41] Table S.3 reports the reasons for migration during the sample periods (in the wave 5 survey) by panel respondents aged 15 to 50.

S.3 Fertility: Robustness checks

Despite the plausible empirical findings reported in Table 5 and explained in subsection 5.2, several concerns should be addressed. First, as the estimated outcome is the number of children born to a household's head, the estimation results may also be consistent with the view that in villages where the practice of levirate marriage became less common, young females who lost a husband entered into polygynous relationships with male heads having multiple wives and thus many children. This is possible if the traditional safety net no longer provided appropriate life protection for widows. Of the female sample included in the estimations in Table 5, approximately 15% (resp., 4%) were in polygynous marriages in wave 1 (wave 5). However, additionally controlling for the total number of a head's wives and its interaction with a measure of levirate marriage in column (a) in Table S.5 did not affect the previous findings.

Another concern is that the estimated number of children does not include children residing elsewhere. As parents grow older, co-residence with their children is less likely because most adult children leave their natal home to form their own family. Consequently, the elder cohorts of wives tend to have a smaller number of co-resident children. The level effects from ages of a head and wives that are already included in regressors are expected to, at least partly, control for this possibility. However, the previously identified correlation between fertility and the deterioration of levirate marriage may still be attributed to this issue, provided that decisions relevant to children's separation from their parents systematically differ between villages that made the practice of levirate marriage less customary during the investigation period and all the other villages (although this study has difficulty in enumerating the factors that encourage such a possibility).

To test the possibility that the previous estimation results are not entirely driven by this concern, this study attempted to utilize the number of co-resident children plus children living elsewhere as a dependent variable. However, the latter information was available only in the first four waves of the KHDS. Therefore, alternatively, cash and in-kind gifts that a household either received from or sent to non-household members (including children residing elsewhere) in the last 12 months and its interactions with a measure of levirate marriage were included as regressors in the estimations performed in column (b) in Table S.5. Admittedly, this approach is not perfect enough to control for the influence of children living separately. Nevertheless, the key findings are robust to the inclusion of these additional controls.

Finally, given the presumed non-normal distribution of the fertility outcome (see Figure S.6 for a histogram of the number of children relevant to the observations considered in the estimations in Table 5), the OLS estimations might not provide adequate implications. In an economic analysis of fertility, examining the spacing of births based on a survival model is one traditional technique. However, the current research cannot take this approach owing to the lack of relevant information. Alternatively, this study estimated an ordered probit model in columns (c) to (f) in Table S.5, which is often seen in the literature of demography. Estimating this alternative model yields results similar to those obtained from the OLS estimations. Strictly speaking, it is not straightforward to interpret the coefficients reported in these columns because they are not marginal effects. However, positive (resp., negative) coefficients in the ordered probit model indicate that the variables reduce (increase) the likelihood of having no children, while raising (decreasing) the probability of having many children. In other words, the variables characterized by the positive (resp., negative) coefficients shift the distribution of the fertility toward the right (left). Based on these estimation results, it is likely that the disappearance of levirate marriage positively correlates with an increase in the expected number of children born to young females, particularly those aged 21 to 40 in wave 5.[42]

S.4 Threats to identification

In this study, an attempt was made to estimate the correlation between the deterioration of levirate marriage and welfare outcomes driven by the theoretical mechanisms presented in Section 2. While a triple-difference approach was taken to identify such a correlation, several empirical concerns might still have prevented the current study from achieving the objective. In this section, several identification issues are discussed.

Given the findings provided in Figure 2 (see Table S.4 for the precise estimates), the analytical results of consumption reported in this section (i.e., Table S.9 and Table S.10) are based on data pertaining to young female respondents aged 15 to 28 that enable this study to provide the most distinct empirical findings in a statistical sense. However, the relevant estimation results exploiting the full-sample do not alter the implications of the analyses performed in this section, and are also available upon request.

S.4.1 Migration

Analyses performed in Table 4 and Table 5 used data pertaining to panel respondents who stayed in their original villages throughout the sample periods (i.e., non-migrants) as well as those who left between wave 1 and wave 5 (i.e., migrants). As described in Section S.2, exploiting the migrants in the estimations does not necessarily make the analysis invalid. For example, a woman who became widowed during the sample periods might have left a KHDS

[42]The gender-based breakdown of the relationship between fertility and institutional change is also reported in Table S.6, whereby the number of sons and daughters are separately estimated in columns (a) to (d), respectively. The analysis shows a similar magnitude for the relevant positive correlation between the groups, although it might have lost some statistical power owing to less variation in outcomes, compared with cases estimating the total number of children in Table 5.

village because she did not have the traditional safety net precisely because of the dissolution of levirate marriage in that village. In this case, such migrants should be included in the estimated sample.

Nevertheless, Table S.3 reports the reasons for migrations undertaken during the sample periods (in the wave 5 survey) by panel respondents aged 15 to 50. As the results show, almost half of female migration in this group was driven by marriage. Indeed, owing to traditional rules characterized by clan exogamy and patrilocality, a woman in Kagera typically leaves her kin to reside with her husband and thus lives outside her natal village when she marries (Kudo, 2015). Accordingly, it is possible that the institutional change occurring in the KHDS villages might have had no relationship with the welfare and decision-making of females who married outside their natal village between wave 1 and wave 5.

To control for this issue, this study created an indicator for those who left KHDS villages during the sample periods (notably, this indicator is set to a value of zero for all the observations in wave 1). As seen from the estimation results in columns (a) and (e) in Table S.9, including this indicator and its interaction with a measure of levirate marriage in the regressors yielded similar implications to those obtained previously. Furthermore, this study also modified the indicator so that it would take the value of one even in wave 1 for the observations relevant to those who migrated out of KHDS villages between wave 1 and wave 5. Controlling for this alternative indicator and its interaction with D_{jt} leaves the implications almost entirely unaffected. The corresponding estimation results are available from the author upon request.

S.4.2 Attrition

While the rate of sample attrition in the KHDS is not so high, potential "bias" resulting from this possibility still exists. To mitigate this concern, two exercises were performed. First, this study additionally controlled for a dummy variable for those who dropped out of the sample between wave 1 and wave 5 (notably, this indicator takes the value of zero for all the observations in wave 5) and its interaction with D_{jt}, and the relevant estimation results were reported in columns (b) and (f) in Table S.9. These additional controls did not affect the previously obtained implications.

Second, this study also exploited the insight obtained from Lee (2009) that under the monotonicity assumption, trimming the sample observed only under the treated condition helps identify the bounds of the treatment effects on the sub-population that would always be observed regardless of the treatment assignment.

In wave 5, 36.63% of the female respondents aged 15 to 28 years in wave 1 were not observed in villages that made levirate marriage less customary during the sample periods (group A), along with the corresponding rate of 30.79% in all the remaining villages (group B). Then, focusing on the same age cohort, this study excluded the wave 5 respondents belonging to group A as well as to the top or bottom 16 percentiles ($\approx \frac{36.63\%-30.79\%}{36.63\%}$) of the consumption distribution among the group A respondents in wave 5, and estimated equation (7). Similarly, 31.76% of the reproductive-age women in wave 1 whose husbands are household heads were missing in group A in wave 5, along with the corresponding rate of 22.26% in group B. This study also removed the wave 5 respondents who originated from group A villages and reported the number of children belonging to the top or bottom 30 percentiles ($\approx \frac{31.76\%-22.26\%}{31.76\%}$) of the fertility distribution among group A respondents in wave 5, and estimated equation (8).

Admittedly, these exercises do not necessarily provide the bounds (of the examined correlation) in Lee (2009)'s original sense, because this study is interested in the correlations between the deterioration of levirate marriage and consumption of "widows" or fertility of "young" wives, rather than the correlations between institutional change and consumption or fertility of the total population. Nevertheless, it is still useful to assess the sensitivity of the estimates based on this approach. The relevant estimation results reported in Table S.10 still provided evidence indicating a negative correlation between the dissolution of levirate marriage and young widows' consumption as well as a positive correlation between this institutional change and young wives' fertility.

S.4.3 Selective mortality

Like the attrition issue, selective mortality is another concern. The traditional safety net's disappearance might have contributed to the deaths of many relatively poor widows in the villages that made levirate marriage less customary. As a result, in the reform villages in wave 5, the sample used for the estimation of (7) may include a greater proportion of widows who are wealthy, compared to those living in all the remaining villages, biasing the estimated α_2 upward.

The data set contained information on the number of people who died in the past 12 months in each KHDS village, which enabled this study to calculate a mortality rate (percentage) by dividing this number by the village population.[43] Exploiting such information (interacted with w_{ijt} and o^k_{ijt}) in the estimations in columns (c) and (g) in Table S.9 yielded similar findings to those obtained previously. In addition, if such selective mortality does indeed "bias" the estimates, the supposed correlation between the deterioration of levirate marriage and widows' welfare would be more negative.

[43]In wave 1 (resp., wave 5), one village (12 villages) did not report this number. Similarly, information on the total population was absent for one village (resp., one village) in wave 1 (wave 5). For these villages, it was assumed that the number took the value of the sample average.

S.4.4 Refugees

In Kagera, the most significant events that occurred during the sample periods were great influxes of refugees from Burundi (1993) and Rwanda (1994) (e.g., Alix-Garcia and Saah, 2010; Baez, 2011; Jean-François and Verwimp, 2014; Whitaker, 2002). It is possible that the previous analysis was affected by resulting relevant factors such as massive population displacement, development of aid projects (e.g., establishment of refugee camps, food rationing, improvement of healthcare facilities), and the associated price changes in both commodity and labor markets (although the village-specific time trend may, in part, control for the respective influences).

The analysis in columns (d) and (h) in Table S.9 control for the number of refugee camps established within a 25 km radius from each KHDS village during the relevant time frames.[44] While this number of camps is time-invariant, it is still possible to include the number interacted with w_{ijt} and o^k_{ijt}. Inclusion of these additional controls did not change the implications derived from the previous analysis.

S.4.5 Potential noise of the measured marital status

Another important concern is the possibility that female marital status may be subject to noise. Specifically, it is not clearly discerned from the dataset based on the standard survey module whether the survey enumerators identified the status of females who lost their husband and entered into a levirate marriage as "widowed" or "married" (Luke, 2006). If the enumerators tend to view females engaging in levirate marriage as "married," the current concern could possibly "bias" the estimated α_2 downward because the enumerators are more likely to identify as "widowed" those who are wealthy and therefore avoid levirate marriage as well as stay independent. In other words, poor widows who engaged in this traditional marriage might have been included in the "married" group in wave 1. However, in villages where the practice of levirate marriage became less customary, similarly poor widows might have belonged to the "widowed" group in wave 5.

However, note that if this concern is true (i.e., while the enumerators called marital status of poor widows engaging in levirate marriage "married" before, similarly poor widows come to be included in a group of "widowed" because of the disappearance of the practice), the proportion of females whom the enumerators regard as "widowed" is likely to increase in villages where the customary practices became less common. However, as described in Section 4 (see also Table S.2), the simple DID estimate did not reject the null hypothesis that the likelihood of widowhood was not affected by the institutional change.

[44] In that time frame, 13 refugee camps were established: Benaco, Burigi, Chabalisa, Kagenyi, Keza, Kitalli, Lukole A, Lukole B, Mbuba, Musuhura, Mwisa, Omukariro, and Rubwera. Information on a village's distance to these camps is available from `http://www.edi-africa.com/research/khds/introduction.htm` owing to a contribution made by Jean-François Maystadt.

Moreover, if the enumerators indeed regard an inherited widow as "married," they are less likely to identify her as "a household head" compared to a widow who refused levirate marriage. Then, the correlation between being a household head and being widowed is likely to increase in villages where the customary practice became less conventional compared to that found in all the remaining villages. The exercises performed to check this correlation in Table S.11 provided no evidence supporting this possibility.

Overall, my view on this measurement issue is that the enumerators still identified widows inherited by other male relatives as "widowed" in the survey because levirate marriage (also called widow inheritance) is seen as being different from standard marriage. It should also be noted that an inherited widow does not typically live together with her inheritor, who resides with his wife and children at his homestead. In addition, an inherited widow does not share a household budget with her inheritor's family when purchasing food and other items. In the KHDS, household members are defined as including "all people who normally sleep and eat their meals together in the household during at least three of the twelve months preceding the interview."

S.4.6 Within-village trend between widows' and other women's consumption

Consumption enjoyed by "Other" females shown in Figure S.3 might have declined in villages where the practice of levirate marriage became less common, provided that the disappearance of this practice coincided with an increase in the investment (e.g., fertility) made by currently married females (who are, thus, included in the "Other" group). In turn, this means that the current empirical approach comparing widows' consumption with that of "Other" females within the same village might have underestimated the negative correlation between the institutional change and widows' consumption.

S.4.7 Selected sample of a head's wife

In the analysis of fertility, limiting attention to data on females whose husbands are household heads potentially generates "bias," if they have particular preferences for fertility that are correlated with the village-level prevalence of levirate marriage. To alleviate this concern, this study replaced f_{ijt} in equation (8) with an indicator for a head's wife, and estimated the equation for all females aged 15 to 50. The results reported in Table S.12, where the exploited controls in columns (a) to (f) correspond to those used in columns (a) to (f) in Table 5, provided no evidence indicating significant effects of the institutional change on the probability of being a head's wife.

S.5 Assessing the subjective measure of HIV prevalence in the KHDS

In each wave of the KHDS, the survey team asked a group of village leaders about the health-relevant situation in a community. The number of villages that referred to HIV/AIDS as the most or second-most important health problem in a community increased from 18 in wave 1 to 32 in wave 5, with the corresponding in-between figures summarized as 25, 24, and 35 in wave 2, 3, and 4, respectively.

An attempt was made to assess the extent to which this information is useful for an empirical analysis. First, the wave 5 (i.e., 2004) information was first evaluated based on data sourced from the 2003—04 Tanzania HIV/AIDS Indicator Survey (2003—04 THIS), which is the first population-based comprehensive survey carried out on this infectious disease in Tanzania. With the technical assistance provided by the MEASURE DHS program, this survey was conducted by the National Bureau of Statistics (NBS) in cooperation with the Tanzania Commission for AIDS (TACAIDS) and the National AIDS Control Program (NACP) from December 2003 to March 2004.[45] In this survey, the respondents' blood was collected for HIV testing if they volunteered for the test.

By taking the following three steps, the quality of the wave 5 information was checked. First, a proportion of HIV-positive respondents among those that went for the testing was calculated for each THIS community. Second, two proxies for HIV prevalence in a KHDS community at the time of the wave 5 survey (i.e., 2004) were constructed based on the calculated proportion, namely (1) the proportion in a THIS community in closest proximity to a KHDS community and (2) an average of the corresponding proportion among the THIS communities situated within a 40-km radius from a KHDS community (see Figure S.9 for the position of the KHDS and THIS communities).[46] Third, an indicator for the KHDS villages that referred to HIV/AIDS as the most or second-most important health problem in wave 5 was regressed on these biomarker-based measures of HIV/AIDS prevalence.

Approximately 50% (resp., 80%) of the 51 KHDS communities corresponded with the nearest THIS community situated less than 10 km (18 km) away, with the KHDS community having a maximum distance of approximately 34 km to the nearest THIS community. Among the 51 communities, the mean infection rate based on the HIV-positive population in the nearest THIS communities is 0.049, with the minimum rate of zero that is recorded in 14 communities as well as the maximum figure of 0.138. The mean of the average infected proportion in the THIS communities surrounding a KHDS community is 0.041, with the minimum (resp., maximum) figure of zero (0.081). Based on this measure, no HIV-positive case was identified in nine communities.

[45] See Tanzania Commission for AIDS (TACAIDS), National Bureau of Statistics (NBS), and ORC Macro (2005) for the details. The data and relevant documents are available from `https://dhsprogram.com/what-we-do/survey/survey-display-234.cfm`.

[46] The positional information of the KHDS communities was obtained from the survey team under my agreement relevant to the confidentiality of the surveyed communities.

The estimated infection rate of the KHDS communities seems plausible, compared with that provided by several studies that date back to the late 1980s. As seen from Figure 5-3 (p. 147) in Ainsworth et al. (1998), for example, the estimated HIV prevalence among sexually active adults in 1989 is the greatest in Kagera among all the regions of Tanzania, with the infected population estimated at more than 10% in the urban and more than 3% in the rural areas.

Regressing the KHDS-based indicator pertaining to the prevalence of HIV/AIDS in wave 5 on these objective measures yielded the results reported in Table S.13. In columns (a) and (b), the prevalence of HIV/AIDS in the nearest THIS community was used as an explanatory variable, with or without the control of a KHDS community's distance (km) to the nearest THIS community. In analyses in columns (c) and (d), a continuous measure of the prevalence exploited in columns (a) and (b) was replaced by an indicator, equal to one if the prevalence was positive and zero otherwise. The mean of the average HIV-positive proportion in the THIS communities in the vicinity of a KHDS community was utilized in the estimations reported in columns (e) and (f), whereby a continuous measure of the prevalence was used in the former, with the latter exploiting an indicator that takes one if the prevalence was positive and zero otherwise.

As the results show, all the estimated coefficients of interest are positive and particularly in the estimations exploiting the indicators, the statistical significance is more evident. These findings suggest that the HIV/AIDS-relevant information collected in wave 5 of the KHDS is consistent with the biomarker-based prevalence of HIV/AIDS and thus is still helpful in measuring the significance that this communicable disease had on the surveyed communities.

For the quality assessment of the information in waves 1—4 (i.e., 1991—1994), the district-level values of the infection rate reported in Killewo et al. (1990) were assigned to each KHDS community. Killewo et al. (1990) conducted a population-based survey in Kagera in 1987 and estimated that the overall prevalence of HIV-1 infection among adults aged 15—54 was 9.6%, with a higher prevalence in the Bukoba Urban district (24.2%) compared with rural areas of the region (10.0% for the Bukoba Rural and Muleba districts, 4.5% for the Karagwe district, and 0.4% for the Ngara and Biharamulo districts).

As shown in columns (g) (for wave 1) and (h) (for all the earlier four waves) in Table S.13, regressing an indicator for the KHDS villages that referred to HIV/AIDS as the most or second-most important health problem with respect to this district-level prevalence also yielded statistically significant positive coefficients. This statistical significance is obtained at the conventional levels even if the standard errors are adjusted for clustering on a district. The information pertaining to HIV-prevalence collected in the earlier four waves in the KHDS also appears consistent with the actual prevalence.

S.6 Literature review: Fertility response to HIV/AIDS

Evidence on the fertility response to HIV/AIDS is mixed. In addition to the possible physiological effects, negative fertility response is possible owing to several behavioral reasons. According to Young (2005), for instance, HIV/AIDS reduces fertility, because people may hesitate to engage in unprotected sex to avoid contracting this communicable disease and/or the spread of HIV/AIDS may increase the perceived value of women in labor markets by contributing to the scarcity of labor force. The behavioral response to avoid risky sexual intercourse may also be affected by people's life expectancy unrelated to HIV/AIDS (Oster, 2012) and/or knowledge of their sero-status (Gong, 2015; Thornton, 2008). The perceived risk of HIV/AIDS may also alter the relational type of sexual partners (casual or committed) while affecting the likelihood of early fertility (Duflo et al., 2015). In addition, HIV-positive parents may also dislike having sero-positive babies that would die in early infancy (Grieser et al., 2001) as well as (if they are altruistic) avoid leaving many children orphaned.

On the other hand, an increasing risk of mortality may encourage parents to have more children for a precautionary purpose and/or owing to a quantity-quality trade-off of childbearing (e.g., Kalemli-Ozcan, 2003; Soares, 2005), for example. Furthermore, it is also possible that any fertility response arises from people's beliefs about the relationship between childbirth and AIDS that may not necessarily be correct (e.g., Yeatman, 2011).

S.7 Proof

In this section, all the propositions claimed in this paper are proved. The basic strategy for the proof is as follows. First, for a certain range of n, a strategy profile that enables a clan to obtain maximum utility when a widow rejects levirate marriage is explored. Second, for the same range of n, a strategy profile that enables a clan to encourage her to accept levirate marriage and to obtain maximum utility is explored. Third, of all these strategy profiles, the strategy profile that enables a clan to receive the greatest utility is selected as a pure strategy subgame perfect equilibrium.

Proof of proposition 1:

Find n_0 satisfying $k_0 - c(n_0) = r_0 = 0$. Since $k_0 \leq c(n^*)$ by assumption, it is the case that $c(n_0) \leq c(n^*)$, i.e., $n_0 \leq n^*$ (see also Figure S.2 for the graphical interpretation of n^* and n_0).

First, consider the case of $n \leq n_0$. In this case, $k_0 - c(n) \geq k_0 - c(n_0) = r_0 = 0$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), yielding $v_c = u(n_0) - k_0 = u(n_0) - c(n_0)$ as well as $v_w = k_0 - c(n_0) = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \leq n_0$, it must be the case that $s - c(n) \geq k_0 - c(n)$. Then, a clan chooses $s = k_0$ and obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), which results in $v_c = u(n_0) - s = u(n_0) - k_0 = u(n_0) - c(n_0)$ and $v_w = s - c(n_0) = k_0 - c(n_0) = r_0 = 0$. Consequently, for $n \leq n_0$, the strategy profiles $(n_0, 0, z)$ and $(n_0, c(n_0), a)$ provide a clan with maximum utility $u(n_0) - c(n_0)$.

In case of $n \geq n_0$ (i.e., $k_0 - c(n) \leq r_0 = 0$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = u(n^*) - c(n^*) - \tau$ and $v_w = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \geq n_0$, it must be the case that $s - c(n) \geq r_0 = 0$. Then, a clan chooses $s = c(n)$ and obtains utility $u(n) - c(n)$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*)$ and $v_w = r_0 = 0$. Since $u(n^*) - c(n^*) > u(n^*) - c(n^*) - \tau$, the strategy profile $(n^*, c(n^*), a)$ provides a clan with maximum utility $u(n^*) - c(n^*)$.

Since $u(n^*) - c(n^*) > u(n_0) - c(n_0)$, the strategy profile $(n^*, c(n^*), a)$ is subgame perfect. In this case, a widow obtains utility $r_0 = 0$.

Proof of proposition 2:

Find n_1 satisfying $k_1 - c(n_1) = r_0 = 0$. Since $k_1 > c(n^*)$ by assumption, it is the case that $c(n_1) > c(n^*)$, i.e., $n_1 > n^*$ (see also Figure S.2 for the graphical interpretation of n^* and n_1).

First, consider the case of $n \leq n_1$. In this case, $k_1 - c(n) \geq k_1 - c(n_1) = r_0 = 0$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_1$. A clan can maximize this utility by selecting $n = n_1$ (i.e., maximum in the domain of $n \leq n_1$), yielding $v_c = u(n_1) - k_1 = u(n_1) - c(n_1)$ as well as $v_w = k_1 - c(n_1) = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \leq n_1$, it must be the case that $s - c(n) \geq k_1 - c(n)$. Then, a clan chooses $s = k_1$ and obtains utility $u(n) - k_1$. A clan can maximize this utility by selecting $n = n_1$ (i.e., maximum in the domain of $n \leq n_1$), which results in $v_c = u(n_1) - s = u(n_1) - k_1 = u(n_1) - c(n_1)$ and $v_w = s - c(n_1) = k_1 - c(n_1) = r_0 = 0$. Consequently, for $n \leq n_1$, the strategy profiles $(n_1, 0, z)$ and $(n_1, c(n_1), a)$ provide a clan with maximum utility $u(n_1) - c(n_1)$.

In case of $n \geq n_1$ (i.e., $k_1 - c(n) \leq r_0 = 0$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility *subject to* $n \geq n_1 > n^*$. Then, a clan selects $n = n_1$ (corner solution), yielding $v_c = u(n_1) - c(n_1) - \tau$ as well as $v_w = r_0 = 0$. To encourage a widow to choose levirate marriage for $n \geq n_1$, it must be the case that $s - c(n) \geq r_0 = 0$. Then, a clan chooses $s = c(n)$ and obtains utility $u(n) - c(n)$. A clan can maximize this utility *subject to* $n \geq n_1 > n^*$. Then, a clan selects $n = n_1$ (corner solution), which results in $v_c = u(n_1) - c(n_1)$ and $v_w = r_0 = 0$. Since $u(n_1) - c(n_1) > u(n_1) - c(n_1) - \tau$, the strategy profile $(n_1, c(n_1), a)$ provides a clan with maximum utility $u(n_1) - c(n_1)$ when $n \geq n_1$.

Consequently, both the strategy profiles $(n_1, 0, z)$ and $(n_1, c(n_1), a)$ are subgame perfect. In this case, a widow obtains utility $r_0 = 0$.

Proof of proposition 3:

Find n_2 satisfying $k_0 - c(n_2) = r_1$. Since $k_0 \leq c(n^*)$ by assumption, it is the case that $c(n_2) < c(n^*)$ (i.e., $c(n_2) = k_0 - r_1 < k_0 \leq c(n^*)$), therefore $n_2 < n^*$ (see also Figure S.2 for the graphical interpretation of n^* and n_2). Now, two cases are considered, either $r_1 \geq k_0$ or $r_1 < k_0$.

Case 1: $r_1 \geq k_0$.

Note that for any value of n, a widow never chooses action z when she rejects levirate marriage, because $k_0 - c(n) \leq r_1 - c(n) \leq r_1$. Then, given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = u(n^*) - c(n^*) - \tau$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage for any value of n, it must be the case that $s - c(n) \geq r_1$. Then, a clan chooses $s = c(n) + r_1$ and obtains utility $u(n) - c(n) - r_1$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - r_1$ and $v_w = s - c(n^*) = r_1$. Thus, when $r_1 > \tau$, the strategy profile $(n^*, 0, l)$ provides a clan with maximum utility $u(n^*) - c(n^*) - \tau$. Otherwise, the strategy profile $(n^*, c(n^*) + r_1, a)$ provides a clan with maximum utility $u(n^*) - c(n^*) - r_1$.

Case 2: $r_1 < k_0$

First, consider the case of $n \leq n_2$. In this case, $k_0 - c(n) \geq k_0 - c(n_2) = r_1$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), yielding $v_c = u(n_2) - k_0 = u(n_2) - c(n_2) - r_1$ as well as $v_w = k_0 - c(n_2) = r_1$. To encourage a widow to accept levirate marriage for $n \leq n_2$, it must be the case that $s - c(n) \geq k_0 - c(n)$. Then, a clan chooses $s = k_0$ and obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in $v_c = u(n_2) - s = u(n_2) - k_0 = u(n_2) - c(n_2) - r_1$ and $v_w = s - c(n_2) = k_0 - c(n_2) = r_1$. Consequently, for $n \leq n_2$, the strategy profiles $(n_2, 0, z)$ and $(n_2, c(n_2) + r_1, a)$ provide a clan with maximum utility $u(n_2) - c(n_2) - r_1$.

In case of $n \geq n_2$ (i.e., $k_0 - c(n) \leq r_1$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = u(n^*) - c(n^*) - \tau$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage for $n \geq n_2$, it must be the case that $s - c(n) \geq r_1$. Then, a clan chooses $s = c(n) + r_1$ and obtains utility $u(n) - c(n) - r_1$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - r_1$ and $v_w = s - c(n^*) = r_1$. Consequently, for $n \geq n_2$, the strategy profile $(n^*, 0, l)$ provides a clan with maximum utility $u(n^*) - c(n^*) - \tau$ when

$r_1 > \tau$. Otherwise, the strategy profile $(n^*, c(n^*) + r_1, a)$ provides a clan with maximum utility $u(n^*) - c(n^*) - r_1$. Here, note that when $r_1 > \tau$, it is the case that $u(n^*) - c(n^*) - \tau > u(n^*) - c(n^*) - r_1 > u(n_2) - c(n_2) - r_1$. In addition, it is always the case that $u(n^*) - c(n^*) - r_1 > u(n_2) - c(n_2) - r_1$.

Considering both the cases of $r_1 \geq k_0$ and $r_1 < k_0$, when $r_1 > \tau$, the strategy profile $(n^*, 0, l)$ is subgame perfect. Otherwise, the strategy profile $(n^*, c(n^*) + r_1, a)$ is subgame perfect. In both cases, a widow obtains utility r_1.

Proof of proposition 4:

First, consider the case of $n \leq n_0$. In this case, $k_0 - c(n) \geq k_0 - c(n_0) = r_0 = 0$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), yielding $v_c = u(n_0) - k_0 = u(n_0) - c(n_0)$ as well as $v_w = k_0 - c(n_0) = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \leq n_0$, it must be the case that $s - c(n) - h_w \geq k_0 - c(n)$. Then, a clan chooses $s = k_0 + h_w$ and obtains utility $u(n) - k_0 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), which results in $v_c = u(n_0) - s - h_c = u(n_0) - k_0 - h_w - h_c = u(n_0) - c(n_0) - h_w - h_c$ and $v_w = s - c(n_0) - h_w = k_0 + h_w - c(n_0) - h_w = k_0 - c(n_0) = r_0 = 0$. Consequently, for $n \leq n_0$, the strategy profile $(n_0, 0, z)$ provides a clan with maximum utility $u(n_0) - c(n_0)$.

In case of $n \geq n_0$ (i.e., $k_0 - c(n) \leq r_0$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = u(n^*) - c(n^*) - \tau$ as well as $v_w = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \geq n_0$, it must be the case that $s - c(n) - h_w \geq r_0 = 0$. Then, a clan chooses $s = c(n) + h_w$ and obtains utility $u(n) - c(n) - h_w - h_c$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - h_w - h_c$ and $v_w = s - c(n^*) - h_w = r_0 = 0$. Consequently, for $n \geq n_0$, the strategy profile $(n^*, 0, l)$ provides a clan with maximum utility $u(n^*) - c(n^*) - \tau$.

Now, compare $u(n_0) - c(n_0)$ with $u(n^*) - c(n^*) - \tau$. When $\tau \geq \Delta \equiv u(n^*) - c(n^*) - u(n_0) + c(n_0)$, it becomes that $u(n_0) - c(n_0) \geq u(n^*) - c(n^*) - \tau$. Then, the strategy profile $(n_0, 0, z)$ is subgame perfect. Otherwise, $u(n_0) - c(n_0) < u(n^*) - c(n^*) - \tau$ and thus, the strategy profile $(n^*, 0, l)$ is subgame perfect. In both cases, a widow obtains utility $r_0 = 0$.

Proof of proposition 5:

Find n_3 satisfying $k_1 - c(n_3) = r_2$. Since $k_1 > c(n^*) > c(n^*) + r_2$ by assumption, it is the case that $c(n_3) > c(n^*)$, i.e., $n_3 > n^*$ (see also Figure S.2 for the graphical interpretation of n^* and n_3).

First, consider the case of $n \leq n_3$. In this case, $k_1 - c(n) \geq k_1 - c(n_3) = r_2$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_1$. A clan can maximize this utility by selecting $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), yielding $v_c = u(n_3) - k_1 = u(n_3) - c(n_3) - r_2$ as well as $v_w = k_1 - c(n_3) = r_2$. To encourage a widow to accept levirate marriage $n \leq n_3$, it must be the case that $s - c(n) - h_w \geq k_1 - c(n)$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $u(n) - k_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), which results in $v_c = u(n_3) - s - h_c$ $= u(n_3) - k_1 - h_w - h_c = u(n_3) - c(n_3) - r_2 - h_w - h_c$ and $v_w = s - c(n_3) - h_w = k_1 + h_w - c(n_3) - h_w = r_2$. Consequently, for $n \leq n_3$, the strategy profile $(n_3, 0, z)$ provides a clan with maximum utility $u(n_3) - c(n_3) - r_2$.

In case of $n \geq n_3$ (i.e., $k_1 - c(n) \leq r_2$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility *subject to* $n \geq n_3$ $> n^*$. Then, a clan selects $n = n_3$ (corner solution), yielding $v_c = u(n_3) - c(n_3) - \tau$ as well as $v_w = r_2$. To encourage a widow to accept levirate marriage for $n \geq n_3$, it must be the case that $s - c(n) - h_w \geq r_2$. Then, a clan chooses s $= c(n) + r_2 + h_w$ and obtains utility $u(n) - c(n) - r_2 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_3 >$ n^*. Then, a clan selects $n = n_3$ (corner solution), which results in $v_c = u(n_3) - s - h_c = u(n_3) - c(n_3) - r_2 - h_w - h_c$ and $v_w = s - c(n_3) - h_w = r_2$. Consequently, for $n \geq n_3$, the strategy profile $(n_3, 0, l)$ provides a clan with maximum utility $u(n_3) - c(n_3) - \tau$.

Since $u(n_3) - c(n_3) - r_2 > u(n_3) - c(n_3) - \tau$, the strategy profile $(n_3, 0, z)$ is subgame perfect. In this case, a widow obtains utility r_2.

Proof of proposition S.1:

Find $\hat{n}_0$ satisfying $\hat{k}_0 - c(\hat{n}_0) = -g$. Since $\hat{k}_0 \leq c(n^*) - g$ by assumption, it is the case that $c(\hat{n}_0) \leq c(n^*)$, i.e., $\hat{n}_0 \leq$ n^*. Also, note that a widow never chooses the action l_2 because $-c(n) - b < \hat{k}_0 - c(n)$. Then, consider two cases of n $\leq \hat{n}_0$ and $n \geq \hat{n}_0$. Following similar steps taken when proving the proposition 1 yields proposition S.1.

Proof of proposition S.2:

Find $\hat{n}_1$ satisfying $\hat{k}_1 - c(\hat{n}_1) = r_2 - g$. Since $\hat{k}_1 > c(n^*) - g > c(n^*) + r_2 - g$ by assumption, it is the case that $c(\hat{n}_1) > c(n^*)$, i.e., $\hat{n}_1 > n^*$. Also, note that a widow never chooses the action l_2 because $r_2 - c(n) - b < \hat{k}_1 - c(n)$. Then, consider two cases of $n \leq \hat{n}_1$ and $n \geq \hat{n}_1$. Following similar steps taken when proving the proposition 5 yields proposition S.2.

Proof of proposition S.3:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$. Since $k_0 \leq c(n^*)$ by assumption, it is the case that $c(n_0) \leq c(n^*)$, i.e., $n_0 \leq$

n^*. Also, find n_p satisfying $u'(n_p) = (1-p)c'(n_p)$. Note that $n^* \leq n_p$, which can be proved as follows; suppose $n^* > n_p$, $u'(n_p) > u'(n^*) = c'(n^*) > c'(n_p)$, which is a contradiction to $u'(n_p) = (1-p)c'(n_p)$. Therefor, it becomes $n_0 \leq n^* \leq n_p$.

First, consider the case of $n \leq n_0$. In this case, $p(k_0 - c(n)) \geq p(k_0 - c(n_0)) = pr_0 = 0$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - pk_0 - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), yielding $v_c = u(n_0) - pk_0 - (1-p)c(n_0) - (1-p)\tau = u(n_0) - c(n_0) - (1-p)\tau$ as well as $v_w = p(k_0 - c(n_0)) = 0$. To encourage a widow to accept levirate marriage for $n \leq n_0$, it must be the case that $p(s - c(n)) \geq p(k_0 - c(n))$. Then, a clan chooses $s = k_0$ and obtains utility $u(n) - pk_0 - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), which results in $v_c = u(n_0) - pk_0 - (1-p)c(n_0) - (1-p)\tau$ $= u(n_0) - c(n_0) - (1-p)\tau$ and $v_w = p(s - c(n_0)) = p(k_0 - c(n_0)) = 0$. Consequently, for $n \leq n_0$, the strategy profiles $(n_0, 0, z)$ and $(n_0, c(n_0), a)$ provide a clan with maximum utility $u(n_0) - c(n_0) - (1-p)\tau$.

In case of $n \geq n_0$ (i.e., $p(k_0 - c(n)) \leq pr_0 = 0$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = u(n^*) - c(n^*) - \tau$ as well as $v_w = 0$. To encourage a widow to accept levirate marriage for $n \geq n_0$, it must be the case that $p(s - c(n)) \geq pr_0 = 0$. Then, a clan chooses $s = c(n)$ and obtains utility $u(n) - c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - (1-p)\tau$ and $v_w = p(s - c(n^*)) = 0$. Consequently, for $n \geq n_0$, the strategy profile $(n^*, c(n^*), a)$ provides a clan with maximum utility $u(n^*) - c(n^*) - (1-p)\tau$.

Since $u(n^*) - c(n^*) - (1-p)\tau > u(n_0) - c(n_0) - (1-p)\tau$, the strategy profile $(n^*, c(n^*), a)$ is subgame perfect. In this case, a widow obtains utility $pr_0 = 0$.

Proof of proposition S.4:

Recall n_3 satisfying $k_1 - c(n_3) = r_2$. Since $k_1 > c(n^*) > c(n^*) + r_2$ by assumption, it is the case that $c(n_3) > c(n^*)$, i.e., $n_3 > n^*$. Also, recall n_p satisfying $u'(n_p) = (1-p)c'(n_p)$, whereby $n^* \leq n_p$. Now, two cases are considered, either $k_1 \leq c(n_p) + r_2$ (i.e., $c(n^*) < k_1 \leq c(n_p) + r_2$) or $k_1 > c(n_p) + r_2$ (including both the cases of $k_1 > c(n^*) > c(n_p) + r_2$ and $k_1 > c(n_p) + r_2 > c(n^*)$).

Case 1: $k_1 \leq c(n_p) + r_2$.

Since $c(n_3) = k_1 - r_2 \leq c(n_p)$, it is the case that $n_3 \leq n_p$. Consequently, $n^* < n_3 \leq n_p$.

First, consider the case of $n \leq n_3$. In this case, $p(k_1 - c(n)) \geq p(k_1 - c(n_3)) = pr_2$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - pk_1 - (1-p)c(n) - (1-p)\tau$.

A clan can maximize this utility by selecting $n = n_3$ (corner solution), yielding $v_c = u(n_3) - pk_1 - (1-p)c(n_3) - (1-p)\tau$ $= u(n_3) - c(n_3) - pr_2 - (1-p)\tau$ as well as $v_w = p(k_1 - c(n_3)) = pr_2$. To encourage a widow to accept levirate marriage for $n \leq n_3$, it must be the case that $p(s - c(n) - h_w) \geq p(k_1 - c(n))$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $u(n) - pk_1 - ph_w - ph_c - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_3$ (corner solution), which results in $v_c = u(n_3) - pk_1 - ph_w - ph_c - (1-p)c(n_3) - (1-p)\tau = u(n_3) - c(n_3) - pr_2 - (1-p)\tau - ph_w - ph_c$ and $v_w = p(s - c(n_3) - h_w) = p(k_1 + h_w - c(n_3) - h_w) = pr_2$. Consequently, for $n \leq n_3$, the strategy profile $(n_3, 0, z)$ provides a clan with maximum utility $u(n_3) - c(n_3) - pr_2 - (1-p)\tau$.

In case of $n \geq n_3$ (i.e., $p(k_1 - c(n)) \leq pr_2$), a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility *subject to* $n \geq n_3 > n^*$. Then, a clan selects $n = n_3$ (corner solution), yielding $v_c = u(n_3) - c(n_3) - \tau$ as well as $v_w = pr_2$. To encourage a widow to accept levirate marriage for $n \geq n_3$, it must be the case that $p(s - c(n) - h_w) \geq pr_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $u(n) - c(n) - pr_2 - ph_w - ph_c - (1-p)\tau$. A clan can maximize this utility *subject to* $n \geq n_3 > n^*$. Then, a clan selects $n = n_3$ (corner solution), which results in $v_c =$ $u(n_3) - c(n_3) - pr_2 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_3) - h_w) = pr_2$. Consequently, for $n \geq n_3$, the strategy profile $(n_3, 0, l)$ provides a clan with maximum utility $u(n_3) - c(n_3) - \tau$.

Since $u(n_3) - c(n_3) - pr_2 - (1-p)\tau > u(n_3) - c(n_3) - (1-p)\tau > u(n_3) - c(n_3) - \tau$, the strategy profile $(n_3, 0, z)$ is subgame perfect. In this case, a widow obtains utility pr_2.

Case 2: $k_1 > c(n_p) + r_2$.

Since $k_1 > c(n_p) + r_2$, $c(n_3) = k_1 - r_2 > c(n_p)$, so $n_3 > n_p$. Consequently, $n^* \leq n_p < n_3$.

First, consider the case of $n \leq n_3$. In this case, $p(k_1 - c(n)) \geq p(k_1 - c(n_3)) = pr_2$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - pk_1 - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_p$, yielding $v_c = u(n_p) - pk_1 - (1-p)c(n_p) - (1-p)\tau = u(n_p) - pc(n_3) -$ $(1-p)c(n_p) - pr_2 - (1-p)\tau$ as well as $v_w = p(k_1 - c(n_p)) = pr_2 + pc(n_3) - pc(n_p)$. To encourage a widow to accept levirate marriage for $n \leq n_3$, it must be the case that $p(s - c(n) - h_w) \geq p(k_1 - c(n))$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $u(n) - pk_1 - ph_w - ph_c - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_p$, which results in $v_c = u(n_p) - pk_1 - ph_w - ph_c - (1-p)c(n_p) - (1-p)\tau = u(n_p) - pc(n_3) - (1-p)c(n_p) - pr_2 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_p) - h_w) = pr_2 + pc(n_3) - pc(n_p)$. Consequently, for $n \leq n_3$, the strategy profile $(n_p, 0, z)$ provides a clan with maximum utility $u(n_p) - pc(n_3) - (1-p)c(n_p) - pr_2 - (1-p)\tau$.

In case of $n \geq n_3$ (i.e., $p(k_1 - c(n)) \leq pr_2$), a widow choose action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility *subject to* $n \geq n_3 >$

n^*. Then, a clan selects $n = n_3$ (corner solution), yielding $v_c = u(n_3) - c(n_3) - \tau$ as well as $v_w = pr_2$. To encourage a widow to accept levirate marriage for $n \geq n_3$, it must be the case that $s - c(n) - h_w \geq r_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $u(n) - c(n) - pr_2 - ph_w - ph_c - (1-p)\tau$. A clan can maximize this utility *subject to* $n \geq n_3 > n^*$. Then, a clan selects $n = n_3$ (corner solution), which results in $v_c = u(n_3) - c(n_3) - pr_2 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_3) - h_w) = pr_2$. Note that $\tau < (1-p)\tau + pr_2 + ph_w + ph_c$ because $\tau - r_2 < h_w + h_c$ by assumption. Consequently, for $n \geq n_3$, the strategy profile $(n_3, 0, l)$ provides a clan with maximum utility $u(n_3) - c(n_3) - \tau$.

Now, compare utility $u(n_p) - pc(n_3) - (1-p)c(n_p) - pr_2 - (1-p)\tau$ with $u(n_3) - c(n_3) - \tau$. Since $u(n_p) - (1-p)c(n_p) - pr_2 > u(n_p) - (1-p)c(n_p) > u(n_3) - (1-p)c(n_3)$, it becomes that $u(n_p) - pc(n_3) - (1-p)c(n_p) - pr_2 > u(n_3) - c(n_3)$, which indicates $u(n_p) - pc(n_3) - (1-p)c(n_p) - pr_2 - (1-p)\tau > u(n_3) - c(n_3) - \tau$. Thus, the strategy profile $(n_p, 0, z)$ is subgame perfect. In this case, a widow obtains utility $pr_2 + pc(n_3) - pc(n_p)$.

Note that $pr_2 + pc(n_3) - pc(n_p) = pr_2 + p(k_1 - r_2 - c(n_p)) = p(k_1 - c(n_p))$. Thus, when $k_1 \geq c(n_p)$, it becomes that $p(k_1 - c(n_p)) \geq 0$. Otherwise, $p(k_1 - c(n_p)) < 0$.

Proof of proposition S.5:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$. Find n_4 and n_5 satisfying $k_0 - c(n_4) = \frac{d}{1-q}$ and $k_0 - c(n_5) = d$. Since $\frac{d}{1-q} > d > 0$, it is the case that $n_4 < n_5 < n_0$. In addition, since $c(n_4) = k_0 - \frac{d}{1-q} < k_0 = c(n_0) \leq c(n^*)$, it is the case that $c(n_4) < c(n_0) \leq c(n^*)$, i.e., $n_4 < n_0 \leq n^*$. Since $c(n_5) = k_0 - d < k_0 = c(n_0) \leq c(n^*)$, it is the case that $c(n_5) < c(n_0) \leq c(n^*)$, i.e., $n_5 < n_0 \leq n^*$. Consequently, it becomes that $n_4 < n_5 < n_0 \leq n^*$.

Also, note that, to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_0 - c(n) - d \geq q(k_0 - c(n)) + (1-q)r_0$, i.e., $k_0 - c(n) \geq \frac{d}{1-q}$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d \geq q(s - c(n)) + (1-q)r_0$, i.e., $s \geq c(n) + \frac{d}{1-q}$. Now, two cases are considered, either $k_0 \geq \frac{d}{1-q}$ or $k_0 < \frac{d}{1-q}$.

Case 1: $k_0 \geq \frac{d}{1-q}$.

First, consider the case of $n \leq n_4$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_0 - c(n) - d \geq k_0 - c(n_4) - d > k_0 - c(n_5) - d = 0$, a widow chooses action z and makes fertility effort when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_4$ (i.e., maximum in the domain of $n \leq n_4$), yielding $v_c = u(n_4) - k_0 = u(n_4) - c(n_4) - \frac{d}{1-q}$ as well as $v_w = k_0 - c(n_4) - d = \frac{d}{1-q} - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort for $n \leq n_4$, it must be the case that $s - c(n) - d \geq k_0 - c(n) - d$ (i.e., $s \geq k_0$) *and* $s \geq c(n) + \frac{d}{1-q}$. Since $k_0 - c(n) - \frac{d}{1-q} = c(n_4) - c(n) \geq 0$, the above conditions result in $s \geq k_0 \geq c(n) + \frac{d}{1-q}$. Then, a clan chooses $s = k_0$ and obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_4$ (i.e., maximum in the domain of $n \leq n_4$), which results in $v_c = u(n_4) - s = u(n_4) - k_0 = u(n_4) - c(n_4) - \frac{d}{1-q}$ and $v_w = s - c(n_4) - d = k_0 - c(n_4) - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \leq n_4$, it must be the case that $q(s - c(n)) \geq k_0 - c(n) - d$ (i.e., $s \geq \frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n)$) *and* $s \leq c(n) + \frac{d}{1-q}$. Since $\left(\frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n)\right) - \left(c(n) + \frac{d}{1-q}\right) = \frac{1}{q}\left(k_0 - c(n) - \frac{d}{1-q}\right) = \frac{1}{q}\left(c(n_4) - c(n)\right) \geq 0$, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_4$, the strategy profiles $(n_4, 0, z, \bar{e})$ and $(n_4, c(n_4) + \frac{d}{1-q}, a, \bar{e})$ provide a clan with maximum utility $u(n_4) - c(n_4) - \frac{d}{1-q}$.

Second, consider the case of $n_4 \leq n \leq n_0$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) \geq q(k_0 - c(n_0)) = 0$, a widow chooses action z and makes no fertility effort when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $q(u(n) - k_0)$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), yielding $v_c = q(u(n_0) - k_0) = q\left(u(n_0) - c(n_0)\right)$ as well as $v_w = q(k_0 - c(n_0)) = 0$. To encourage a widow to accept levirate marriage while making fertility effort for $n_4 \leq n \leq n_0$, it must be the case that $s - c(n) - d \geq q(k_0 - c(n))$ (i.e., $s \geq q(k_0 - c(n)) + c(n) + d$) *and* $s \geq c(n) + \frac{d}{1-q}$. Since $q(k_0 - c(n)) + c(n) + d - \left(c(n) + \frac{d}{1-q}\right) = q\left(k_0 - c(n) - \frac{d}{1-q}\right) = q(c(n_4) - c(n)) \leq 0$, the above conditions result in $s \geq c(n) + \frac{d}{1-q} \geq q(k_0 - c(n)) + c(n) + d$ for all $n_4 \leq n \leq n_0$. Then, a clan chooses $s = c(n) + \frac{d}{1-q}$ and obtains utility $u(n) - c(n) - \frac{d}{1-q}$. In this case, a clan can maximize utility by selecting $n = n_0$ (corner solution), which results in $v_c = u(n_0) - c(n_0) - \frac{d}{1-q}$ and $v_w = s - c(n_0) - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n_4 \leq n \leq n_0$, it must be the case that $q(s - c(n)) \geq q(k_0 - c(n))$ (i.e., $s \geq k_0$) *and* $s \leq c(n) + \frac{d}{1-q}$. Since $k_0 - \left(c(n) + \frac{d}{1-q}\right) = c(n_4) - c(n) \leq 0$, the above conditions result in $k_0 \leq s \leq c(n) + \frac{d}{1-q}$. Then, a clan chooses $s = k_0$ and obtains utility $q(u(n) - k_0)$. A clan can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), which results in $v_c = q(u(n_0) - s) = q(u(n_0) - k_0) = q\left(u(n_0) - c(n_0)\right)$ and $v_w = q(s - c(n_0)) = q(k_0 - c(n_0)) = 0$. Consequently, for $n_4 \leq n \leq n_0$, either of $q(u(n_0) - c(n_0))$ or $u(n_0) - c(n_0) - \frac{d}{1-q}$ provides a clan with maximum utility, depending upon the relevant functional forms and parameter values.

Third, consider the case of $n \geq n_0$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) \leq q(k_0 - c(n_0)) = 0$, a widow chooses action l and makes no fertility effort when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $q(u(n) - c(n) - \tau)$. A clan can maximize this utility by selecting $n = n^*$, yielding $v_c = q(u(n^*) - c(n^*) - \tau)$ as well as $v_w = 0$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_0$, it must be the case that $s - c(n) - d \geq 0$ *and* $s \geq c(n) + \frac{d}{1-q}$, namely $s \geq c(n) + \frac{d}{1-q} > c(n) + d$. Then, a clan chooses $s = c(n) + \frac{d}{1-q}$ and obtains utility $u(n) - c(n) - \frac{d}{1-q}$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d}{1-q}$ and $v_w = s - c(n^*) - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for

$n \geq n_0$, it must be the case that $q(s - c(n)) \geq 0$ *and* $s \leq c(n) + \frac{d}{1-q}$, namely $c(n) \leq s \leq c(n) + \frac{d}{1-q}$. Then, a clan chooses $s = c(n)$ and obtains utility $q\,(u(n) - c(n))$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = q\,(u(n^*) - c(n^*))$ and $v_w = q(s - c(n^*)) = 0$. Consequently, for $n \geq n_0$, when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d}{1-q}$, it becomes that $u(n^*) - c(n^*) - \frac{d}{1-q} \geq q(u(n^*) - c(n^*)) > q(u(n^*) - c(n^*) - \tau)$. In this case, the strategy profile $(n^*, c(n^*) + \frac{d}{1-q}, a, \bar{e})$ provides a clan with maximum utility $u(n^*) - c(n^*) - \frac{d}{1-q}$. When $(1-q)(u(n^*) - c(n^*)) < \frac{d}{1-q}$, it becomes $q(u(n^*) - c(n^*)) > u(n^*) - c(n^*) - \frac{d}{1-q}$ and $q(u(n^*) - c(n^*)) > q(u(n^*) - c(n^*) - \tau)$. In this case, the strategy profile $(n^*, c(n^*), a, \underline{e})$ provides a clan with maximum utility $q(u(n^*) - c(n^*))$.

Now, compare maximum utility across cases. Note that $u(n_4) - c(n_4) - \frac{d}{1-q} < u(n^*) - c(n^*) - \frac{d}{1-q}$; $q(u(n_0) - c(n_0)) < q(u(n^*) - c(n^*))$; and $u(n_0) - c(n_0) - \frac{d}{1-q} < u(n^*) - c(n^*) - \frac{d}{1-q}$. Thus, when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d}{1-q}$, the strategy profile $(n^*, c(n^*) + \frac{d}{1-q}, a, \bar{e})$ is subagme perfect. In this case, a widow obtains utility $\frac{qd}{1-q}$. When $(1-q)(u(n^*) - c(n^*)) < \frac{d}{1-q}$, the strategy profile $(n^*, c(n^*), a, \underline{e})$ is subagme perfect. In this case, a widow obtains utility $r_0 = 0$.

Case 2: $k_0 < \frac{d}{1-q}$.

In this case, a woman never makes fertility effort when she rejects levirate marriage. In this case, it is fine to consider two cases of $n \leq n_0$ and $n \geq n_0$. Applying similar proof exploited in the Case 1 to these cases, it becomes that the strategy profile $(n^*, c(n^*) + \frac{d}{1-q}, a, \bar{e})$ is subagme perfect when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d}{1-q}$. In this case, a widow obtains utility $\frac{qd}{1-q}$. When $(1-q)(u(n^*) - c(n^*)) < \frac{d}{1-q}$, the strategy profile $(n^*, c(n^*), a, \underline{e})$ is subagme perfect. In this case, a widow obtains utility r_0 =0.

Proof of proposition S.6:

Find n_6, n_7, and n_8 satisfying $k_1 - c(n_6) = \frac{d}{1-q} + r_2$, $k_1 - c(n_7) = r_2 + d$, and $k_1 - c(n_8) = r_2$. Since $\frac{d}{1-q} + r_2 > d + r_2 > r_2$, it is the case that $n_6 < n_7 < n_8$. In addition, since $c(n_8) = k_1 - r_2 > k_1 > c(n^*)$, it is the case that $c(n_8) > c(n^*)$, i.e., $n_8 > n^*$.

Also, note that to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_1 - c(n) - d \geq q(k_1 - c(n)) + (1-q)r_2$, i.e., $k_1 - c(n) \geq \frac{d}{1-q} + r_2$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d - h_w \geq q(s - c(n) - h_w) + (1-q)r_2$, i.e., $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Now, two cases are considered, either $\frac{d}{1-q} + r_2 > 0$ or $\frac{d}{1-q} + r_2 \leq 0$.

Case 1: $\frac{d}{1-q} + r_2 > 0$.

Now, consider three subcases of either $k_1 < \frac{d}{1-q} + r_2$, $\frac{d}{1-q} + r_2 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_2$, and $k_1 > c(n^*) + \frac{d}{1-q} + r_2$.

Subcase 1: $k_1 < \frac{d}{1-q} + r_2$.

Since $k_1 < \frac{d}{1-q} + r_2 < c(n^*) + \frac{d}{1-q} + r_2$, it is the case that $c(n_6) = k_1 - \frac{d}{1-q} - r_2 < c(n^*)$, so $n_6 < n^*$. Consequently, $n_6 < 0 < n^* < n_8$. Also, note that in this case, a woman never makes fertility effort when she rejects leviraet marriage.

First, consider the case of $0 \leq n \leq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \geq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $q(u(n) - k_1)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), yielding $v_c = q(u(n_8) - k_1) = q\,(u(n_8) - c(n_8) - r_2)$ as well as $v_w = q(k_1 - c(n_8)) + (1-q)r_2 = r_2$.

To encourage a widow to accept levirate marriage while making fertility effort for $0 \leq n \leq n_8$, it must be the case that $s - c(n) - d - h_w \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $(qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = q\left(k_1 - \frac{d}{1-q} - r_2 - c(n)\right) < 0$, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 > qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = c(n^*) + \frac{d}{1-q} + h_w + r_2 - c(n^*) - d - h_w = r_2 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $0 \leq n \leq n_8$, it must be case that $q(s - c(n) - h_w) + (1-q)r_2 \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_1 - \frac{d}{1-q} - r_2 - c(n) < 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $q(u(n) - k_1 - h_w - h_c)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), which results in $v_c = q(u(n_8) - k_1 - h_w - h_c)$ $= q\,(u(n_8) - c(n_8) - r_2 - h_w - h_c)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$.

Since $q\,(u(n_8) - c(n_8) - r_2 - h_w - h_c) < q\,(u(n_8) - c(n_8) - r_2)$, the strategy profile $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_8) - c(n_8) - r_2) > u(n^*) - c(n^*) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $0 \leq n \leq n_8$, the strategy profile $(n_8, 0, z, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - r_2)$.

Second, consider the case of $n \geq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \leq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $q(u(n) - c(n) - \tau)$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), yielding $v_c = q(u(n_8) - c(n_8) - \tau)$ as well as $v_w = r_2$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_8$, it must be the case that $s - c(n) - d - h_w \geq r_2$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq c(n) + d + h_w + r_2$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c =$

$u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_8) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_8$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq r_2$ (i.e., $s \geq c(n) + r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $c(n) + r_2 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $q\left(u(n) - c(n) - r_2 - h_w - h_c\right)$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c = q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$. Since $q(u(n_8) - c(n_8) - \tau) > q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ due to $\tau - r_2 < h_w + h_c$ and $q(u(n_8) - c(n_8) - \tau) > u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$ due to an infinitely large disease cost, the strategy profiles $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ and $(n_8, c(n_8) + \frac{d}{1-q} + r_2 + h_w, a, \bar{e})$ are not selected. Consequently, for $n \geq n_8$, the strategy profile $(n_8, 0, l, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - \tau)$.

Now, compare utility $q(u(n_8)-c(n_8)-r_2)$ and $q(u(n_8)-c(n_8)-\tau)$. Since $q(u(n_8)-c(n_8)-r_2) > q(u(n_8)-c(n_8)-\tau)$, the strategy profile $(n_8, 0, l, \underline{e})$ is not selected. As a result, the strategy profile $(n_8, 0, z, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - r_2)$. In this case, a widow obtains utility r_2.

Subcase 2: $\frac{d}{1-q} + r_2 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_2$.

Since $k_1 \leq c(n^*) + \frac{d}{1-q} + r_2$, it is the case that $c(n_6) = k_1 - \frac{d}{1-q} - r_2 \leq c(n^*)$, so $n_6 \leq n^*$. Consequently, $0 \leq n_6 \leq n^* < n_8$.

First, consider the case of $n \leq n_6$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_1 - c(n) - d \geq k_1 - c(n_6) - d > k_1 - c(n_7) - d = r_2$. So, a widow chooses action z and makes fertility effort when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_1$. A clan can maximize this utility by selecting $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), yielding $v_c = u(n_6) - k_1 = u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$ as well as $v_w = k_1 - c(n_6) - d = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort, it must be the case that $s - c(n) - d - h_w \geq k_1 - c(n) - d$ (i.e., $s \geq k_1 + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_1 - c(n) - \frac{d}{1-q} - r_2 = c(n_6) - c(n) \geq 0$, the above conditions result in $s \geq k_1 + h_w \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $u(n) - k_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), which results in $v_c = u(n_6) - k_1 - h_w - h_c = u(n_6) - c(n_6) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_6) - d - h_w = k_1 + h_w - c(n_6) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq k_1 - c(n) - d$ (i.e., $s \geq \frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $\left(\frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = \frac{1}{q}\left(k_1 - c(n) - \frac{d}{1-q} - r_2\right) = \frac{1}{q}(c(n_6) - c(n)) \geq 0$ for all $n \leq n_6$. Thus, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_6$, the strategy profile $(n_6, 0, z, \bar{e})$ provides a clan with maximum utility

$u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$.

Second, consider the case of $n_6 \leq n \leq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \geq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $q(u(n) - k_1)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), yielding $v_c = q(u(n_8) - k_1) = q\left(u(n_8) - c(n_8) - r_2\right)$ as well as $v_w = q(k_1 - c(n_8)) + (1-q)r_2 = r_2$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_6 \leq n \leq n_8$, it must be the case that $s - c(n) - d - h_w \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $(qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = q\left(k_1 - \frac{d}{1-q} - r_2 - c(n)\right) = q(c(n_6) - c(n))$ ≤ 0, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = c(n^*) + \frac{d}{1-q} + h_w + r_2 - c(n^*) - d - h_w$ $= r_2 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_6 \leq n \leq n_8$, it must be case that $q(s - c(n) - h_w) + (1-q)r_2 \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_1 - \frac{d}{1-q} - r_2 - c(n) = c(n_6) - c(n) \leq 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $q(u(n) - k_1 - h_w - h_c)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), which results in $v_c = q(u(n_8) - k_1 - h_w - h_c) = q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$.

Since $q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right) < q\left(u(n_8) - c(n_8) - r_2\right)$, the strategy profile $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_8) - c(n_8) - r_2) > u(n^*) - c(n^*) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n_6 \leq n \leq n_8$, the strategy profile $(n_8, 0, z, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - r_2)$.

Third, consider the case of $n \geq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \leq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $q(u(n) - c(n) - \tau)$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), yielding $v_c = q(u(n_8) - c(n_8) - \tau)$ as well as $v_w = r_2$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_8$, it must be the case that $s - c(n) - d - h_w \geq r_2$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq c(n) + d + h_w + r_2$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c = u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_8) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_8$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq r_2$ (i.e., $s \geq c(n) + r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $c(n) + r_2 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $q\left(u(n) - c(n) - r_2 - h_w - h_c\right)$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c = q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$. Since $q(u(n_8) - c(n_8) - \tau) > q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ due to $\tau - r_2 < h_w + h_c$, the strategy profile $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_8) - c(n_8) - \tau) > u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n \geq n_8$, the strategy profile $(n_8, 0, l, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - \tau)$.

Now, compare utility $u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$, $q(u(n_8) - c(n_8) - r_2)$, and $q(u(n_8) - c(n_8) - \tau)$. Since $q(u(n_8) - c(n_8) - r_2) > q(u(n_8) - c(n_8) - \tau)$, the strategy profile $(n_8, 0, l, \underline{e})$ is not selected. Here, note that $\left(u(n_6) - c(n_6) - \frac{d}{1-q} - r_2\right) - q(u(n_8) - c(n_8) - r_2) = (u(n_6) - k_1) - q(u(n_8) - k_1) = u(n_6) - u(n_8) + (1-q)(u(n_8) - k_1)$. Thus, when $u(n_8) - k_1 > \frac{u(n_8) - u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect and a widow obtains utility $r_2 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect and a widow obtains utility r_2.

Subcase 3: $k_1 > c(n^*) + \frac{d}{1-q} + r_2$

Since $c(n_6) = k_1 - \frac{d}{1-q} - r_2 > c(n^*)$, $c(n_6) > c(n^*)$, so $n_6 > n^*$. Consequently, $n^* < n_6 < n_8$.

First, consider the case of $n \leq n_6$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_1 - c(n) - d \geq k_1 - c(n_6) - d > k_1 - c(n_7) - d = r_2$. So, a widow chooses action z and makes fertility effort when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_1$. A clan can maximize this utility by selecting $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), yielding $v_c = u(n_6) - k_1 = u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$ as well as $v_w = k_1 - c(n_6) - d = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort, it must be the case that $s - c(n) - d - h_w \geq k_1 - c(n) - d$ (i.e., $s \geq k_1 + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_1 - c(n) - \frac{d}{1-q} - r_2 = c(n_6) - c(n) \geq 0$, the above conditions result in $s \geq k_1 + h_w \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $u(n) - k_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), which results in $v_c = u(n_6) - k_1 - h_w - h_c = u(n_6) - c(n_6) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_6) - d - h_w = k_1 + h_w - c(n_6) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq k_1 - c(n) - d$ (i.e., $s \geq \frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $\left(\frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = \frac{1}{q}\left(k_1 - c(n) - \frac{d}{1-q} - r_2\right)$

$= \frac{1}{q}(c(n_6) - c(n)) \geq 0$ for all $n \leq n_6$. Thus, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_6$, the strategy profile $(n_6, 0, z, \bar{e})$ provides a clan with maximum utility $u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$.

Second, consider the case of $n_6 \leq n \leq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \geq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $q(u(n) - k_1)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), yielding $v_c = q(u(n_8) - k_1) = q\left(u(n_8) - c(n_8) - r_2\right)$ as well as $v_w = q(k_1 - c(n_8)) + (1-q)r_2 = r_2$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_6 \leq n \leq n_8$, it must be the case that $s - c(n) - d - h_w \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $(qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = q\left(k_1 - \frac{d}{1-q} - r_2 - c(n)\right) = q(c(n_6) - c(n))$ ≤ 0, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq qk_1 + (1-q)c(n) + (1-q)r_2 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_6$ (corner solution), which results in $v_c = u(n_6) - c(n_6) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = c(n_6) + \frac{d}{1-q} + h_w + r_2 - c(n_6) - d - h_w = r_2 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_6 \leq n \leq n_8$, it must be case that $q(s - c(n) - h_w) + (1-q)r_2 \geq q(k_1 - c(n)) + (1-q)r_2$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_1 - \frac{d}{1-q} - r_2 - c(n) = c(n_6) - c(n) \leq 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_1 + h_w$ and obtains utility $q(u(n) - k_1 - h_w - h_c)$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), which results in $v_c = q(u(n_8) - k_1 - h_w - h_c) = q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$.

Since $q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right) < q\left(u(n_8) - c(n_8) - r_2\right)$, the strategy profile $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_8) - c(n_8) - r_2) > u(n_6) - c(n_6) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n_6 \leq n \leq n_8$, the strategy profile $(n_8, 0, z, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - r_2)$.

Third, consider the case of $n \geq n_8$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_1 - c(n)) + (1-q)r_2 \leq q(k_1 - c(n_8)) + (1-q)r_2 = r_2$, a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $q(u(n) - c(n) - \tau)$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), yielding $v_c = q(u(n_8) - c(n_8) - \tau)$ as well as $v_w = r_2$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_8$, it must be the case that $s - c(n) - d - h_w \geq r_2$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq c(n) + d + h_w + r_2$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c = u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_8) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_8$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq r_2$ (i.e., $s \geq c(n) + r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $c(n) + r_2 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $q\left(u(n) - c(n) - r_2 - h_w - h_c\right)$. A clan can maximize this utility *subject to n* $\geq n_8 > n^*$. Then, a clan selects $n = n_8$ (corner solution), which results in $v_c = q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_8) - h_w) + (1-q)r_2 = r_2$. Since $q(u(n_8) - c(n_8) - \tau) > q\left(u(n_8) - c(n_8) - r_2 - h_w - h_c\right)$ due to $\tau - r_2 < h_w + h_c$, the strategy profile $(n_8, c(n_8) + r_2 + h_w, a, \underline{e})$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_8) - c(n_8) - \tau) > u(n_8) - c(n_8) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n \geq n_8$, the strategy profile $(n_8, 0, l, \underline{e})$ provides a clan with maximum utility $q(u(n_8) - c(n_8) - \tau)$.

Now, compare utility $u(n_6) - c(n_6) - \frac{d}{1-q} - r_2$, $q(u(n_8) - c(n_8) - r_2)$, and $q(u(n_8) - c(n_8) - \tau)$. Since $q(u(n_8) - c(n_8) - r_2) > q(u(n_8) - c(n_8) - \tau)$, the strategy profile $(n_8, 0, l, \underline{e})$ is not selected. Here, note that $\left(u(n_6) - c(n_6) - \frac{d}{1-q} - r_2\right) - q(u(n_8) - c(n_8) - r_2) = (u(n_6) - k_1) - q(u(n_8) - k_1) = u(n_6) - u(n_8) + (1-q)(u(n_8) - k_1)$. Thus, when $u(n_8) - k_1 > \frac{u(n_8) - u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect and a widow obtains utility $r_2 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect and a widow obtains utility r_2.

Case 2: $\frac{d}{1-q} + r_2 \leq 0$.

In this case, $k_1 > c(n^*) \geq c(n^*) + \frac{d}{1-q} + r_2$. Then, consider the case that $k_1 > c(n^*) + \frac{d}{1-q} + r_2$. Similar to the above Subcase 3, when $u(n_8) - k_1 > \frac{u(n_8) - c(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect and a widow obtains utility $r_2 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect and a widow obtains utility r_2.

Now, consider the Case 1 (including the Subcase 1 to Subcase 3) and Case 2 together. Then, assuming that $r = r_2 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough in the sense that $\tau - r_2 < h_c + h_w \approx \infty$, we get

1. When $\frac{d}{1-q} + r_2 > 0$
   (a) and $k_1 < \frac{d}{1-q} + r_2$ (in this case, $n_6 < 0 < n^* < n_8$), the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$.
   (b) and $\frac{d}{1-q} + r_2 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_2$ (in this case, $0 \leq n_6 \leq n^* < n_8$)
      i. and $u(n_8) - k_1 \leq \frac{u(n_8) - u(n_6)}{1-q}$, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equi-

librium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$.

ii. and $u(n_8) - k_1 > \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_6 \leq n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} < \frac{qd}{1-q}$.

(c) and $k_1 > c(n^*) + \frac{d}{1-q} + r_2$ (in this case, $0 < n^* < n_6 < n_8$)

i. and $u(n_8) - k_1 \leq \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$.

ii. and $u(n_8) - k_1 > \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_6 > n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} < \frac{qd}{1-q}$.

2. When $\frac{d}{1-q} + r_2 \leq 0$ and thus, $k_1 > c(n^*) \geq c(n^*) + \frac{d}{1-q} + r_2$ (in this case, $0 < n^* < n_6 < n_8$)

(a) and $u(n_8) - k_1 \leq \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_8, 0, z, \underline{e})$ is subgame perfect, along with the equilibrium number of children $n_8 > n^*$ and a widow's payoff $r_2 < 0 < \frac{qd}{1-q}$.

(b) and $u(n_8) - k_1 > \frac{u(n_8)-u(n_6)}{1-q}$, the strategy profile $(n_6, 0, z, \bar{e})$ is subgame perfect, along with the equilibrium number of children $n_6 > n^*$ and a widow's payoff $r_2 + \frac{qd}{1-q} = r_2 + \frac{d}{1-q} - d < 0 < \frac{qd}{1-q}$.

Summarizing these more succinctly yields proposition S.6.

Proof of proposition S.7:

Find n_9, n_{10}, and n_{11} satisfying $k_0 - c(n_9) = \frac{d}{1-q} + r_2$, $k_0 - c(n_{10}) = r_2 + d$, and $k_0 - c(n_{11}) = r_2$. Since $\frac{d}{1-q} + r_2 > d + r_2 > r_2$, it is the case that $n_9 < n_{10} < n_{11}$. Since $c(n_9) = k_0 - \frac{d}{1-q} - r_2 > c(n^*)$, $c(n_9) > c(n^*)$, so $n_9 > n^*$. Consequently, $n^* < n_9 < n_{11}$.

Also, note that to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_0 - c(n) - d \geq q(k_0 - c(n)) + (1-q)r_2$, i.e., $k_0 - c(n) \geq \frac{d}{1-q} + r_2$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d - h_w \geq q(s - c(n) - h_w) + (1-q)r_2$, i.e., $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$.

First, consider the case of $n \leq n_9$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_0 - c(n) - d \geq k_0 - c(n_9) - d > k_0 - c(n_{10}) - d = r_2$. So, a widow chooses action z and makes fertility effort when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - k_0$. A clan can maximize this utility by selecting $n = n_9$ (i.e., maximum in the domain of $n \leq n_9$), yielding $v_c = u(n_9) - k_0 = u(n_9) - c(n_9) - \frac{d}{1-q} - r_2$ as well as $v_w = k_0 - c(n_9) - d = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort, it must be the case that $s - c(n) - d - h_w \geq k_0 - c(n) - d$ (i.e., $s \geq k_0 + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_0 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_0 - c(n) - \frac{d}{1-q} - r_2 = c(n_9) - c(n) \geq 0$, the above conditions result in $s \geq k_0 + h_w \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_0 + h_w$ and obtains utility $u(n) - k_0 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_9$ (i.e., maximum in the domain of $n \leq n_9$), which results in $v_c = u(n_9) - k_0 - h_w - h_c = u(n_9) - c(n_9) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_9) - d - h_w = k_0 + h_w - c(n_9) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq k_0 - c(n) - d$ (i.e., $s \geq \frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $\left(\frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_2 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = \frac{1}{q}\left(k_0 - c(n) - \frac{d}{1-q} - r_2\right)$ $= \frac{1}{q}(c(n_9) - c(n)) \geq 0$ for all $n \leq n_9$. Thus, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_9$, the strategy profile $(n_9, 0, z, \bar{e})$ provides a clan with maximum utility $u(n_9) - c(n_9) - \frac{d}{1-q} - r_2$.

Second, consider the case of $n_9 \leq n \leq n_{11}$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_0 - c(n)) + (1-q)r_2 \geq q(k_0 - c(n_{11})) + (1-q)r_2 = r_2$, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $q(u(n) - k_0)$. A clan can maximize this utility by selecting $n = n_{11}$ (i.e., maximum in the domain of $n \leq n_{11}$), yielding $v_c = q(u(n_{11}) - k_0) = q\left(u(n_{11}) - c(n_{11}) - r_2\right)$ as well as $v_w = q(k_0 - c(n_{11})) + (1-q)r_2 = r_2$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_9 \leq n \leq n_{11}$, it must be the case that $s - c(n) - d - h_w \geq q(k_0 - c(n)) + (1-q)r_2$ (i.e., $s \geq qk_0 + (1-q)c(n) + (1-q)r_2 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $(qk_0 + (1-q)c(n) + (1-q)r_2 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = q\left(k_0 - \frac{d}{1-q} - r_2 - c(n)\right) = q(c(n_9) - c(n))$ ≤ 0, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq qk_0 + (1-q)c(n) + (1-q)r_2 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_9$ (corner solution), which results in $v_c = u(n_9) - c(n_9) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = c(n_9) + \frac{d}{1-q} + h_w + r_2 - c(n_9) - d - h_w = r_2 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_9 \leq n \leq n_{11}$, it must be case that $q(s - c(n) - h_w) + (1-q)r_2 \geq q(k_0 - c(n)) + (1-q)r_2$ (i.e., $s \geq k_0 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Since $k_0 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_2\right) = k_0 - \frac{d}{1-q} - r_2 - c(n) = c(n_9) - c(n) \leq 0$, the above conditions result in $k_0 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = k_0 + h_w$ and obtains utility $q(u(n) - k_0 - h_w - h_c)$. A clan can maximize this utility by selecting $n = n_{11}$ (i.e., maximum in the domain of $n \leq n_{11}$), which results in $v_c = q(u(n_{11}) - k_0 - h_w - h_c) = q\left(u(n_{11}) - c(n_{11}) - r_2 - h_w - h_c\right)$ and $v_w = q(s - c(n_{11}) - h_w) + (1-q)r_2 = r_2$.

Since $q\left(u(n_{11}) - c(n_{11}) - r_2 - h_w - h_c\right) < q\left(u(n_{11}) - c(n_{11}) - r_2\right)$, the strategy profile $(n_{11}, c(n_{11}) + r_2 + h_w, a, \underline{e})$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_{11}) - c(n_{11}) - r_2) > u(n_9) - c(n_9) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n_9 \leq n \leq n_{11}$, the strategy profile $(n_{11}, 0, z, \underline{e})$ provides a clan with maximum utility $q(u(n_{11}) - c(n_{11}) - r_2)$.

Third, consider the case of $n \geq n_{11}$. In this case, a woman has no incentive to make fertility effort when she choose action z. Since $q(k_0 - c(n)) + (1-q)r_2 \leq q(k_0 - c(n_{11})) + (1-q)r_2 = r_2$, a widow chooses action l when she rejects levirate marriage. Given the action l taken by a widow, a clan obtains utility $q(u(n) - c(n) - \tau)$. A clan can maximize this utility *subject to* $n \geq n_{11} > n^*$. Then, a clan selects $n = n_{11}$ (corner solution), yielding $v_c = q(u(n_{11}) - c(n_{11}) - \tau)$ as well as $v_w = r_2$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_{11}$, it must be the case that $s - c(n) - d - h_w \geq r_2$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_2 \geq c(n) + d + h_w + r_2$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_2$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_2 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_{11} > n^*$. Then, a clan selects $n = n_{11}$ (corner solution), which results in $v_c = u(n_{11}) - c(n_{11}) - \frac{d}{1-q} - r_2 - h_w - h_c$ and $v_w = s - c(n_{11}) - d - h_w = r_2 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_{11}$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_2 \geq r_2$ (i.e., $s \geq c(n) + r_2 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_2$, yielding $c(n) + r_2 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_2$. Then, a clan chooses $s = c(n) + r_2 + h_w$ and obtains utility $q\,(u(n) - c(n) - r_2 - h_w - h_c)$. A clan can maximize this utility *subject to* $n \geq n_{11} > n^*$. Then, a clan selects $n = n_{11}$ (corner solution), which results in $v_c = q\,(u(n_{11}) - c(n_{11}) - r_2 - h_w - h_c)$ and $v_w = q(s - c(n_{11}) - h_w) + (1-q)r_2 = r_2$. Since $q(u(n_{11}) - c(n_{11}) - \tau) > q\,(u(n_{11}) - c(n_{11}) - r_2 - h_w - h_c)$ due to $\tau - r_2 < h_w + h_c$, the strategy profile $(n_{11}, c(n_{11}) + r_2 + h_w, a, \underline{e})$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_{11}) - c(n_{11}) - \tau) > u(n_{11}) - c(n_{11}) - \frac{d}{1-q} - r_2 - h_w - h_c$. Consequently, for $n \geq n_{11}$, the strategy profile $(n_{11}, 0, l, \underline{e})$ provides a clan with maximum utility $q(u(n_{11}) - c(n_{11}) - \tau)$.

Now, compare utility $u(n_9) - c(n_9) - \frac{d}{1-q} - r_2$, $q(u(n_{11}) - c(n_{11}) - r_2)$, and $q(u(n_{11}) - c(n_{11}) - \tau)$. Since $q(u(n_{11}) - c(n_{11}) - r_2) > q(u(n_{11}) - c(n_{11}) - \tau)$, the strategy profile $(n_{11}, 0, l, \underline{e})$ is not selected. Here, note that $\left(u(n_9) - c(n_9) - \frac{d}{1-q} - r_2\right) - q(u(n_{11}) - c(n_{11}) - r_2) = (u(n_9) - k_0) - q(u(n_{11}) - k_0) = u(n_9) - u(n_{11}) + (1-q)(u(n_{11}) - k_0)$. Thus, when $u(n_{11}) - k_0 > \frac{u(n_{11}) - u(n_9)}{1-q}$, the strategy profile $(n_9, 0, z, \bar{e})$ is subgame perfect and a widow obtains utility $r_2 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_{11}, 0, z, \underline{e})$ is subgame perfect and a widow obtains utility r_2.

Proof of proposition S.8:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$ and n_1 satisfying $k_1 - c(n_1) = r_0 = 0$, whereby $n_0 \leq n^* < n_1$. Also, note that $n^* \leq n_\rho$, which can be proved as follows; suppose $n^* > n_\rho$, $u'(n_\rho) > u'(n^*) = c'(n^*) > c'(n_\rho) > \rho_0 c'(n_\rho)$, which is a contradiction to $u'(n_\rho) = \rho_0 c'(n_\rho)$. Since $n_\rho > n_1$ by assumption, therefore, it becomes $n_0 \leq n^* < n_1 < n_\rho$. Below, denote a woman who loses her husband early and late as w_y and w_o, respectively.

First, consider the case of $n \leq n_0$. In this case, $k_0 - c(n) \geq k_0 - c(n_0) = r_0 = 0$. Also, $k_1 - c(n) \geq k_1 - c(n_0) > k_1 - c(n_1) = r_0 = 0$. So, whether w_y or w_o, a widow chooses action z when she rejects levirate marriage. To encourage

w_y to accept levirate marriage for $n \leq n_0$, it must be the case that $s_y - c(n) \geq k_0 - c(n)$. Then, a clan chooses $s_y = k_0$. To encourage w_o to accept levirate marriage for $n \leq n_0$, it must be the case that $s_o - c(n) \geq k_1 - c(n)$. Then, a clan chooses $s_o = k_1$.

Now, consider four subcases: (Case A) a clan never offers levirate marriage, (Case B) a clan offers levirate marriage only to w_y, (Case C) a clan offers levirate marriage only to w_o, and (Case D) a clan offers levirate marriage to both w_y and w_o. A clan obtains utility $\rho_0(u(n) - k_0) + (1 - \rho_0)(u(n) - k_1)$ in all these cases and can maximize this utility by selecting $n = n_0$ (i.e., maximum in the domain of $n \leq n_0$), which results in $v_c = u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_1))$. Consequently, for $n \leq n_0$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_1), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_1), a_o))$ provide a clan with maximum utility $u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_1))$.

Second, consider the case of $n_0 < n \leq n_1$. In this case, w_y chooses action l_y when she rejects levirate marriage, because $k_0 - c(n) < k_0 - c(n_0) = r_0 = 0$. On the other hand, w_o chooses action z_o when she rejects levirate marriage, because $k_1 - c(n) \geq k_1 - c(n_1) = r_0 = 0$. To encourage w_y to accept levirate marriage when $n_0 < n \leq n_1$, it must be the case that $s_y - c(n) \geq r_0 = 0$. Then, a clan chooses $s_y = c(n)$. To encourage w_o to accept levirate marriage when $n_0 < n \leq n_1$, it must be the case that $s_o - c(n) \geq k_1 - c(n)$. Then, a clan chooses $s_o = k_1$.

Again, consider a clan's utility obtained in the aforementioned four subcases, which becomes $\rho_0(u(n) - c(n) - \tau) + (1 - \rho_0)(u(n) - k_1)$ in Case A and Case C and $\rho_0(u(n) - c(n)) + (1 - \rho_0)(u(n) - k_1)$ in Case B and Case D. Since $\rho_0(u(n) - c(n)) + (1 - \rho_0)(u(n) - k_1) > \rho_0(u(n) - c(n) - \tau) + (1 - \rho_0)(u(n) - k_1)$, a clan prefers the latter two cases to the former ones. In these cases, to maximizes utility $\rho_0(u(n) - c(n)) + (1 - \rho_0)(u(n) - k_1)$ *subject to* $n \leq n_1 < n_\rho$, a clan selects $n = n_1$ (corner solution), which results in $v_c = u(n_1) - c(n_1)$. Consequently, when $n_0 < n \leq n_1$, the strategy profiles $(n_1, (c(n_1), a_y), (0, z_o))$ and $(n_1, (c(n_1), a_y), (c(n_1), a_o))$ provide a clan with maximum utility $u(n_1) - c(n_1)$.

Third, consider the case of $n \geq n_1$. In this case, $k_0 - c(n) \leq k_0 - c(n_1) < k_0 - c(n_0) = r_0 = 0$. Also, $k_1 - c(n) \leq k_1 - c(n_1) = r_0 = 0$. So, whether w_y or w_o, a widow chooses action l when she rejects levirate marriage. To encourage w_y to accept levirate marriage for $n \geq n_1$, it must be the case that $s_y - c(n) \geq r_0 = 0$. Then, a clan chooses $s_y = c(n)$. To encourage w_o to accept levirate marriage for $n \geq n_1$, it must be the case that $s_o - c(n) \geq r_0 = 0$. Then, a clan chooses $s_o = c(n)$.

As before, consider a clan's utility obtained in the aforementioned four subcases, which becomes $u(n) - c(n) - \tau$ in Case A; $\rho_0(u(n) - c(n)) + (1 - \rho_0)(u(n) - c(n) - \tau)$ in Case B; $\rho_0(u(n) - c(n) - \tau) + (1 - \rho_0)(u(n) - c(n))$ in Case C; and $u(n) - c(n)$ in Case D. Therefore, a clan prefers the Case D to the remaining cases. In Case D, to maximizes utility $u(n) - c(n)$ *subject to* $n \geq n_1 > n^*$, a clan selects $n = n_1$ (corner solution), which results in $v_c = u(n_1) - c(n_1)$. Consequently, when $n \geq n_1$, the strategy profile $(n_1, (c(n_1), a_y), (c(n_1), a_o))$ provides a clan with maximum utility

$u(n_1) - c(n_1)$.

Now, compare utility $u(n_1) - c(n_1)$ with $u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_1))$. When $u(n_1) - u(n_0) \geq \rho_0(c(n_1) - c(n_0))$, $u(n_1) - c(n_1) \geq u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_1))$. In this case, the strategy profiles $(n_1, (c(n_1), a_y), (0, z_o))$ and $(n_1, (c(n_1), a_y), (c(n_1), a_o))$ are subgame perfect and $v_w^y = v_w^o = 0$. Otherwise, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_1), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_1), a_o))$ are subgame perfect and $v_w^y = r_0 = 0$ and $v_w^o = c(n_1) - c(n_0) > 0$.

Proof of proposition S.9:

Recall n_3 satisfying $k_1 - c(n_3) = r_2 < 0$, whereby $n_3 > n_1 > n^*$ because $k_1 - c(n_3) = r_2 < k_1 - c(n_1) = r_0$ and so, $c(n_1) < c(n_3)$. As before, denote a woman who loses her husband early and late as w_y and w_o, respectively. First, consider the case of $n \leq n_3$. In this case, $k_1 - c(n) \geq k_1 - c(n_3) = r_2$. So, whether w_y or w_o, a widow chooses action z when she rejects levirate marriage. Whether w_y or w_o, to encourage a widow to accept levirate marriage for $n \leq n_3$, it must be the case that $s - c(n) - h_w \geq k_1 - c(n)$. Then, a clan chooses $s_y = s_o = k_1 + h_w$.

Now, consider four subcases: (Case A) a clan never offers levirate marriage, (Case B) a clan offers levirate marriage only to w_y, (Case C) a clan offers levirate marriage only to w_o, and (Case D) a clan offers levirate marriage to both w_y and w_o. A clan obtains utility $u(n) - k_1$ in Case A; $\rho_1(u(n) - k_1 - h_w - h_c) + (1 - \rho_1)(u(n) - k_1)$ in Case B; $\rho_1(u(n) - k_1) + (1 - \rho_1)(u(n) - k_1 - h_w - h_c)$ in Case C; and $u(n) - k_1 - h_w - h_c$ in Case D. Therefore, a clan prefers the Case A to the remaining cases. In Case A, a clan can maximize $u(n) - k_1$ by selecting $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), which results in $v_c = u(n_3) - c(n_3) - r_2$. Consequently, for $n \leq n_3$, the strategy profile $(n_3, (0, z_y), (0, z_o))$ provides a clan with maximum utility $u(n_3) - c(n_3) - r_2$.

Second, consider the case of $n \geq n_3$. In this case, $k_1 - c(n) \leq k_1 - c(n_3) = r_2$. So, whether w_y or w_o, a widow chooses action l when she rejects levirate marriage. Whether w_y or w_o, to encourage a widow to accept levirate marriage for $n \geq n_3$, it must be the case that $s - c(n) - h_w \geq r_2$. Then, a clan chooses $s_y = s_o = c(n) + r_2 + h_w$.

Again, consider a clan's utility obtained in the aforementioned four subcases, which becomes $u(n) - c(n) - \tau$ in Case A; $\rho_1(u(n) - c(n) - r_2 - h_w - h_c) + (1 - \rho_1)(u(n) - c(n) - \tau)$ in Case B; $\rho_1(u(n) - c(n) - \tau) + (1 - \rho_1)(u(n) - c(n) - r_2 - h_w - h_c)$ in Case C; and $u(n) - c(n) - r_2 - h_w - h_c$ in Case D. Since $\tau - r_2 < h_w + h_c$, therefore, a clan prefers the Case A to the remaining cases. In Case A, a clan maximizes utility $u(n) - c(n) - \tau$ *subject to* $n \geq n_3 > n^*$ and then, selects $n = n_3$ (corner solution), which results in $v_c = u(n_3) - c(n_3) - \tau$. Consequently, when $n \geq n_3$, the strategy profile $(n_3, (0, l_y), (0, l_o))$ provides a clan with maximum utility $u(n_3) - c(n_3) - \tau$.

Since $u(n_3) - c(n_3) - r_2 > u(n_3) - c(n_3) - \tau$, the strategy profile $(n_3, (0, z_y), (0, z_o))$ is subgame perfect and $v_w^y = v_w^o = r_2$.

Proof of proposition S.10:

Recall n_3 satisfying $k_1 - c(n_3) = r_2 < 0$, whereby $n_3 > n_1 > n^*$ because $k_1 - c(n_3) = r_2 < k_1 - c(n_1) = r_0$ and so, $c(n_1) < c(n_3)$. As before, denote a woman who loses her husband early and late as w_y and w_o, respectively. Since $k_1 - c(\bar{n}) > k_1 - c(n_3) = r_2$ by assumption, w_y always chooses action z_y when she rejects levirate marriage. To encourage w_y to accept levirate marriage, it must be the case that $s_y - c(\bar{n}) - h_w \geq k_1 - c(\bar{n})$. Then, a clan chooses $s_y = k_1 + h_w$.

First, consider the case of $n \leq n_3$. In this case, $k_1 - c(n) \geq k_1 - c(n_3) = r_2$. So, w_o chooses action z_o when she rejects levirate marriage. To encourage w_o to accept levirate marriage for $n \leq n_3$, it must be the case that $s_o - c(n) - h_w \geq k_1 - c(n)$. Then, a clan chooses $s_o = k_1 + h_w$.

Now, consider four subcases: (Case A) a clan never offers levirate marriage, (Case B) a clan offers levirate marriage only to w_y, (Case C) a clan offers levirate marriage only to w_o, and (Case D) a clan offers levirate marriage to both w_y and w_o. A clan obtains utility $\rho_1(u(\bar{n}) - k_1) + (1-\rho_1)(u(n) - k_1)$ in Case A; $\rho_1(u(\bar{n}) - k_1 - h_w - h_c) + (1-\rho_1)(u(n) - k_1)$ in Case B; $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - k_1 - h_w - h_c)$ in Case C; and $\rho_1(u(\bar{n}) - k_1 - h_w - h_c) + (1 - \rho_1)(u(n) - k_1 - h_w - h_c)$ in Case D. Therefore, a clan prefers the Case A to the remaining cases. In Case A, a clan can maximize $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - k_1)$ by selecting $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), which results in $v_c = \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - r_2$. Consequently, for $n \leq n_3$, the strategy profile $(n_3, (0, z_y), (0, z_o))$ provides a clan with maximum utility $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - r_2$.

Second, consider the case of $n \geq n_3$. In this case, $k_1 - c(n) \leq k_1 - c(n_3) = r_2$. So, w_o chooses action l_o when she rejects levirate marriage. To encourage w_o to accept levirate marriage for $n \geq n_3$, it must be the case that $s_o - c(n) - h_w \geq r_2$. Then, a clan chooses $s_o = c(n) + r_2 + h_w$.

Again, consider a clan's utility obtained in the aforementioned four subcases, which becomes $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - c(n) - \tau)$ in Case A; $\rho_1(u(\bar{n}) - k_1 - h_w - h_c) + (1 - \rho_1)(u(n) - c(n) - \tau)$ in Case B; $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - c(n) - r_2 - h_w - h_c)$ in Case C; and $\rho_1(u(\bar{n}) - k_1 - h_w - h_c) + (1 - \rho_1)(u(n) - c(n) - r_2 - h_w - h_c)$ in Case D. Since $\tau - r_2 < h_w + h_c$, therefore, a clan prefers the Case A to the remaining cases. In Case A, a clan maximizes utility $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - c(n) - \tau)$ *subject to* $n \geq n_3 > n^*$ and then, selects $n = n_3$ (corner solution), which results in $v_c = \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - \rho_1 r_2 - (1 - \rho_1)\tau$. Consequently, when $n \geq n_3$, the strategy profile $(n_3, (0, z_y), (0, l_o))$ provides a clan with maximum utility $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - \rho_1 r_2 - (1 - \rho_1)\tau$.

Since $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - r_2 > \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_3) - c(n_3) - \rho_1 r_2 - (1 - \rho_1)\tau$, the strategy profile $(n_3, (0, z_y), (0, z_o))$ is subgame perfect, along with $v_w^y = k_1 - c(\bar{n}) = c(n_1) - c(\bar{n})$ and $v_w^o = r_2$.

(For the supplemental appendix)

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Table S.1: Checking on parallel trends before wave 1 (OLS)

Dependent variables:	Log of per capita consumption (TSH)		No. of children	
Sample (wave 1 only):	Females aged 15 to 50		Head's wives aged 15 o 50	
	(a)	(b)	(c)	(d)
Group A × Widow × Age	-0.014	0.026	-	-
	(0.015)	(0.066)		
Group A × Widow × Age squared	-	-0.001	-	-
		(0.001)		
Group A × Age	0.005	0.007	0.024	-0.113
	(0.003)	(0.019)	(0.038)	(0.205)
Group A × Age squared	-	-0.000	-	0.002
		(0.000)		(0.003)
Group A × Widow	0.377	-0.262	-	-
	(0.489)	(1.055)		
Widow × Age	0.010	-0.059	-	-
	(0.008)	(0.046)		
Widow × Age squared	-	0.001	-	-
		(0.001)		
Widow	-0.509*	0.638	-	-
	(0.266)	(0.779)		
Age (years)	0.001	-0.011	0.034**	0.771***
	(0.002)	(0.013)	(0.016)	(0.097)
Age squared	-	0.000	-	-0.011***
		(0.000)		(0.001)
Village FE	YES	YES	YES	YES
R-squared	0.307	0.310	0.213	0.317
No. of obs.	1200	1200	444	444

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

Table S.2: Summary statistics (DID estimates)

Dependent variables:	Coefficient	Standard errors	R-sqd.	No. of obs.
Per capita consumption (TSH)	-11049.539*	(6487.507)	0.007	2916
No. of biological children	0.153	(0.265)	0.019	2920
No. of biological sons	0.102	(0.161)	0.014	2920
No. of biological daughters	0.051	(0.168)	0.011	2920
Education (years)	-0.201	(0.233)	0.023	2875
Widow (dummy)	0.012	(0.025)	0.008	2917
Age (years)	1.483*	(0.759)	0.002	2920
Head's age (years)	1.123	(1.638)	0.027	2909
Head male (dummy)	0.059	(0.043)	0.008	2909
HH size	0.213	(0.664)	0.074	2916
HH land (acre)	-0.836	(1.100)	0.037	2657

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

Table S.3: Reason for migration: Panel respondents aged 15 to 50 in wave 5

	Male	Female
(1) Economic reasons		
Job-related	0.37	0.08
Look for land	0.10	0.02
(2) Schooling	0.09	0.06
(3) Family-related reasons		
Marriage	0.03	0.53
Divorce	0.00	0.03
Death of parents	0.05	0.02
Inheritance	0.05	0.01
Illness of family members	0.00	0.00
Other	0.07	0.05
(4) Other	0.20	0.15
No. of migrants	500	839

Note: The figure is the proportion relative to the total number of migrants in each gender-category.

Table S.4: Age heterogeneity: Institutional change and widows' welfare (OLS)

	Log of consumption per capita (TSH)			Log of consumption per adult equivalent (TSH)			Log of consumption per adjusted adult equivalent (TSH)			
Sample	Coefficient	Std.	R-sqd.	Coefficient	Std.	R-sqd.	Coefficient	Std.	R-sqd.	No. of obs.
Aged 15	1.136***	(0.279)	0.816	0.674***	(0.244)	0.818	-0.565**	(0.248)	0.863	138
Aged 15 to 16	-0.273	(0.506)	0.642	-0.340	(0.374)	0.653	-0.134	(0.415)	0.725	276
Aged 15 to 17	1.417***	(0.505)	0.568	1.105**	(0.541)	0.558	0.510	(0.604)	0.629	421
Aged 15 to 18	0.943**	(0.366)	0.497	0.746**	(0.356)	0.488	0.449	(0.361)	0.586	560
Aged 15 to 19	0.690*	(0.393)	0.461	0.371	(0.394)	0.450	-0.074	(0.397)	0.549	683
Aged 15 to 20	0.765*	(0.395)	0.435	0.504	(0.377)	0.421	0.119	(0.364)	0.524	805
Aged 15 to 21	0.001	(0.191)	0.433	-0.053	(0.185)	0.422	-0.333	(0.212)	0.530	894
Aged 15 to 22	-0.033	(0.164)	0.422	-0.041	(0.172)	0.410	-0.249	(0.221)	0.530	1002
Aged 15 to 23	0.063	(0.151)	0.417	0.129	(0.152)	0.404	0.068	(0.211)	0.532	1098
Aged 15 to 24	-0.098	(0.204)	0.408	-0.055	(0.196)	0.402	-0.158	(0.219)	0.536	1204
Aged 15 to 25	-0.230	(0.225)	0.400	-0.175	(0.213)	0.395	-0.140	(0.242)	0.537	1303
Aged 15 to 26	-0.394*	(0.233)	0.404	-0.355	(0.228)	0.398	-0.424	(0.287)	0.538	1380
Aged 15 to 27	-0.440**	(0.205)	0.391	-0.410**	(0.196)	0.386	-0.461*	(0.251)	0.536	1451
Aged 15 to 28	-0.458***	(0.159)	0.391	-0.459***	(0.153)	0.382	-0.530**	(0.222)	0.528	1553
Aged 15 to 29	-0.257	(0.157)	0.382	-0.268*	(0.152)	0.375	-0.340	(0.219)	0.526	1638
Aged 15 to 30	-0.164	(0.127)	0.379	-0.186	(0.124)	0.372	-0.304	(0.193)	0.524	1756
Aged 15 to 31	-0.173	(0.120)	0.376	-0.158	(0.111)	0.368	-0.195	(0.160)	0.518	1812
Aged 15 to 32	-0.214*	(0.114)	0.376	-0.211**	(0.102)	0.368	-0.231	(0.164)	0.513	1894
Aged 15 to 33	-0.158	(0.097)	0.375	-0.168*	(0.085)	0.365	-0.169	(0.149)	0.505	1946
Aged 15 to 34	-0.151	(0.091)	0.375	-0.170**	(0.081)	0.366	-0.201	(0.144)	0.507	1995
Aged 15 to 35	-0.129	(0.089)	0.378	-0.162**	(0.080)	0.369	-0.210	(0.138)	0.509	2052
Aged 15 to 36	-0.101	(0.090)	0.379	-0.142*	(0.084)	0.370	-0.239	(0.147)	0.503	2103
Aged 15 to 37	-0.130	(0.097)	0.376	-0.164*	(0.088)	0.367	-0.246*	(0.141)	0.500	2156
Aged 15 to 38	-0.091	(0.097)	0.374	-0.124	(0.089)	0.365	-0.196	(0.147)	0.498	2195
Aged 15 to 39	-0.086	(0.091)	0.370	-0.127	(0.085)	0.361	-0.208	(0.138)	0.495	2237
Aged 15 to 40	-0.070	(0.086)	0.373	-0.116	(0.081)	0.363	-0.208	(0.130)	0.495	2290
Aged 15 to 41	-0.053	(0.082)	0.371	-0.096	(0.075)	0.361	-0.196	(0.122)	0.494	2319
Aged 15 to 42	-0.053	(0.074)	0.373	-0.091	(0.070)	0.362	-0.195	(0.123)	0.494	2358
Aged 15 to 43	-0.049	(0.074)	0.375	-0.088	(0.070)	0.363	-0.189	(0.122)	0.494	2389
Aged 15 to 44	-0.068	(0.080)	0.376	-0.108	(0.075)	0.365	-0.203*	(0.119)	0.495	2416
Aged 15 to 45	-0.100	(0.081)	0.373	-0.141*	(0.076)	0.362	-0.214*	(0.114)	0.493	2448
Aged 15 to 46	-0.066	(0.084)	0.373	-0.113	(0.077)	0.364	-0.186*	(0.111)	0.494	2482
Aged 15 to 47	-0.045	(0.086)	0.372	-0.086	(0.081)	0.361	-0.149	(0.116)	0.494	2516
Aged 15 to 48	-0.047	(0.084)	0.376	-0.091	(0.080)	0.364	-0.163	(0.112)	0.494	2545
Aged 15 to 49	-0.052	(0.075)	0.374	-0.115	(0.075)	0.361	-0.199*	(0.108)	0.492	2573
Aged 15 to 50	-0.049	(0.074)	0.370	-0.105	(0.074)	0.357	-0.197*	(0.106)	0.490	2616

Notes: (1) This table reports the estimated α_2 in equation (7) by changing the exploited sample by the respondents' age. (2) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (3) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

Table S.5: Institutional change and fertility: Robustness checks

Dependent variable:	No. of children					
Sample:	Head's wives aged 15 to 50					
	OLS	OLS	Ordered probit	Ordered probit	Ordered probit	Ordered probit
	(a)	(b)	(c)	(d)	(e)	(f)
No levirate marriage						
× Aged 15 to 20	0.044	-0.080	-0.102	-0.100	-	-
	(0.352)	(0.366)	(0.313)	(0.313)		
× Aged 21 to 30	0.436	0.371	0.403*	-	-	-
	(0.271)	(0.279)	(0.244)			
× Aged 31 to 40	0.710*	0.692*	0.643**	-	-	-
	(0.384)	(0.363)	(0.299)			
× Aged 21 to 40	-	-	-	0.504**	-	-
				(0.253)		
× Aged 15 to 40	-	-	-	-	0.419*	-
					(0.238)	
× Age	-	-	-	-	-	0.251**
						(0.101)
× Age squared	-	-	-	-	-	-0.004**
						(0.002)
× No. of a head's wives	0.015	-	-	-	-	-
	(0.490)					
× HH's cash and in-kind gifts received ($\times 10^{-3}$)	-	0.014***	-	-	-	-
		(0.004)				
× HH's cash and in-kind gifts sent ($\times 10^{-3}$)	-	-0.010**	-	-	-	-
		(0.004)				
Aged 15 to 20	-0.400	-0.331	-0.450	-0.452	-0.838***	-
	(0.380)	(0.400)	(0.335)	(0.335)	(0.299)	
Aged 21 to 30	0.356	0.381	0.371	0.285	0.356	-
	(0.265)	(0.277)	(0.231)	(0.241)	(0.229)	
Aged 31 to 40	0.490	0.455	0.483*	0.592**	0.655***	-
	(0.375)	(0.352)	(0.268)	(0.233)	(0.220)	
Age (years)	-	-	-	-	-	0.311***
						(0.093)
Age squared	-	-	-	-	-	-0.005***
						(0.001)
Education (years)	-0.001	0.003	0.002	0.002	0.005	-0.010
	(0.011)	(0.011)	(0.011)	(0.011)	(0.010)	(0.011)
Head's age (years)	-0.010*	-0.010	-0.009*	-0.009*	-0.009*	-0.013**
	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Head male	-0.361	-0.312	-0.177	-0.167	-0.128	-0.131
	(0.550)	(0.496)	(0.715)	(0.709)	(0.754)	(0.675)
HH size	0.556***	0.560***	0.506***	0.505***	0.504***	0.500***
	(0.034)	(0.027)	(0.045)	(0.045)	(0.045)	(0.044)
HH land (acre)	-0.002	-0.001	-0.003	-0.003	-0.003	-0.002
	(0.013)	(0.014)	(0.010)	(0.010)	(0.010)	(0.011)
No. of a head's wives	-0.040	-	-	-	-	-
	(0.271)					
HH's cash and in-kind gifts received ($\times 10^{-3}$)	-	-0.013***	-	-	-	-
		(0.004)				
HH's cash and in-kind gifts sent ($\times 10^{-3}$)	-	0.006***	-	-	-	-
		(0.002)				
Head's ethnicity	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES
Village time-trend	YES	YES	YES	YES	YES	YES
R-squared	0.730	0.732	0.290	0.289	0.288	0.303
No. of obs.	1217	1201	1217	1217	1217	1217

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.6: Institutional change and fertility: Gender heterogeneity (OLS)

Dependent variables:	No. of			
	Sons	Sons	daughters	daughters
Sample:	Head's wives aged 15 to 50	Head's wives aged 15 to 50	Head's wives aged 15 to 50	Head's wives aged 15 to 50
	(a)	(b)	(c)	(d)
No levirate marriage				
× Aged 15 to 20 (a1)	0.086	-	-0.034	-
	(0.270)		(0.269)	
× Aged 21 to 30 (a2)	0.166	-	0.278	-
	(0.236)		(0.260)	
× Aged 31 to 40 (a3)	0.278	-	0.441	-
	(0.234)		(0.267)	
× Age	-	0.145***	-	0.102
		(0.050)		(0.086)
× Age squared	-	-0.002***	-	-0.002
		(0.001)		(0.001)
Aged 15 to 20	-0.700**	-	0.284	-
	(0.316)		(0.303)	
Aged 21 to 30	-0.098	-	0.440*	-
	(0.265)		(0.257)	
Aged 31 to 40	0.113	-	0.366	-
	(0.245)		(0.252)	
Age (years)	-	0.125***	-	0.164**
		(0.046)		(0.077)
Age squared	-	-0.002**	-	-0.003**
		(0.001)		(0.001)
Education (years)	-0.000	-0.006	-0.001	-0.007
	(0.011)	(0.010)	(0.012)	(0.013)
Head's age (years)	-0.012**	-0.013**	0.002	-0.001
	(0.005)	(0.006)	(0.005)	(0.005)
Head male	-0.568	-0.487	0.216	0.155
	(0.412)	(0.351)	(0.177)	(0.122)
HH size	0.253***	0.245***	0.301***	0.292***
	(0.030)	(0.029)	(0.016)	(0.017)
HH land (acre)	0.010	0.011	-0.012	-0.011
	(0.010)	(0.011)	(0.009)	(0.009)
Head's ethnicity	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES
Village time-trend	YES	YES	YES	YES
Joint significance (p-values)				
a2+ a3 = 0	0.325	-	0.139	-
a1 + a2 + a3 = 0	0.440	-	0.314	-
R-squared	0.448	0.455	0.505	0.514
No. of obs.	1217	1217	1217	1217

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.7: Age heterogeneity: Reduced-form impacts of HIV/AIDS on widows' welfare (OLS)

	Log of consumption per capita (TSH)			Log of consumption per adult equivalent (TSH)			Log of consumption per adjusted adult equivalent (TSH)			
Sample	Coefficient	Std.	R-sqd.	Coefficient	Std.	R-sqd.	Coefficient	Std.	R-sqd.	No. of obs.
Aged 15	-0.458	(0.697)	0.744	-0.991	(0.712)	0.746	-1.607*	(0.906)	0.772	390
Aged 15 to 16	0.006	(0.760)	0.606	-0.021	(0.776)	0.610	0.662	(0.794)	0.686	723
Aged 15 to 17	0.697	(0.517)	0.543	0.402	(0.542)	0.535	-0.202	(0.560)	0.612	1040
Aged 15 to 18	0.526*	(0.266)	0.477	0.286	(0.261)	0.466	-0.158	(0.277)	0.561	1392
Aged 15 to 19	0.144	(0.274)	0.461	-0.044	(0.222)	0.452	-0.227	(0.215)	0.549	1678
Aged 15 to 20	0.275	(0.235)	0.443	0.124	(0.208)	0.432	-0.129	(0.239)	0.531	1974
Aged 15 to 21	0.368*	(0.214)	0.441	0.207	(0.210)	0.430	-0.151	(0.229)	0.532	2182
Aged 15 to 22	0.094	(0.230)	0.431	-0.015	(0.209)	0.421	-0.172	(0.207)	0.534	2388
Aged 15 to 23	-0.076	(0.176)	0.430	-0.137	(0.158)	0.421	-0.188	(0.181)	0.543	2582
Aged 15 to 24	-0.123	(0.167)	0.427	-0.179	(0.148)	0.422	-0.216	(0.186)	0.552	2766
Aged 15 to 25	-0.079	(0.164)	0.418	-0.109	(0.152)	0.416	-0.120	(0.213)	0.559	2944
Aged 15 to 26	-0.256	(0.159)	0.398	-0.258*	(0.146)	0.397	-0.328	(0.210)	0.555	3106
Aged 15 to 27	-0.311**	(0.135)	0.388	-0.321***	(0.116)	0.388	-0.374**	(0.167)	0.557	3240
Aged 15 to 28	-0.338***	(0.118)	0.383	-0.353***	(0.102)	0.382	-0.450***	(0.155)	0.556	3404
Aged 15 to 29	-0.251**	(0.111)	0.381	-0.276***	(0.099)	0.380	-0.364**	(0.153)	0.556	3562
Aged 15 to 30	-0.143	(0.100)	0.381	-0.177*	(0.093)	0.379	-0.339**	(0.142)	0.555	3762
Aged 15 to 31	-0.122	(0.089)	0.381	-0.153*	(0.083)	0.376	-0.244*	(0.135)	0.552	3890
Aged 15 to 32	-0.022	(0.103)	0.378	-0.053	(0.104)	0.372	-0.181	(0.134)	0.546	4040
Aged 15 to 33	0.039	(0.108)	0.375	0.004	(0.111)	0.368	-0.167	(0.129)	0.540	4142
Aged 15 to 34	0.060	(0.103)	0.375	0.026	(0.107)	0.368	-0.166	(0.124)	0.538	4244
Aged 15 to 35	0.095	(0.097)	0.378	0.063	(0.101)	0.371	-0.082	(0.134)	0.538	4362
Aged 15 to 36	0.078	(0.094)	0.380	0.048	(0.099)	0.373	-0.082	(0.130)	0.532	4493
Aged 15 to 37	0.050	(0.095)	0.377	0.033	(0.098)	0.371	-0.086	(0.122)	0.529	4611
Aged 15 to 38	0.035	(0.091)	0.374	0.028	(0.095)	0.367	-0.082	(0.118)	0.527	4719
Aged 15 to 39	0.018	(0.084)	0.371	0.007	(0.088)	0.365	-0.116	(0.107)	0.523	4818
Aged 15 to 40	0.018	(0.080)	0.369	0.005	(0.083)	0.363	-0.104	(0.106)	0.520	4950
Aged 15 to 41	-0.007	(0.072)	0.367	-0.023	(0.072)	0.361	-0.120	(0.095)	0.519	5032
Aged 15 to 42	-0.010	(0.068)	0.366	-0.030	(0.068)	0.359	-0.148	(0.091)	0.518	5120
Aged 15 to 43	-0.009	(0.068)	0.368	-0.028	(0.068)	0.361	-0.149	(0.092)	0.518	5187
Aged 15 to 44	0.001	(0.066)	0.369	-0.016	(0.065)	0.362	-0.141	(0.088)	0.518	5250
Aged 15 to 45	-0.010	(0.063)	0.368	-0.023	(0.061)	0.360	-0.140	(0.085)	0.518	5319
Aged 15 to 46	-0.014	(0.063)	0.368	-0.025	(0.060)	0.361	-0.150*	(0.084)	0.517	5397
Aged 15 to 47	-0.030	(0.060)	0.364	-0.037	(0.057)	0.358	-0.151*	(0.081)	0.516	5463
Aged 15 to 48	-0.047	(0.058)	0.367	-0.050	(0.056)	0.360	-0.162**	(0.081)	0.515	5531
Aged 15 to 49	-0.048	(0.057)	0.365	-0.054	(0.056)	0.357	-0.164**	(0.079)	0.513	5602
Aged 15 to 50	-0.046	(0.054)	0.364	-0.049	(0.054)	0.356	-0.146*	(0.079)	0.513	5688

Notes: (1) After replacing D_{jt} in equation (7) with an indicator for villages that referred to HIV/AIDS as the most or second most important health problem in a community in each wave, this figure reports the estimated impacts of HIV/AIDS on widows' consumption by changing the exploited sample by the respondents' age. (2) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (3) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

Table S.8: Impacts on married women's bargaining power (OLS)

Dependent variable:	A proportion of mother-related expenditures					
Sample:	Head's wives aged 15 to 50					
Mother-related expenditures:	(A) = jewelry & perfume		(B)= (A) + fabric, clothing, & shoes		(C) = (B) + education	
	(a)	(b)	(c)	(d)	(e)	(f)
No levirate marriage						
× Aged 15 to 20	-0.004	-0.004	0.003	0.003	-0.003	-0.003
	(0.005)	(0.005)	(0.011)	(0.011)	(0.007)	(0.008)
× Aged 21 to 30	-0.003	-0.003	0.010	0.010	-0.011	-0.010
	(0.004)	(0.004)	(0.006)	(0.006)	(0.007)	(0.007)
× Aged 31 to 40	-0.004	-0.004	0.003	0.003	-0.002	-0.001
	(0.003)	(0.003)	(0.007)	(0.007)	(0.008)	(0.008)
Aged 15 to 20	0.002	0.002	0.004	0.004	-0.009	-0.008
	(0.003)	(0.003)	(0.010)	(0.010)	(0.008)	(0.008)
Aged 21 to 30	0.001	0.001	-0.008	-0.008	-0.008	-0.007
	(0.003)	(0.003)	(0.005)	(0.005)	(0.007)	(0.007)
Aged 31 to 40	0.000	0.000	-0.006	-0.006	-0.008	-0.007
	(0.003)	(0.003)	(0.006)	(0.006)	(0.007)	(0.007)
Education (years)	0.000	0.000	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head's age (years)	-0.000**	-0.000**	-0.000**	-0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head male	-0.023*	-0.023*	0.011	0.010	-0.014***	-0.017***
	(0.013)	(0.013)	(0.018)	(0.018)	(0.005)	(0.005)
HH size	0.000	0.000	0.001***	0.001**	0.003***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
HH land (acre)	-0.000	-0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HH total consumption	-	-0.000	-	0.000	-	0.000
		(0.000)		(0.000)		(0.000)
Head's ethnicity	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES
Village-time trend	YES	YES	YES	YES	YES	YES
R-squared	0.137	0.137	0.245	0.245	0.333	0.339
No. of obs.	1217	1217	1217	1217	1217	1217

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.9: Threats to identification (OLS)

Dependent variables:	Log of per capita consumption (TSH)				No. of children			
Sample:	Females aged 15 to 28				Head's wives aged 15 to 50			
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
No levirate marriage								
× Widow	-0.442***	-0.455***	-0.491***	-0.486***	-	-	-	-
	(0.155)	(0.158)	(0.148)	(0.167)				
× Aged 15 to 20	-	-	-	-	0.052	0.069	0.068	0.002
					(0.359)	(0.338)	(0.354)	(0.379)
× Aged 21 to 30	-	-	-	-	0.441	0.444	0.453*	0.403
					(0.292)	(0.277)	(0.268)	(0.287)
× Aged 31 to 40	-	-	-	-	0.724*	0.728*	0.733**	0.594
					(0.371)	(0.369)	(0.362)	(0.362)
× Migrant in wave 5	0.017	-	-	-	0.125	-	-	-
	(0.146)				(0.268)			
× Drop by wave 5	-	-0.013	-	-	-	-0.142	-	-
		(0.097)				(0.348)		
Widow								
× Mortality rate	-	-	0.053	-	-	-	-	-
			(0.048)					
× No. of refugee camps	-	-	-	-0.140*	-	-	-	-
				(0.074)				
Aged 15 to 20								
× Mortality rate	-	-	-	-	-	-	-0.124	-
							(0.131)	
× No. of refugee camps	-	-	-	-	-	-	-	-0.091
								(0.214)
Aged 21 to 30								
× Mortality rate	-	-	-	-	-	-	-0.068	-
							(0.096)	
× No. of refugee camps	-	-	-	-	-	-	-	-0.059
								(0.098)
Aged 31 to 40								
× Mortality rate	-	-	-	-	-	-	-0.129	-
							(0.088)	
× No. of refugee camps	-	-	-	-	-	-	-	-0.191*
								(0.110)
Migrant in wave 5	0.089	-	-	-	-0.175	-	-	-
	(0.138)				(0.243)			
Drop by wave 5	-	0.006	-	-	-	-0.091	-	-
		(0.073)				(0.185)		
R-squared	0.394	0.391	0.392	0.393	0.730	0.731	0.731	0.731
No. of obs	1553	1553	1553	1553	1217	1217	1217	1217
Individual controls	YES	YES	YES	YES	YES	YES	YES	YES
Village-time trend	YES	YES	YES	YES	YES	YES	YES	YES

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) Individual controls include all regressors used in the analysis in Table 4 and Table 5, but the corresponding estimates are not reported here.

Table S.10: Checking on influences of sample attrition (OLS)

Dependent variables:	Log of per capita consumption (TSH)		No. of children							
Sample:	Females aged 15 to 28		Head's wives aged 15 o 50							
Trim:	Top 16%	Bottom 16%	Top 30%	Bottom 30%	Top 30%	Bottom 30%	Top 30%	Bottom 30%	Top 30%	Bottom 30%
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
No levirate marriage										
× widow	-0.414**	-0.413**	-	-	-	-	-	-	-	-
	(0.155)	(0.155)								
× Aged 15 to 20	-	-	0.206	0.013	0.210	0.016	-	-	-	-
			(0.380)	(0.389)	(0.381)	(0.388)				
× Aged 21 to 30	-	-	0.397	0.475*	-	-	-	-	-	-
			(0.272)	(0.280)						
× Aged 31 to 40	-	-	0.594	0.715*	-	-	-	-	-	-
			(0.391)	(0.365)						
× Aged 21 to 40	-	-	-	-	0.480	0.577*	0.389	0.570**	-	-
					(0.302)	(0.296)	(0.234)	(0.238)		
× Age	-	-	-	-	-	-	-	-	0.184*	0.246**
									(0.106)	(0.109)
× Age squared	-	-	-	-	-	-	-	-	-0.003*	-0.004**
									(0.002)	(0.002)
Widow	0.106	0.148	-	-	-	-	-	-	-	-
	(0.097)	(0.100)								
Aged 15 to 20	0.055**	0.084***	-0.375	-0.464	-0.378	-0.467	-0.220	-0.455	-	-
	(0.027)	(0.027)	(0.359)	(0.390)	(0.359)	(0.389)	(0.250)	(0.303)		
Aged 21 to 30	0.000	0.000	0.370	0.313	0.301	0.229	0.372	0.235	-	-
	(0.000)	(0.000)	(0.263)	(0.273)	(0.272)	(0.294)	(0.236)	(0.261)		
Aged 31 to 40	0.000	0.000	0.497	0.477	0.583**	0.585*	0.656***	0.590**	-	-
	(0.000)	(0.000)	(0.340)	(0.359)	(0.283)	(0.300)	(0.245)	(0.270)		
Age (years)	-	-	-	-	-	-	-	-	0.282***	0.297***
									(0.097)	(0.098)
Age squared	-	-	-	-	-	-	-	-	-0.004***	-0.004***
									(0.001)	(0.001)
Education (years)	0.035***	0.037***	0.001	-0.000	0.001	-0.000	-0.000	-0.001	-0.010	-0.010
	(0.005)	(0.005)	(0.011)	(0.012)	(0.011)	(0.012)	(0.011)	(0.012)	(0.012)	(0.013)
Head's age (years)	-0.000	-0.000	-0.008	-0.011*	-0.008	-0.011*	-0.008	-0.011*	-0.011*	-0.015**
	(0.001)	(0.001)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)
Head male	0.094**	0.118**	0.605***	-0.336	0.609***	-0.325	0.573***	-0.327	0.429**	-0.299
	(0.045)	(0.045)	(0.201)	(0.533)	(0.201)	(0.523)	(0.190)	(0.512)	(0.189)	(0.432)
HH size	-0.048***	-0.050***	0.549***	0.541***	0.549***	0.541***	0.548***	0.541***	0.535***	0.525***
	(0.007)	(0.008)	(0.034)	(0.032)	(0.034)	(0.032)	(0.034)	(0.032)	(0.034)	(0.031)
HH land (acre)	0.023***	0.022***	0.005	-0.002	0.005	-0.002	0.005	-0.002	0.007	-0.001
	(0.003)	(0.004)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.014)	(0.014)
Head's ethnicity	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village time-trend	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R-squared	0.398	0.376	0.719	0.722	0.718	0.722	0.718	0.722	0.732	0.736
No. of obs.	1518	1510	1124	1130	1124	1130	1124	1130	1124	1130

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.11: Correlation between a household head and widowhood (OLS)

Dependent variable:	One if a household head		
Sample:	Females aged 15 to 50		
	(a)	(b)	(c)
No levirate marriage			
× Widow	0.033	0.043	0.038
	(0.080)	(0.081)	(0.064)
No levirate marriage	-0.002	-	-
	(0.017)		
Widow	0.597***	0.593***	0.327***
	(0.067)	(0.068)	(0.058)
Aged 15 to 20	-	-	-0.215***
			(0.022)
Aged 21 to 30	-	-	-0.191***
			(0.022)
Aged 31 to 40	-	-	-0.106***
			(0.019)
Education (years)	-	-	0.000
			(0.001)
Head's age (years)	-	-	-0.004***
			(0.000)
Head male	-	-	-0.316***
			(0.018)
HH size	-	-	-0.005**
			(0.002)
HH land (acre)	-	-	0.002**
			(0.001)
Head's ethnicity	NO	NO	YES
Head's religion	NO	NO	YES
Village FE	YES	NO	NO
Region-time trend	YES	NO	NO
Village-time trend	NO	YES	YES
R-squared	0.277	0.290	0.580
No. of obs.	2917	2917	2616

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.12: Impacts on a probability of being a head's wife (OLS)

Dependent variable:	One if a head's wife					
Sample:	Females aged 15 to 50					
	(a)	(b)	(c)	(d)	(e)	(f)
No levirate marriage						
× Aged 15 to 20	0.051	0.057	0.049	0.049	-	-
	(0.075)	(0.076)	(0.075)	(0.074)		
× Aged 21 to 30	0.018	0.019	0.008	-	-	-
	(0.073)	(0.073)	(0.074)			
× Aged 31 to 40	0.034	0.038	0.029	-	-	-
	(0.084)	(0.084)	(0.083)			
× Aged 21 to 40	-	-	-	0.016	-	-
				(0.074)		
× Aged 15 to 40	-	-	-	-	0.028	-
					(0.070)	
× Age	-	-	-	-	-	-0.006
						(0.014)
× Age squared	-	-	-	-	-	0.000
						(0.000)
No levirate marriage	-0.478*	-0.452	-	-	-	-
	(0.271)	(0.279)				
Aged 15 to 20	-0.517***	-0.517***	-0.522***	-0.522***	-0.505***	-
	(0.070)	(0.070)	(0.069)	(0.069)	(0.064)	
Aged 21 to 30	-0.144**	-0.142**	-0.136*	-0.142**	-0.152**	-
	(0.068)	(0.068)	(0.069)	(0.070)	(0.068)	
Aged 31 to 40	-0.062	-0.062	-0.064	-0.054	-0.063	-
	(0.078)	(0.078)	(0.077)	(0.069)	(0.066)	
Age (years)	-	-	-	-	-	0.089***
						(0.013)
Age squared	-	-	-	-	-	-0.001***
						(0.000)
Education (years)	-0.007**	-0.007**	-0.007**	-0.006**	-0.007**	-0.007***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Head's age (years)	-0.007***	-0.007***	-0.007***	-0.007***	-0.007***	-0.007***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head male	0.606***	0.606***	0.604***	0.604***	0.604***	0.605***
	(0.017)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
HH size	-0.020***	-0.020***	-0.019***	-0.019***	-0.019***	-0.020***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
HH land (acre)	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head's ethnicity	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES
Village leader char.	NO	YES	NO	NO	NO	NO
Village FE	YES	YES	NO	NO	NO	NO
Region time-trend	YES	YES	NO	NO	NO	NO
Village time-trend	NO	NO	YES	YES	YES	YES
R-squared	0.567	0.566	0.575	0.575	0.575	0.586
No. of obs.	2618	2566	2618	2618	2618	2618

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village. (3) A head's ethnicity is classified into seven groups, i.e., Hangaza, Haya, Nyambo, Shubi, Subi, Zinza, and other. (4) A head's religion is categorized into six groups, i.e., Muslim, Catholic, Protestant, other Christian, traditional, and other.

Table S.13: Assessing the quality of HIV/AIDS-related information of the KHDS (OLS)

Dependent variable:	One if HIV/AIDS is the most or second most important health problem in a community							
Sample:	wave 5 (i.e., 2004)						wave 1 (i.e., 1991)	wave 1 to 4 (i.e., 1991 to 1994)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
HIV prevalence of the nearest 2003—04 THIS community								
Proportion	2.920*	2.597	-	-	-	-	-	-
	(1.494)	(1.645)						
One if proportion > 0	-	-	0.373**	0.353**	-	-	-	-
			(0.150)	(0.161)				
Mean HIV prevalence of 2003—04 THIS communities situated within 40-km radius from a KHDS community								
Proportion	-	-	-	-	4.736	-	-	-
					(3.006)			
One if proportion > 0	-	-	-	-	-	0.492***	-	-
						(0.158)		
The district-level HIV prevalence (proportion) in 1987 based on Killewo et al. (1990)	-	-	-	-	-	-	1.818**	2.722***
							(0.756)	(0.454)
Distance to the nearest THIS community (km)	-	-0.004	-	-0.004	-	-	-	-
		(0.009)		(0.008)				
Wave FE	NO	NO	NO	NO	NO	NO	NO	YES
R-squared	0.063	0.067	0.118	0.122	0.049	0.151	0.092	0.247
No. of obs.	51	51	51	51	51	51	51	204

Notes: (1) Figures ( ) are standard errors. *** denotes significance at 1%, ** at 5%, and * at 10%. (2) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

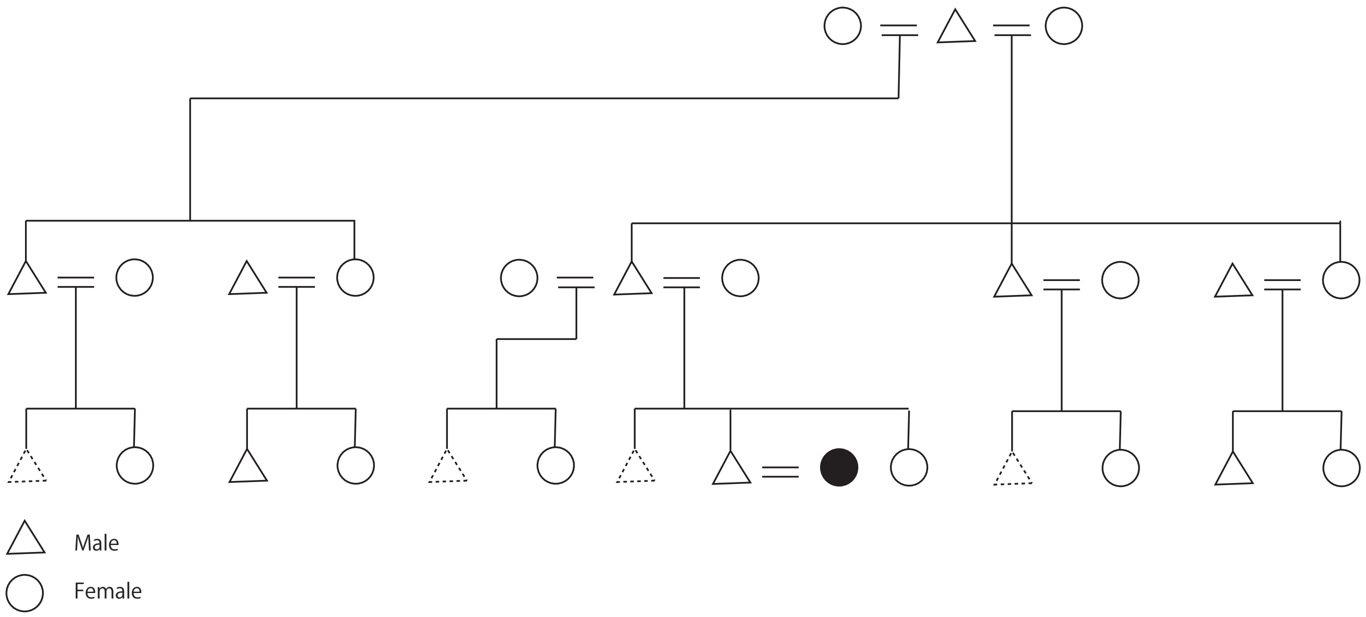


Figure S.1: A woman and the typical expected inheritors

Note: This diagram should be seen from the viewpoint of a female indicated by a shaded circle. Consistent with the convention of social anthropology, the triangles refer to males with the circles meaning females. The vertical and horizontal links represent a descent bond and a co-descent bond, respectively. The sign '=' indicates a marital relationship. In this figure that considers the case that a husband's father as well as grandfather has two wives, the triangles depicted by dashed lines indicate the expected inheritors from the viewpoint of a female represented by the shaded circle, i.e., her husband's brothers and cousins born to his uncles on his father side.

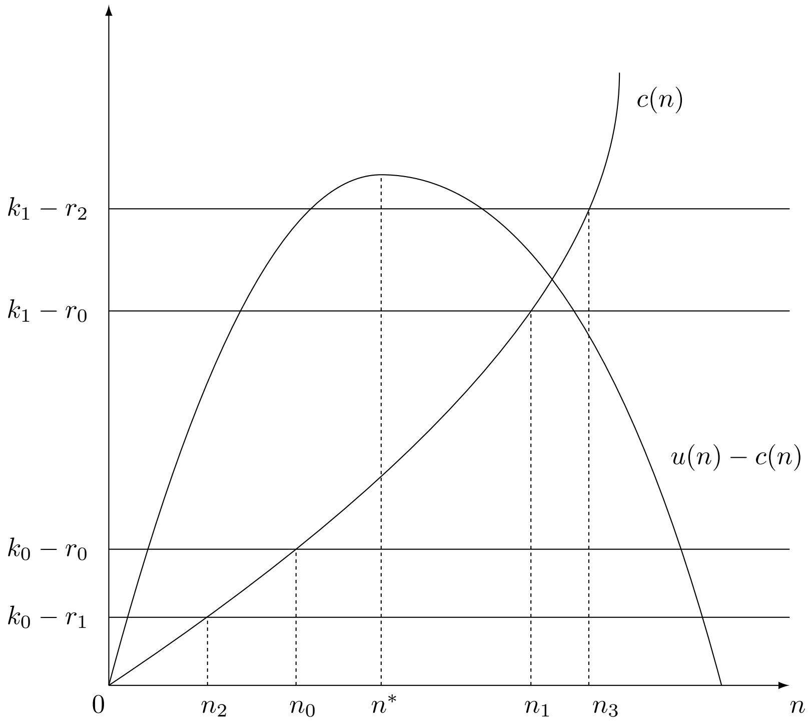
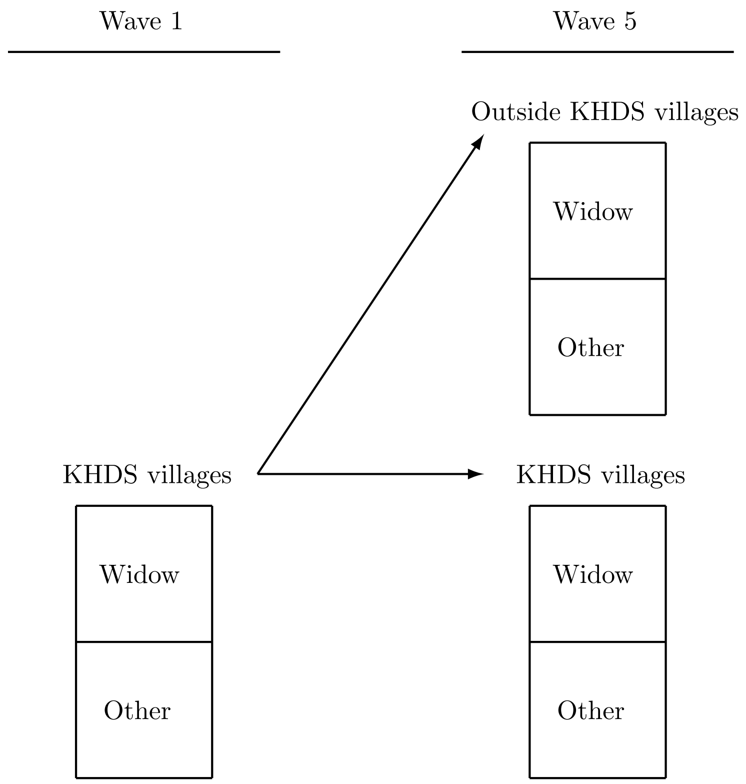


Figure S.2: Graphical interpretation of the theoretical model



$\Delta y^{before} = y$ of "Widow" - y of "Other" $\qquad \Delta y^{after} = y$ of *all* "Widow" - y of *all* "Other"

Figure S.3: Data structure and graphical representation of the identification strategy

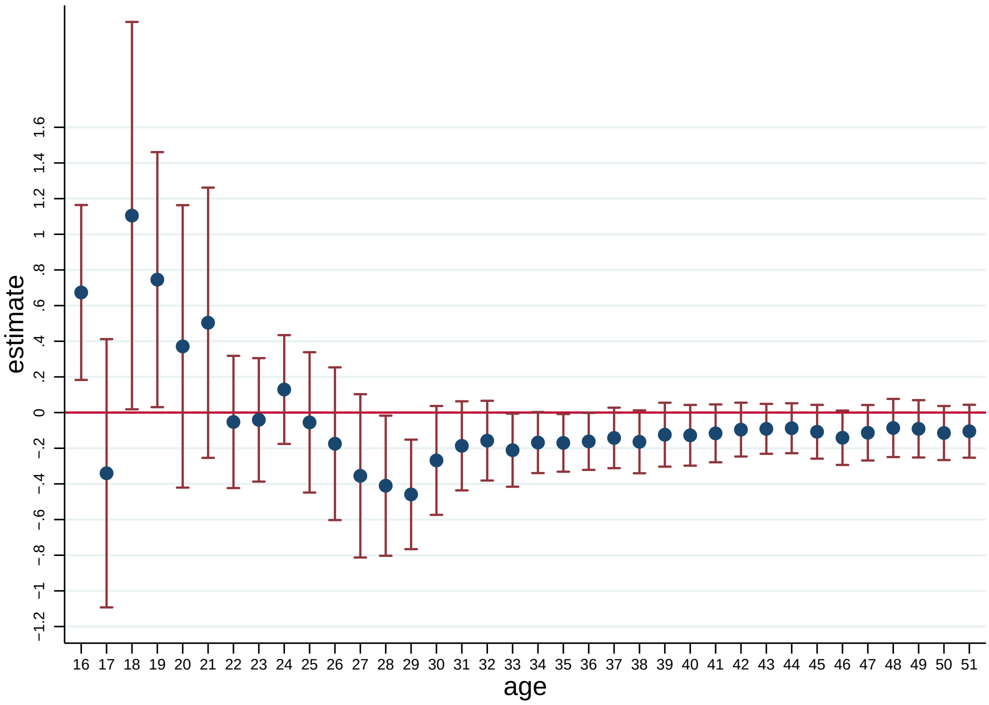


Figure S.4: Age heterogeneity: Institutional change and widows' welfare (consumption per adult equivalent) (OLS)

Notes: (1) This figure reports the estimated α_2 in equation (7) with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.4.

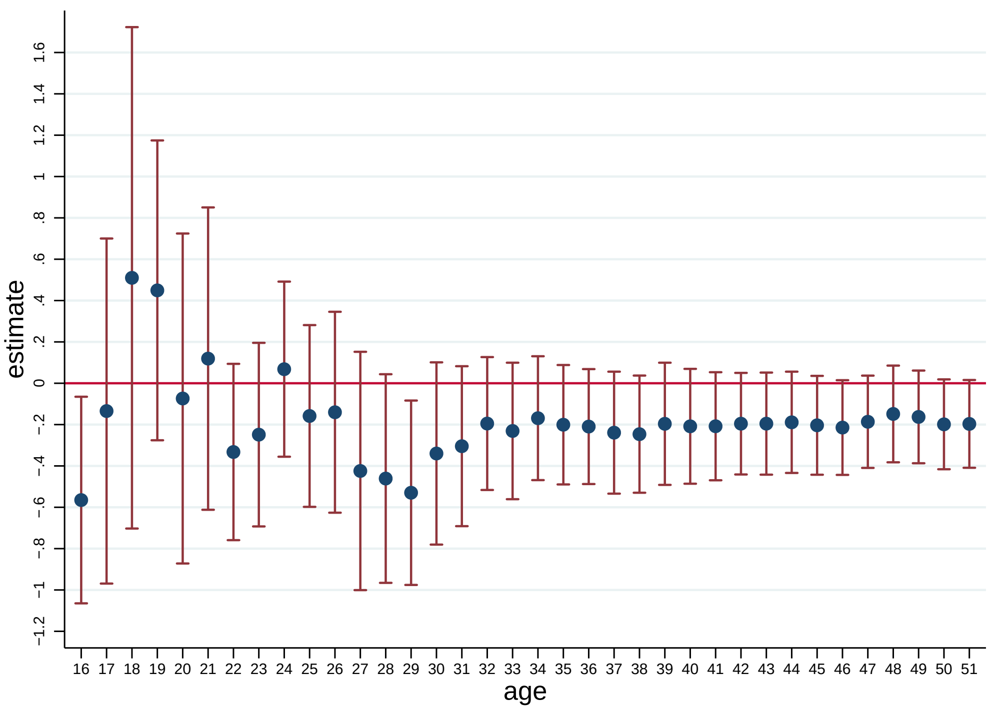


Figure S.5: Age heterogeneity: Institutional change and widows' welfare (consumption per adjusted adult equivalent) (OLS)

Notes: (1) This figure reports the estimated α_2 in equation (7) with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.4.

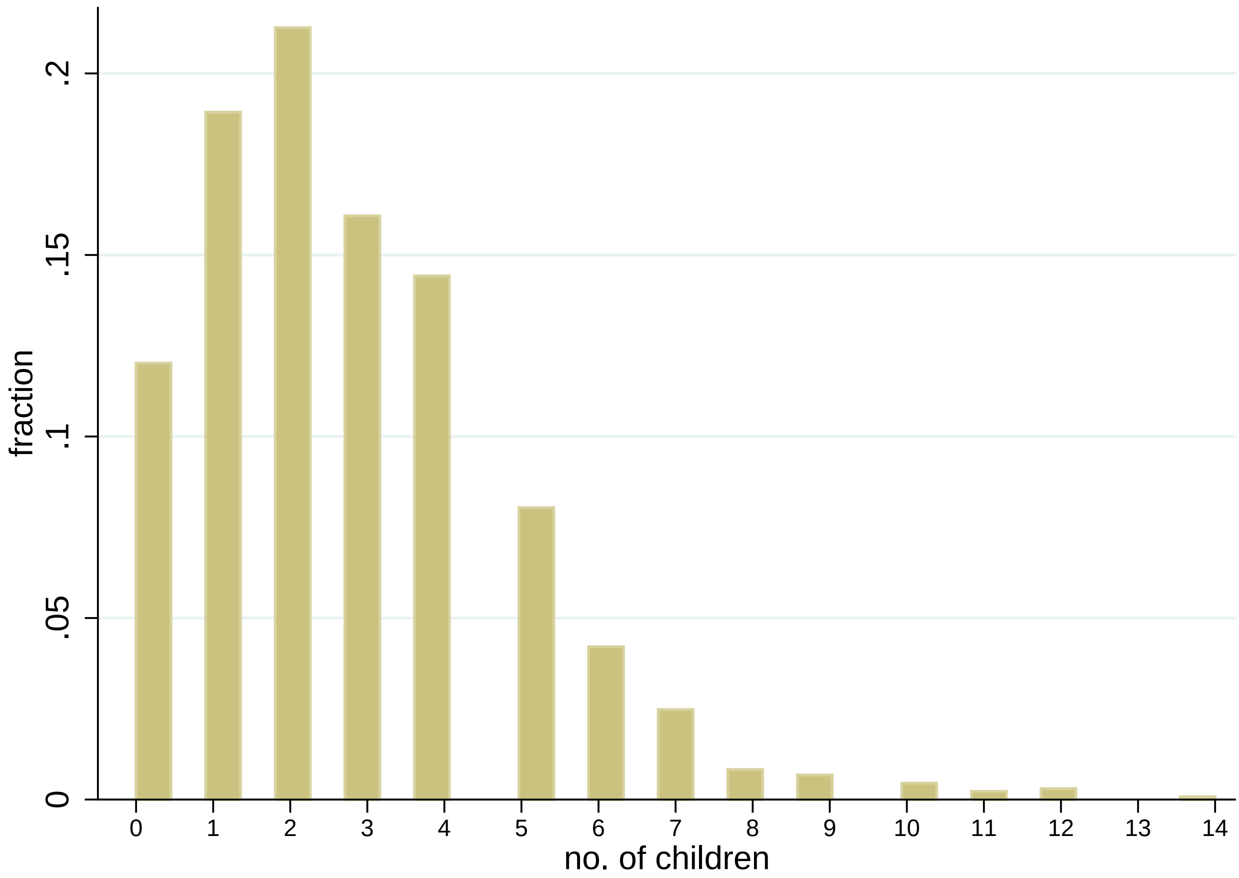


Figure S.6: Distribution of the number of children

Note: This figure reports the distribution of the number of children relevant to the observations exploited in the estimations in Table 5.

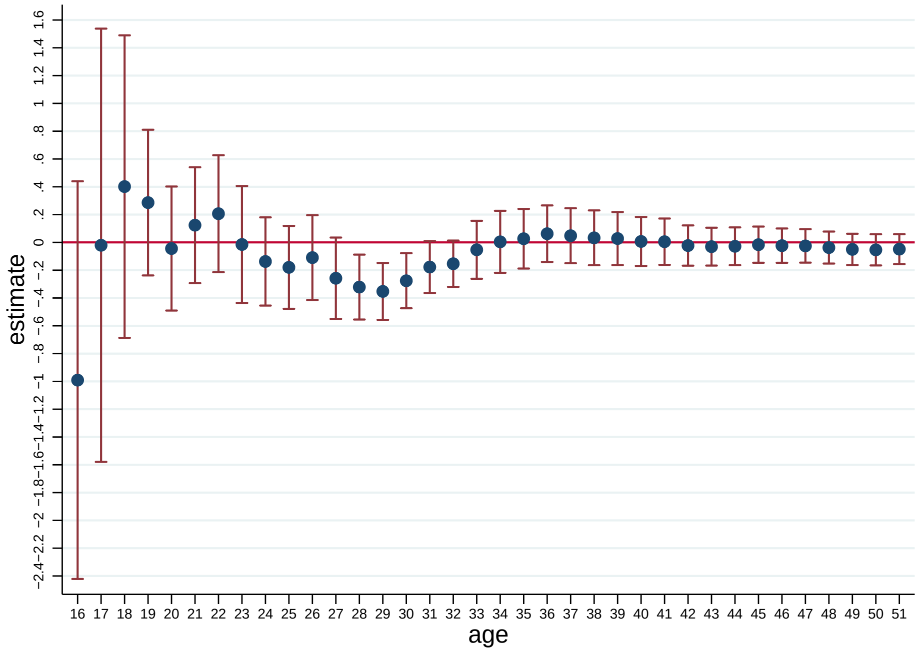


Figure S.7: Age heterogeneity: Reduced-form impacts of HIV/AIDS on widows' welfare (consumption per adult equivalent) (OLS)

Notes: (1) After replacing D_{jt} in equation (7) with an indicator for villages that referred to HIV/AIDS as the most or second most important health problem in a community in each wave, this figure reports the estimated impacts of HIV/AIDS on widows' consumption with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.7.

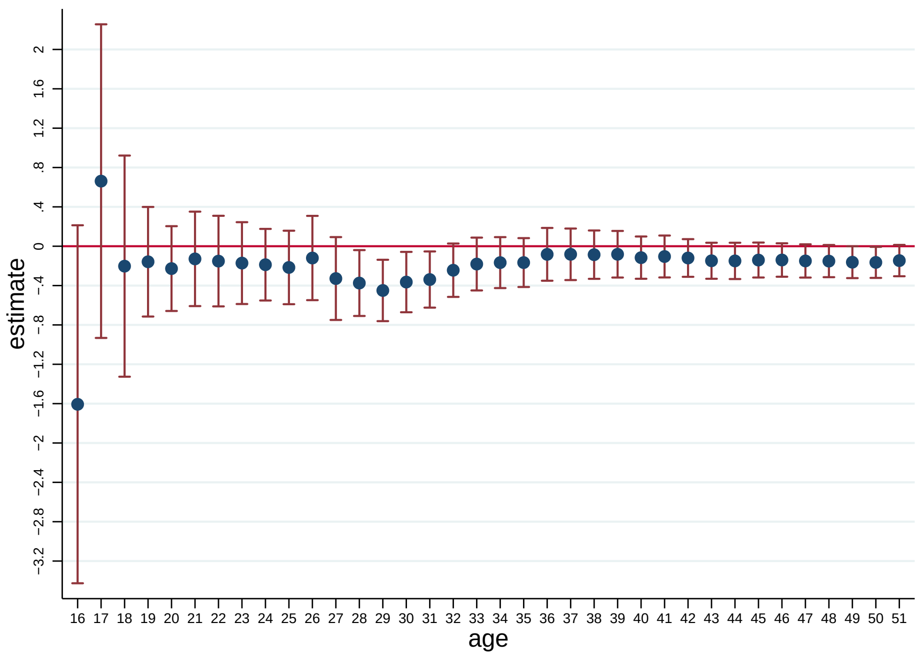


Figure S.8: Age heterogeneity: Reduced-form impacts of HIV/AIDS on widows' welfare (consumption per adjusted adult equivalent) (OLS)

Notes: (1) After replacing D_{jt} in equation (7) with an indicator for villages that referred to HIV/AIDS as the most or second most important health problem in a community in each wave, this figure reports the estimated impacts of HIV/AIDS on widows' consumption with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m-1$. (3) The estimates and statistical significance are reported in more detail in Table S.7.

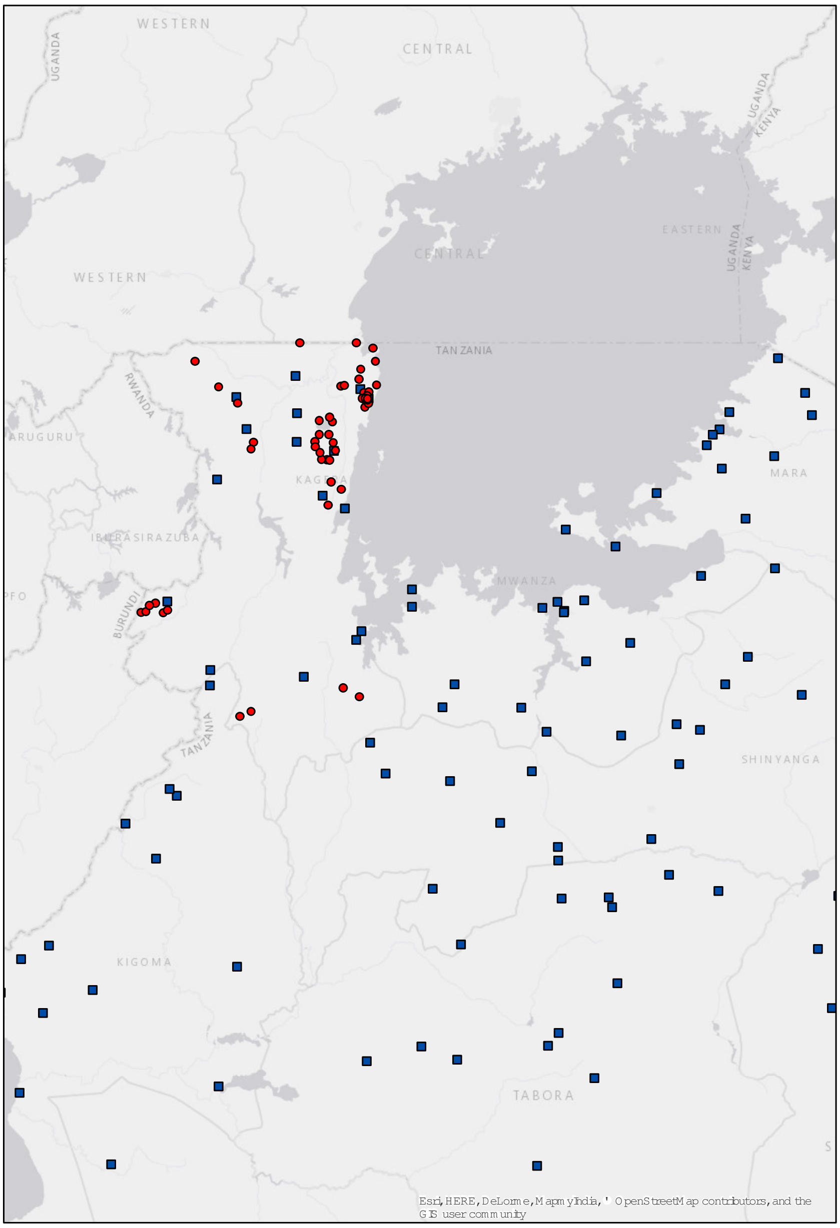


Figure S.9: Position of the KHDS (red circle) and 2003—04 THIS communities (blue square)