Does HIV/AIDS Discourage the Practice of Levirate Marriage? Theory and Evidence from Rural Tanzania*

Yuya Kudo†

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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 examines whether and how HIV/AIDS leads to the deterioration of this practice. 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. HIV/AIDS 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 in step with the disappearance of levirate marriage. By exploiting long-term household panel data drawn from rural Tanzania, this study provides three pieces of evidence consistent with this prediction, namely, a negative impact of HIV/AIDS on the prevalence of levirate marriage, a negative correlation between this institutional change and young widows' welfare, and a negative reduced-form impact of HIV/AIDS on their welfare. Young widows may need some form of social protection against the influence of HIV/AIDS.

Keywords: HIV/AIDS, informal insurance, levirate marriage, social institution, widowhood
JEL classification: J12, J13, J16, K11, Z13

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†Development Studies Center, Institute of Developing Economies (IDE-JETRO), Japan. Yuya_Kudo@ide.go.jp, +81-43-299-9697.

1 Introduction

Levirate marriage (also known as widow or wife inheritance) 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 widely observed in present-day Africa (Potash, 1986; Radcliffe-Brown and Forde, 1987),[1] this century-old practice has recently begun to disappear in some part of this region.

Levirate marriage is often regarded as a harmful traditional practice because it can be seen as treating women as "property" (e.g., Kouyaté, 2009). Therefore, those who propose an outright ban on an anti-social practice that violates women's human rights may praise the disappearance of levirate marriage as a sign of female empowerment. However, prior case studies indicate that the recent spread of HIV/AIDS is responsible for this institutional change (e.g., Malungo, 2001; Ntozi, 1997; Perry et al., 2014). If so, the relationship between this institutional change and women's welfare may not be so simple. This conjecture holds true because anecdotally levirate marriage has been considered to be an informal safety net that provides material support and social protection for widows who have limited property rights. Until now, however, there has apparently been no rigorous effort by economists to understand the role and socioeconomic consequences of this practice. To fill this knowledge gap, this study examines whether and how HIV/AIDS leads to the deterioration of levirate marriage both theoretically and empirically.

To address this 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. 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).

HIV/AIDS discourages this practice. If a husband dies of AIDS, the wives may also be HIV positive. Then, 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. Moreover,

[1] Particular examples include Kenya (Agot, 2007), Nigeria (Doosuur and Arome, 2013), Sudan (Stern, 2012), Uganda (Ntozi, 1997), and Zambia (Malungo, 2001).

HIV-positive widows also have difficulties in getting remarried. As a result, HIV/AIDS could decrease widows' welfare by reducing their reservation utility while simultaneously eliminating levirate marriage.[2]

In its empirical analysis, 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). Exploiting this setting, it provides three pieces of empirical evidence that collectively supports the proposed mechanism; first, HIV/AIDS reduced the prevalence of levirate marriage. Second, the disappearance of levirate marriage was negatively associated with young widows' consumption, which was more pronounced in villages whereby HIV/AIDS increasingly exerted an unfavorable health influence during the sample periods. Third, HIV/AIDS decreased young widows' consumption. The exploited identification strategies include an instrumental variable approach for the first finding, a tripe-difference approach for the second and the third findings, and assessment of the importance of unobservables for the third finding (Oster, forthcoming). According to these findings, young widows may need social protection that shields them from the influence of HIV/AIDS.

This study contributes to a rapidly growing body of economic research on culture and institutions (e.g., Alesina and Giuliano, 2015; Fernández, 2011; Guiso et al., 2006), specifically to studies examining the economic rationality of apparent antisocial marriage-related customs, such as dowry/bridewealth payments (e.g., Anderson, 2007; Anderson and Bidner, 2015; Botticini and Siow, 2003), bride exchange (Jacoby and Mansuri, 2010), and polygyny (e.g., Becker, 1981; Jacoby, 1995; Tertilt, 2005), as well as to studies exploring conditions that facilitate the transformation of those customs (e.g., Anderson, 2003; de la Croix and Mariani, 2015; Gould et al., 2008).

More specifically, this study develops the "first" theoretical framework of levirate marriage and empirically examines the influence of HIV/AIDS on this practice. According to Greif and Iyigun (2013), "social institutions are ... all but absent from our analyses of economic growth and development." In addition, in the developing world, 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 provide a valuable lesson applicable in other development settings, particularly when considering the vulnerability or resistance of non-market institutions to deadly communicable diseases.

Furthermore, several previous studies indicate that "positive" socioeconomic shocks (e.g., English-education op-

[2]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).

portunities, income generating opportunities) affecting "disadvantaged" groups (e.g., girls, low-caste groups) could erode traditional institutions (e.g., caste) while "increasing" their welfare (e.g., 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 group' (e.g., widows') welfare.

Following prior studies (e.g., Fortson, 2009; Kalemli-Ozcan and Turan, 2011; Oster, 2012a; Young, 2005), this study also examines welfare consequences of HIV/AIDS; it particularly focuses on widows' welfare. In sub-Saharan Africa, 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 (Potash, 1986).[3] Traditionally, a widow has limited rights to the property of both her natal and husband's families; therefore, her life is highly vulnerable.[4] 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 lives and survival strategies are insufficiently understood (e.g., Djuikom and van de Walle, 2018; van de Walle, 2013).

This paper is organized as follows. Section 2 provides anecdotal support for the influence of HIV/AIDS on levirate marriage. A theoretical model of levirate marriage is developed in Section 3, followed by the data overview given in Section 4. The empirical findings are reported in Section 5, with concluding remarks summarized in Section 6.

2 Anecdotal Support for the influence of HIV/AIDS

A non-negligible amount of case studies indicate that HIV/AIDS has contributed to the disappearance of levirate marriage in Africa, as studied in Kenya (e.g., Agot et al., 2010; Luke, 2002; Perry et al., 2014), Uganda (e.g., Berger, 1994; Mukiza-Gapere and Ntozi, 1995; Ntozi, 1997), and Zambia (e.g., Malungo, 2001).

This institutional change is taking place because both the inheritors and widows fear infection with HIV/AIDS stemming from practicing this customary marriage. 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.[5] The Luo is an ethnic group that has received much publicity for its practice of levirate marriage.

[3] According to Potash (1986), a quarter of the adult female population is widowed in many African societies.

[4] 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.

[5] 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

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.

Typically, the occurrence of levirate marriage 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. According to Berger (1994), 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. 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).

HIV/AIDS also discouraged sexual cleansing (and thus, likely, levirate marriage). In Zambia, for example, a lobby group asked for legislation banning sex cleansing 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).

The socioeconomic consequences of the break down of levirate marriage triggered by HIV/AIDS apparently 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. This sort of widows' relocation may indicate that HIV/AIDS lowered their reservation utility (and therefore, equilibrium utility).

As Mukiza-Gapere and Ntozi (1995) found in Uganda, another scenario also emerged, whereby property was increasingly left to wives of the deceased, even though clan members of the deceased used to take over the property

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.

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, 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 to inherit 20% 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.

3 A simple theoretical framework

This section offers a theoretical model that explains how HIV/AIDS prompts the deterioration of levirate marriage. 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. During marriage, 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) chooses the number of children n that a woman should bear before her husband's death. This assumption implies the case of a man's family members putting some pressure on a young couple's fertility decisions during their married life. On the other hand, during marriage, 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 $d > 0$. 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.

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, e, 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 $c(0) = 0$.[6] This cost is incurred by either a mother whenever she is available or female members of the clan. The payoffs $v_i(\cdot, \cdot, \cdot, \cdot)$ 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 and fourth terms referring to a woman's fertility effort and action taken after her husband's death:

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

$$v_c(n, s, \underline{e}, a) = q(u(n) - s), \tag{2}$$

$$v_w(n, s, \bar{e}, a) = s - c(n) - d, \tag{3}$$

$$v_w(n, s, \underline{e}, a) = q(s - c(n)) + (1 - q)r, \tag{4}$$

$$v_c(n, s, \bar{e}, l) = u(n) - c(n) - \tau, \tag{5}$$

$$v_c(n, s, \underline{e}, l) = q(u(n) - c(n) - \tau), \tag{6}$$

$$v_w(n, s, \bar{e}, l) = r - d, \tag{7}$$

$$v_w(n, s, \underline{e}, l) = r, \tag{8}$$

$$v_c(n, s, \bar{e}, z) = u(n) - k, \tag{9}$$

$$v_c(n, s, \underline{e}, z) = q(u(n) - k), \tag{10}$$

$$v_w(n, s, \bar{e}, z) = k - c(n) - d, \tag{11}$$

[6] 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.

$$v_w(n, s, \underline{e}, z) \quad = \quad q(k - c(n)) + (1 - q)r. \tag{12}$$

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 $v_c(n, s, \bar{e}, a) = u(n) - s$ and $v_w(n, s, \bar{e}, a) = s - c(n) - d$. 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.[7] 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.[8] 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 $v_c(n, s, \bar{e}, l) = u(n) - c(n) - \tau$ and $v_w(n, s, \bar{e}, l) = r - d$. However, explicitly considering a widow's (emotional) cost resulting from separation from her own children would not alter the key theoretical implications demonstrated below (see subsection S.2.2 in the supplemental appendix).[9] When a woman does not expend fertility effort and produces no children, she has to leave her husband's home when he dies, i.e., $v_w(n, s, \underline{e}, l) = r$.

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

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

[8] 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, it is also possible to treat $\tau = 0$, provided it is alternatively assumed that $r_0 < 0$ and $r_1 < r_0$. Moreover, it is also possible to regard the child-rearing cost incurred by a clan as $(1+\tau)c(n)$, rather than $c(n)+\tau$. The key theoretical implications demonstrated below are robust to these differences.

[9] 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).

allow a widow to inherit property of the deceased, this amount is expected to be zero. These yield the payoff profiles $v_c(n, s, \bar{e}, z) = u(n) - k$ and $v_w(n, s, \bar{e}, z) = k - c(n) - d$.

Whether choosing a or z, a widow has to leave her husband's home when she produces no children, yielding $v_w(n, s, \underline{e}, a) = q(s - c(n)) + (1 - q)r$ and $v_w(n, s, \underline{e}, z) = q(k - c(n)) + (1 - q)r$. A clan also obtains zero utility when a woman produces no children and thus, the remaining payoff profiles are written as $v_c(n, s, \underline{e}, a) = q(u(n) - s)$, $v_c(n, s, \underline{e}, z) = q(u(n) - k)$, and $v_c(n, s, \underline{e}, l) = q(u(n) - c(n) - \tau)$.

In the above setup, $\frac{d}{1-q}$ represents an incentive cost needed for a clan to encourage a woman's fertility effort and depending upon this amount, multiple equilibria (i.e., an effort or a no-effort equilibrium) arise. In traditional agrarian societies, however, women are expected to have limited power to control fertility (i.e., large q) and women's access to family planning methods are limited (i.e., large d).[10] Both these factors generate a large incentive cost.[11] While the full explanation of the multiple equibliria is relegated to Section S.1 in the supplemental appendix, thus, the theoretical analysis in subsection 3.1 and subsection 3.2 focuses on the cases pertaining to the large incentive cost.

[Here, Figure 1]

3.1 Levirate marriage equilibrium

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

See the proof of proposition S.1 in the supplemental appendix.

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 payoffs indicate, 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

[10] Married women may use concealable contraception (e.g., Ashraf et al., 2014). Despite considerable increases in the use of injectables and pills for the period of 1991—2004 in Tanzania, 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). The corresponding rate of male condom use was approximately 2.0% (resp., 3.0%) among the currently married women (all women).

[11] The incentive cost becomes larger as the value of q increases because a woman's limited power enables a clan to achieve its desired fertility without inducing a marked fertility effort.

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.[12] 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., $c(n) < c(n) + \tau$.

3.2 HIV/AIDS as an agent of institutional change

HIV/AIDS alters the underlying theoretical parameters from three perspectives, all of which are motivated by anecdotal evidence summarized in Section 2. First, 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 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, i.e., $v_c(n, s, \bar{e}, a) = u(n) - s - h_c$ and $v_w(n, s, \bar{e}, a) = s - c(n) - d - h_w$ as well as $v_c(n, s, \underline{e}, a) = q(u(n) - s - h_c)$ and $v_w(n, s, \underline{e}, a) = q(s - c(n) - h_w) + (1 - q)r$.

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; however, levriate marriage typically follows sexual cleansing, which cannot be separated from the former in traditional societies. In addition, 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 $h_w > 0$. Thus, 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.

Second, HIV/AIDS may also establish widows' de facto property rights from $k = k_0$ to $k = k_1 > c(n^*)$; the shrinkage of the male labor force caused by HIV/AIDS may enable widows to obtain land rights in a family/village, as females have to control land owing to a greater number of male deaths (also recall Section 2).[13]

Third, HIV/AIDS may also reduce widows' reservation payoffs. This is possible because widows who lose their husbands to this disease may also be HIV positive and therefore, face difficulty in finding a new marital partner. This

[12] 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.

[13] This HIV/AIDS-driven female empowerment is also 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.

situation can be interpreted as $r = r_1 < 0$. Consequently,

Proposition 2 *Assume that $r = r_1 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_1 < h_c + h_w \approx \infty$, and $k_1 - c(n^*) < k_1 < \frac{d}{1-q} + r_1$ (in this case, $n_1 < 0 < n^* < n_2$), the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0$.*

Here, n_1 and n_2 satisfy $k_1 - c(n_1) = \frac{d}{1-q} + r_1$ and $k_1 - c(n_2) = r_1$. See the proof of proposition S.2 (Case 1) in the supplemental appendix.

As a result of HIV/AIDS, levirate marriage disappears and a widow makes a living with her children by inheriting her husband's property. A husband's clan has several reasons to stop levirate marriage.[14][15] 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. Third, securing a widow's right to inherit her husband's property from k_0 to k_1 increases her utility obtained outside a levirate marriage. To encourage such widows to remain in this traditional marriage, a clan must also increase the amount of support s, which makes this practice costly.

The disappearance of levirate marriage coincides with an increase in the number of children (i.e., $n_2 > n^*$) as well as a decrease in widows' welfare (i.e., $r_1 < 0$). First, even if levirate marriage disappears, widows' social status is lower than before because of the decline in their reservation payoffs. Since a husband's clan always attempts to keep a widow's equilibrium payoff at the minimum, she achieves only r_1 after the deterioration of levirate marriage. This holds true even if the amount of k does not increase owning to HIV/AIDS. Second, increases in bequest amounts allow widows to afford many children. Accordingly, a clan increases the number of children to the level of $n_2 > n^*$.[16]

In Section S.2 in the supplemental appendix, it is ensured that the theoretical implications pertaining to fertility and widows' welfare are robust to several model extensions considering (a) additional costs borne by a widow relocating from her husband's home and/or not following levirate marriage (e.g., peer pressure), (b) a widow's option to leave together with her own children, (c) a possibility of a woman passing away before her husband's death, and (d) influence of HIV/AIDS on the probability of a husband's death.

[14] On the other hand, 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 levirate marriage as long as her husband's clan compensates for her infection risk (h_w) by increasing the material support given to her.

[15] 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 present argument because men still tend to avoid marrying HIV-positive women (e.g., Ueyama and Yamauchi, 2009).

[16] 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_2.

3.3 Old-age security motive for fertility

The fertility can also increase even if HIV/AIDS does not improve widows' property rights, which is briefly explained in this subsection because one may be interested in this perspective. 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).[17] As female reproductive rights are not entirely suppressed within a family, therefore, a woman may respond to the disappearance of levirate marriage by making more effort to produce children.

As detailed more formally in subsection S.1.3 in the supplemental appendix, an increase in women's intrinsic motive to substitute own children for levirate marriage can be interpreted as a reduction in an extrinsic incentive cost needed for a clan to induce women's fertility effort. Then, it can be shown that the equilibrium number of children increases due to this effort in the absence of an improvement of widows' property rights. However, widows' welfare still declines from the previous levirate marriage equilibrium when a clan's incentive cost greatly decreases due to HIV/AIDS.

4 Data

The exploited data used in this study is drawn from the KHDS. The World Bank launched the KHDS 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. 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 does not use the data drawn from wave 6 because the data set in this 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

[17] More generally, an investment in childbearing can be an important strategy for young women to protect them in their old age in agrarian societies (e.g., Hoddinott, 1992).

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.[18] This sample includes those who resided in different places from their original villages in wave 5 (i.e., migrants). Inclusion of the migrants does not invalidate the analysis (see Section S.3 in the supplemental appendix). Information on new respondents in the wave 5 survey is not exploited.

4.1 Summary statistics

Table 1 provides summary statistics pertaining to the sample females aged 15 to 28 years for the wave 1 [panel (A)] and wave 5 [panel (B)] surveys. This study primarily focuses on this young cohort for two reasons. First, 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). In my 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, as often so elsewhere in Africa (e.g., Rwebangira, 1996). This finding suggests that the de facto amount of k bequeathed to widows tends to be large for elderly widows, likely, having many and/or adult children. As recalled from Section 3, levirate marriage plays a role when this bequest amount is small. Second, HIV/AIDS primarily increased prime-age adult mortality in Kagera (Beegle, 2005; Beegle et al., 2008). Based on a population-based follow-up survey conducted in Kagera in 1988, among males aged above 15 years, incidence of HIV infection was highest in the age group of 25 to 34 (Killewo et al., 1993). Taken together, the deterioration of levirate marriage is expected to more pronouncedly affect young widows who have few and/or young children as well as prime-age husbands.

[Here, Table 1]

4.2 Measurement of levirate marriage

Information relevant to widows' engagement in levirate marriage at the individual level is absent in the KHDS. However, 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

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

to 17 (10 years ago) and 3 (wave 5). This information enables this study to construct an indicator D_{jt}, which takes the value one if levirate marriage is no longer a customary practice in a KHDS village j in the period t. Note that 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.

Admittedly, the community-level information from the group discussions is not solid. As will be explained in Section 5, however, the identification of the relevant estimates relies on "changes" (i.e., trend) of levirate marriage, not its "levels." Since the information on the prevalence of levirate marriage in the present and past is both provided by the same village leaders of the wave 5 survey, its declining tendency seems to be more accurate, compared with the case of such information being provide by different leaders in the respective wave. In addition, if the measured levirate marriage is completely noise, the subsequent empirical analysis would not reveal any meaningful results. However, the yielded empirical findings make this concern less critical, although they are still only suggestive.

Notably, information on levirate marriage is rarely obtained (even at the community level) from standard household surveys and/or national statistics and, to the best of my knowledge, the KHDS is the only panel data that records the transformation of levirate marriage in the long term. The KHDS also provides a promising setting particularly for the present study, because the first case of AIDS in Tanzania 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 due to the high HIV infection rates in this region (e.g., Beegle, 2005; Beegle et al., 2008).[19] Thus, the empirical findings reported herein should still be considered of the first order of importance.

4.3 Measurement of HIV/AIDS

In each wave, the KHDS 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. Exploiting this information, this study creates a time-varying indicator for those villages, called "HIV/AIDS indicator" hereinafter.

While the available data on HIV/AIDS during the analyzed periods is highly limited, this study also collected estimates of the biomarker-based prevalence of HIV/AIDS from the following two information sources: 2003—04 Tanzania HIV/AIDS Indicator Survey (THIS) and Killewo et al. (1990). The THIS is the first population-based

[19] 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).

comprehensive survey carried out on HIV/AIDS in Tanzania from December 2003 to March 2004, whereas Killewo et al. (1990) estimated the district-level infection rate based on a population-based survey conducted in Kagera in 1987.[20] The estimates provided by two "independent" data sources are not temporally comparable, and Killewo et al. (1990)'s estimates, which vary only by the number of (six) districts, also have little data variation. Therefore, it is difficult to use these estimates in a rigorous empirical analysis directly. Nevertheless, these estimates were still used to assess the accuracy of the HIV/AIDS indicator from the KHDS.

For this purpose, this study first calculated a proportion of HIV-positive respondents among those that went for the testing for each THIS community and created two indicators relying on this information, 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.2 in the supplemental appendix for the position of the KHDS and THIS communities).[21] Second, the district-level values of the infection rate reported in Killewo et al. (1990) were also assigned to each KHDS community.[22]

In columns (a) to (d) in Table 2, this study related the HIV/AIDS indicator in wave 5 to the THIS-based estimates of HIV/AIDS prevalence. Exploiting the HIV/AIDS prevalence based on Killewo et al. (1990), similar attempts were also made in column (e) [resp., column (f)] for the HIV/AIDS indicator in wave 1 (wave 1 to wave 4). The HIV/AIDS indicator was consistent with the biomarker-based estimates of HIV/AIDS prevalence, which facilitates its utilization in the empirical analysis that follows.

[Here, Table 2]

4.4 Measurement of marital status

In the subsequent empirical analysis, this study uses information on widows. However, it is not clearly discerned from the dataset 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). However, this study believes that the enumerators still identified those females as "widowed" in the survey, considering that in the KHDS, household members are defined

[20] With the technical assistance provided by the MEASURE DHS program, the THIS 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; 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`. In this survey, the respondents' blood was collected for HIV testing if they volunteered for the test.

[21] 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. The estimated infection rate of the KHDS communities seems plausible, compared with that provided by several studies that date back to the late 1980s; see Figure 5-3 of Ainsworth et al. (1998, p. 147), for example.

[22] Conducting a population-based survey in Kagera in 1987, Killewo et al. (1990) 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 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.” Notably, an inherited widow does not typically live together with her inheritor, who resides with his wife and children at his homestead, according to my field interviews with the Luo in Rorya (recall footnote 12). In addition, an inherited widow does not share a household budget with her inheritor’s family when purchasing food and other items. This study will return to this issue in subsection 5.2.2.

5 Empirical findings

In this section, three empirical findings, which are consistent with the HIV/AIDS-induced deterioration of levirate marriage, are demonstrated: a negative impact of HIV/AIDS on levirate marriage (subsection 5.1), a negative correlation between the deterioration of levirate marriage and widows’ welfare (subsection 5.2), and a negative reduced-form impact of HIV/AIDS on widows’ welfare (subsection 5.3).

5.1 Impact of HIV/AIDS on levirate marriage

Exploiting the village-level 102 observations (i.e., $102 = 51 \times 2$) in waves 1 and 5 as well as controlling for the region-wise time trend and village-fixed effects, this study first regressed the village-level prevalence of levirate marriage (i.e., D_{jt}) on the HIV/AIDS indicator in column (g) in Table 2. While statistically insignificant, this ordinary least-squares (OLS) estimate suggests that HIV/AIDS encouraged the practice of levirate marriage. However, it is difficult to interpret this estimate in a causal manner, because levirate marriage is often blamed for facilitating the sexual transmission of HIV/AIDS (e.g., Malungo, 2001; Okeyo and Allen, 1994).

In columns (h) and (i), two simultaneous equations of levirate marriage and HIV/AIDS were separately estimated with a control of an indicator for communities to which temporal migrants come to find jobs from Uganda located immediately to the north of Kagera. Since this job-related in-migration dummy had little time-variation within a village, these estimations excluded the village-fixed effects to avoid multicollinearity. First, HIV/AIDS discouraged levirate marriage, as seen in column (h), although the reverse causality might have attenuated this impact. Second, this in-migration dummy significantly increased the prevalence of HIV/AIDS, but not that of levirate marriage. This is plausible because migrant workers often engage in risky sexual intercourse and contribute to the spread of HIV/AIDS in Kagera (e.g., Killewo et al., 1990) or elsewhere in Africa (e.g., Anarfi, 1993; Brockerhoff and Biddlecom, 1999; Lurie et al., 2003; see also Oster, 2012b). However, because they are “temporary” workers, they do not form a direct relationship of levirate marriage.

Since this in-migration dummy seems to arguably satisfy both the order and rank conditions for the levirate-marriage equation, this study instrumented the HIV/AIDS indicator with this dummy in column (j). As the result shows, HIV/AIDS causally discouraged the practice of leviratte marriage. The instrument is strong as seen from the F-statistics in the first-stage estimations, reported at the bottom of this table.[23] This two-stage least-squares (2SLS) estimate is greater than the OLS estimate reported in column (h), as expected. One concern for this 2SLS estimate is that communities receiving job-seeking in-migrants may be located in urban areas, whereby those exposed to urban lifestyles and values may prefer to avoid levirate marriage simply because of their preference for modernity. Therefore, in column (k), the 2SLS estimations were performed with an additional control of an indicator for communities located in urban areas. Again, HIV/AIDS is responsible for the disappearance of levirate marriage. Finally, this study also estimated a reduced-form equation of levirate marriage with respect to the in-migration dummy in column (l). Now, the job-related in-migration significantly discouraged levirate marriage, however, the magnitude of the estimate halves and its statistical significance disappears once the HIV/AIDS indicator is additionally controlled for, as already done in column (h). This finding suggests that the in-migration discouraged levirate marriage only through its influence on HIV/AIDS, which supports the exclusion restriction of the instrument.

5.2 Institutional change and widows' welfare

If HIV/AIDS triggers the disappearance of levirate marriage, this institutional change is negatively associated with (young) widows' welfare, while being positively correlated with their fertility, as explained in Section 3. As the fertility-related information available in the KHDS consists only of the number of a household head's co-resident children, this study cannot effectively analyze fertility. This is because a head may have multiple wives and thus many children as well as children residing elsewhere. Therefore, in this subsection, this study attempts to verify the negative "correlation" between the institutional change and widows' welfare. However, exploring a simple correlation is not useful because it is attributable to many confounding factors.[24] Therefore, an appropriate strategy to identify a correlation stemming "only" from the proposed mechanism is required, as discussed below. Unlike standard empirical studies, in this subsection, it is said that the estimates are "biased" if the estimated correlation between the institutional change and widows' welfare arises from factors not relevant to the theoretical mechanism.

[23]In the first stage, the in-migration dummy increased the prevalence of HIV/AIDS (coefficient 0.520 with a standard error of 0.109) with 1% statistical significance.

[24]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.

5.2.1 A triple-difference strategy

Pooling data pertaining to females aged 15 to 28 years in wave 1 and wave 5 of the KHDS, this study estimates the log of annual consumption per adult equivalent y_{ijt} of a female i in a period t (wave 1 or wave 5) as

$$y_{ijt} = \alpha_1 + \alpha_2 D_{jt} \cdot w_{ijt} + \alpha_3 w_{ijt} + \alpha_4 \mathbf{x_{ijt}} + v_{jt} + \epsilon_{ijt}, \tag{13}$$

whereby 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, household size); v_{jt} represents a time trend specific to the KHDS village j; and ϵ_{ijt} is a stochastic error. The standard errors are robust to heteroskedasticity and clustered to allow for arbitrary correlations across individuals within a village. Since the consumption per adult equivalent, which is estimated applying the methodology proposed by Collier et al. (1986) (pp. 70—73) for Tanzania, reflects nutritional requirements that vary by gender and age of typical individuals as well as the number of a household's members, it is more appropriate than per capita annual consumption (i.e., a household's consumption divided by the number of its members) when analyzing individual welfare.[25] If among possible theoretical factors (e.g., female empowerment), HIV/AIDS plays a major role in causing the deterioration of levirate marriage, the estimated α_2 should be negative.

The specification (13) 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, DID). Since this study exploits all the 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.[26] 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. Furthermore, by focusing on a comparison of consumption between widows and others (which implies triple difference), this study eliminates the influence of unobserved village-level characteristics that affected these villages over time in a "different" manner (i.e., v_{jt}).

[25] 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/`.

[26] 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. In fact, 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. The relevant results are available upon request.

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 and its validity, more detailed discussion is provided in Section S.3 in the supplemental appendix.

In this triple-difference approach, the key assumption to identify the α_2 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 aforementioned 16 villages (group A) and all the remaining villages (group B).

While unfortunately, the data prior to wave 1 is not available, it is still possible to examine the pre-survey trend regarding the likelihood of being widowed as well as consumption in wave 1 across different age cohorts. As revealed from the estimation results in columns (a) to (d) in Table S.1 in the supplemental appendix, coefficients on the interaction term between an indicator for villages belonging to the group A and age (years) are insignificantly different from zero. This study also assessed whether changes from wave 1 to wave 5 in the mean value of variables reported in Table 1 were statistically equal between the group A and the group B villages, and the corresponding DID estimates are demonstrated in panel (C) of this table. 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, they may still offer some comfort to the triple-difference approach.

5.2.2 Results

As column (a) in Table 3 shows, the estimated α_2 is negative and statistically significant. In column (b), replacing v_{jt} with region-wise time trend and village-fixed effects would not alter this implication. As expected, this negative correlation is not observed for older females aged 29 to 50 years [column (c)].

More flexibly, the estimated α_2 and its 95% confidence interval are also graphically reported in Figure 2 (left-hand panel). 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.

Several robustness checks were performed. First, this study uses 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). While the migrants should be included in the estimated sample,[27] this study controlled for 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) in column (d) in Table 3.[28]

The institutional change 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 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 estimation in column (e) controlled for a mortality rate (percentage), i.e., the number of people who died in the past 12 month in each KHDS village divided by its village population.[29]

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).[30] The analysis in column (f) included in regressors the (time-invariant) number of refugee camps established within a 25 km radius from each KHDS village during the relevant time frames.[31]

To address possible attrition bias, this study first 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) in column (g). Second, this study also exploited the insight obtained from Lee (2009). In wave 5, 36.63% of the female respondents aged 15 to 28 years in wave 1 were not observed in the aforementioned group A villages, along with the corresponding rate of 30.79% in the group B villages. Then, this study excluded the wave 5 respondents belonging to the group B 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 B respondents in wave 5, and estimated equation (13) in columns (h) and (i). The significantly negative

[27]For example, a woman who became widowed during the sample periods might have left a KHDS 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; see also Section S.3 in the supplemental appendix.

[28]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.

[29]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.

[30]Therefore, 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.

[31]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.

correlation between the disappearance of levirate marriage and young widow's welfare is still observed in columns (d) through (i).

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. 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. In Table 4, the estimation result exploiting data relevant to the 17 communities are reported in column (a), whereas that in column (b) is relevant to the remaining 34 communities. The negative correlation between the deterioration of levirate marriage and widows' welfare is more clearly observed in villages more severely affected by HIV/AIDS from 1991 (wave 1) to 2004 (wave 5). Similar implications are also obtained when exploiting data pertaining to females of reproductive age (15—50), as seen in columns (c) and (d).

As one remaining concern pertaining to the issue discussed in subsection 4.4, poor widows who engaged in levirate marriage might have been included in the "married" group in wave 1. On the other hand, in villages where levirate marriage became less customary, similarly poor widows might have belonged to the "widowed" group in wave 5 because of the disappearance of this practice. This concern could "bias" the estimated α_2 downward. However, if this concern is true, the proportion of females whom the enumerators regard as "widowed" is likely to increase in villages where the customary practices became less common. However, the simple DID estimate (recall panel (C) in Table 1) did not reject the null hypothesis that the likelihood of widowhood was not affected by the institutional change. 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. No evidence supporting this possibility existed, as seen from columns (e) to (g) in Table S.1 in the supplemental appendix (see coefficients on the interaction term).

[Here, Table 3, Table 4, and Figure 2]

5.3 Reduced-form impact of HIV/AIDS on widows' welfare

If HIV/AIDS brought about the deterioration of levirate marriage, it might have causally reduced widows' welfare. Accordingly, after replacing the D_{jt} in equation (13) with the HIV/AIDS indicator in the respective period (which again means triple difference), the impacts of HIV/AIDS on widows' welfare are investigated in Table 4. 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 this analysis, 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 (e) (with a control of a village-specific time trend, v_{ij}) and (f) (with the v_{jt} replaced with region-wise time trend and village-fixed effects) show, HIV/AIDS reduced the consumption of widows aged 15 to 28. This effect does not hold for the elderly cohort (29—50), as seen in column (g). Taking a similar approach to that for the estimations performed in the left-hand panel of 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 the right-hand panel of this figure with 95% confidence intervals. As the results demonstrate, HIV/AIDS significantly reduced the consumption of young widows.[32] This finding is consistent with the fact that the negative correlation between institutional change and widows' welfare is more clearly observed for young widows. The absences of the significant correlation and of the reduced-form impact for the elderly cohort can also be seen as a result of the relevant falsification test.

The negative impact on widows' welfare may be biased upward 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. Following Oster (forthcoming), this study estimated and reported a coefficient of proportionality on selection assumptions at the bottom of Table 4, as denoted as δ, for the coefficients on the interaction term between a widow dummy and the HIV/AID indicator.[33] The reported negative δ values indicate that the aforementioned HIV/AIDS impacts appear to be attenuated if any causality bias exists.

This study does not claim that only the proposed mechanism links HIV/AIDS to the decline in widows' welfare. However, together with the findings reported in the previous subsections, it is difficult to consider that the proposed mechanism does not play a role at all.

6 Conclusion

This study explored whether and how HIV/AIDS leads to the deterioration of levirate marriage both theoretically and empirically. To address this question, this study first developed a simple theoretical model that explained the mechanism responsible for this institutional change based on the findings provided by relevant anthropological and

[32]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 explained in subsection 4.3, 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 the left-hand and the right-hand panels in Figure 2 may mitigate a concern over measurement noise pertaining to the recalled prevalence of levirate marriage in wave 1.

[33]While this treatment does not alter the implications, the respondents' age and education were assumed to be non-proportional to unobservables because HIV/AIDS during the sample periods is unlikely to affect these pre-determined variables. The 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.

ethnographic studies as well as my field surveys in the Kagera and Mara regions in Tanzania. Exploiting one novel setting observed in the survey data collected in rural Tanzania for 1991—2004, it also provided empirical evidence that collectively supported the proposed mechanism. As a result of HIV/AIDS, young widows may need a form of social protection (e.g., formal insurance, access to income-generating opportunities).

While the theoretical results are available upon request, female empowerment as a source of improved women's property rights (i.e., an increase in $k > c(n^*)$ or $r > \tau$) can also make levirate marriage obsolete. In this mechanism, however, widows' welfare does "not" decline in step with this institutional change. As a corollary of these theoretical results, providing social protection for young widows, which implies an increase in widows' reservation payoffs (i.e., r), improves the total welfare enjoyed by a clan and by them, compared to the case of levirate marriage equilibrium.[34]

In the KHDS data, the centuries-long practice of levirate marriage has started to disappear only during the past 20 years. This swift transformation may also be consistent with the influence of HIV/AIDS. While the speed of institutional mobility is not explicitly modeled, intuitively, it is likely that the deterioration of levirate marriage occurs more swiftly in the case of HIV/AIDS compared with the case of female empowerment. This is because a husband's clan, who has institutionally been advantaged in and benefited from a traditional society sustaining levirate marriage, does not resist or rather desires the transformation in the case of HIV/AIDS. Owing to the absence of solid data, however, further empirical research is still required to prove or disprove the plausibility of the asserted mechanism in a strict sense. Nevertheless, the present research should still improve the general understanding of the mechanisms responsible for the transformation of cultural institutions that have been rooted in societies, particularly focusing on the underlying role of deadly infectious diseases.

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[34] In contrast, simply making it possible for a widow to inherit her husband's property (i.e., an increase in k) would reduce this total welfare, compared with the case of the levirate marriage equilibrium. This finding arises because the improvement of widows' property rights is seen as a constraint which prevents a clan from choosing the desired number of children. Given no change in widows' reservation utility (i.e., an increase in r), this type of female empowerment reduces a clan's utility from the levirate marriage equilibrium without increasing widows' one.

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Table 1: Summary statistics (females aged 15 to 28 years)

	(A) Wave 1			(B) Wave 5			(C) DID estimates		
	Mean	Std. dev.	No. of obs.	Mean	Std. dev.	No. of obs.	Coeff.	Std. errors	No. of obs.
Consumption per adult equivalent (TSH)	64119.31	46546.54	710	67055.58	56385.24	1059	-15279.708	9927.740	1769
Widow (dummy)	0.04	0.19	714	0.01	0.09	1056	0.000	0.018	1770
Age (years)	19.94	3.83	714	21.51	4.04	1059	-0.642	0.408	1773
Education (years)	5.88	2.76	695	5.71	3.21	1043	-0.384	0.341	1738
Head's age (years)	47.47	17.49	714	40.34	16.20	1051	0.488	2.206	1765
Head male (dummy)	0.78	0.42	714	0.75	0.43	1051	0.104***	0.039	1765
HH size	7.51	3.89	710	5.42	2.99	1059	0.297	0.709	1769
HH land (acre)	5.73	5.62	696	3.87	3.67	889	-1.060	1.481	1585

Notes: (1) The DID estimates arise from comparing changes in the reported variables from wave 1 to wave 5 between villages where levirate marriage grew less customary during the sample periods (group A) and all the remaining villages (group B). (2) Regarding the DID estimates, *** denotes significance at 1%.

Table 2: Quality check of an HIV/AIDS indicator and impacts of HIV/AIDS on levirate marriage

Dependent variable:	HIV/AIDS indicator (KHDS)					
Sample:	wave 5 (i.e., 2004)	wave 5 (i.e., 2004)	wave 5 (i.e., 2004)	wave 5 (i.e., 2004)	wave 1 (i.e., 1991)	wave 1 to 4 (i.e., 1991 to 1994)
	OLS	OLS	OLS	OLS	OLS	OLS
	(a)	(b)	(c)	(d)	(e)	(f)
HIV prevalence						
Proportion (nearest, THIS)	2.920*	-	-	-	-	-
	(1.494)					
One if positive (nearest, THIS)	-	0.373**	-	-	-	-
		(0.150)				
Proportion (mean < 40km, THIS)	-	-	4.736	-	-	-
			(3.006)			
One if positive (mean < 40km, THIS)	-	-	-	0.492***	-	-
				(0.158)		
Proportion (district, Killewo et al. (1990))	-	-	-	-	1.818**	2.722***
					(0.756)	(0.454)
Wave FE	NO	NO	NO	NO	NO	YES
R-squared	0.063	0.118	0.049	0.151	0.093	0.247
No. of villages	51	51	51	51	51	204
Dependent variables:	No levirate marriage	No levirate marriage	HIV/AIDS indicator	No levirate marriage	No levirate marriage	No levirate marriage
	OLS	OLS	OLS	2SLS	2SLS	OLS
	(g)	(h)	(i)	(j)	(k)	(l)
HIV/AIDS indicator (KHDS)	-0.052	0.160**	-	0.385***	0.419***	-
	(0.171)	(0.074)		(0.136)	(0.129)	
No levirate marriage	-	-	0.261**	-	-	-
			(0.119)			
Temporary job in-migration from Uganda (indicator)	-	0.117	0.468***	-	-	0.200*
		(0.099)	(0.096)			(0.108)
Urban village (indicator)	-	-	-	-	0.080	-
					(0.090)	
Village FE	YES	NO	NO	NO	NO	NO
Wave FE	YES	YES	YES	YES	YES	YES
F-statistics of the 1st stage	-	-	-	22.39	23.84	-
R-squared	0.561	0.161	0.134	0.088	0.072	0.124
No. of villages	102	102	102	102	102	102

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

Table 3: Institutional change and widows' welfare (OLS)

Dependent variable:	Log of consumption per adult equivalent (TSH)								
Sample:	Aged 15 to 28	Aged 15 to 28	Aged 29 to 50	Aged 15 to 28					
								Trim top	Trim bottom
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Widow									
× No levirate marriage	-0.456***	-0.358**	0.052	-0.437***	-0.488***	-0.482***	-0.446***	-0.447***	-0.421***
	(0.152)	(0.151)	(0.117)	(0.149)	(0.144)	(0.162)	(0.152)	(0.154)	(0.154)
× Mortality rate	-	-	-	-	0.051	-	-	-	-
					(0.046)				
× No. of refugee camps	-	-	-	-	-	-0.130*	-	-	-
						(0.068)			
No levirate marriage									
× Migrant in wave 5	-	-	-	0.015	-	-	-	-	-
				(0.146)					
× Drop by wave 5	-	-	-	-	-	-	-0.054	-	-
							(0.093)		
No levirate marriage	-	0.045	-	-	-	-	-	-	-
		(0.097)							
Widow	0.213**	0.242**	-0.174	0.211**	0.091	0.288**	0.211**	0.204**	0.208**
	(0.099)	(0.104)	(0.107)	(0.103)	(0.143)	(0.124)	(0.098)	(0.099)	(0.097)
Age(years)	0.004	0.006*	0.004	0.003	0.004	0.004	0.004	0.005*	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Education (years)	0.034***	0.031***	0.035***	0.034***	0.034***	0.034***	0.034***	0.029***	0.031***
	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)
Head's age (years)	-0.002	-0.002*	-0.001	-0.001	-0.002*	-0.002	-0.002	-0.001	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head male	0.124**	0.123***	0.101*	0.108**	0.123**	0.123**	0.125***	0.119***	0.089*
	(0.046)	(0.041)	(0.051)	(0.047)	(0.046)	(0.046)	(0.046)	(0.044)	(0.046)
HH size	-0.044***	-0.044***	-0.053***	-0.043***	-0.044***	-0.044***	-0.044***	-0.041***	-0.042***
	(0.007)	(0.007)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)
HH land (acre)	0.019***	0.020***	0.021***	0.019***	0.018***	0.018***	0.019***	0.017***	0.016***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)
Migrant in wave 5	-	-	-	0.118	-	-	-	-	-
				(0.140)					
Drop by wave 5	-	-	-	-	-	-	0.018	-	-
							(0.070)		
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 FE	NO	YES	NO	NO	NO	NO	NO	NO	NO
Wave FE	NO	YES	NO	NO	NO	NO	NO	NO	NO
Village time trend	YES	NO	YES	YES	YES	YES	YES	YES	YES
R-squared	0.382	0.319	0.403	0.388	0.383	0.384	0.382	0.385	0.389
No. of individuals	1553	1553	1063	1553	1553	1553	1553	1494	1446

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 4: HIV/AIDS-related heterogeneity and reduced-form impacts of HIV/AIDS (OLS)

Dependent variable:	Log of consumption per adult equivalent (TSH)						
Sample:	Aged 15 to 28		Aged 15 to 50		Aged 15 to 28	Aged 15 to 28	Aged 29 to 51
	Δ HIV/AIDS indicator		Δ HIV/AIDS indicator				
	Positive	Non-positive	Positive	Non-positive			
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Widow							
× No levirate marriage	-1.294***	-0.205	-0.169*	-0.071	-	-	-
	(0.230)	(0.148)	(0.081)	(0.095)			
× HIV/AIDS indicator	-	-	-	-	-0.353***	-0.310***	0.024
					(0.101)	(0.096)	(0.057)
Widow	0.825***	0.151*	-0.006	-0.055	0.082	0.079	-0.167***
	(0.083)	(0.083)	(0.065)	(0.087)	(0.077)	(0.066)	(0.058)
Age (years)	0.002	0.005	0.005**	0.003**	0.006***	0.008***	0.005*
	(0.007)	(0.004)	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)
Education (years)	0.034***	0.033***	0.025***	0.035***	0.033***	0.033***	0.038***
	(0.007)	(0.006)	(0.007)	(0.005)	(0.004)	(0.004)	(0.006)
Head's age (years)	-0.003	-0.001	-0.002	-0.002	-0.001	-0.001	-0.001
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Head male	0.125	0.129**	0.113*	0.114**	0.110***	0.107***	0.082
	(0.072)	(0.060)	(0.056)	(0.048)	(0.037)	(0.034)	(0.051)
HH size	-0.033**	-0.047***	-0.044***	-0.048***	-0.039***	-0.037***	-0.051***
	(0.013)	(0.008)	(0.009)	(0.009)	(0.004)	(0.004)	(0.006)
HH land (acre)	0.020*	0.017***	0.025**	0.018***	0.001*	0.001**	0.025***
	(0.010)	(0.004)	(0.011)	(0.003)	(0.000)	(0.000)	(0.003)
Head's ethnicity	YES	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES	YES
Village FE	NO	NO	NO	NO	NO	YES	NO
Wave FE	NO	NO	NO	NO	NO	YES	NO
Village time trend	YES	YES	YES	YES	YES	NO	YES
Oster (forthcoming)'s δ							
(1) $R_{max} = 1.3\tilde{R}$	-	-	-	-	-10.859	-5.795	-
(2) $R_{max} = 1.0$	-	-	-	-	-2.033	-0.708	-
R-squared	0.353	0.406	0.297	0.389	0.382	0.287	0.423
No. of women	520	1033	867	1749	3404	3404	2284

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.

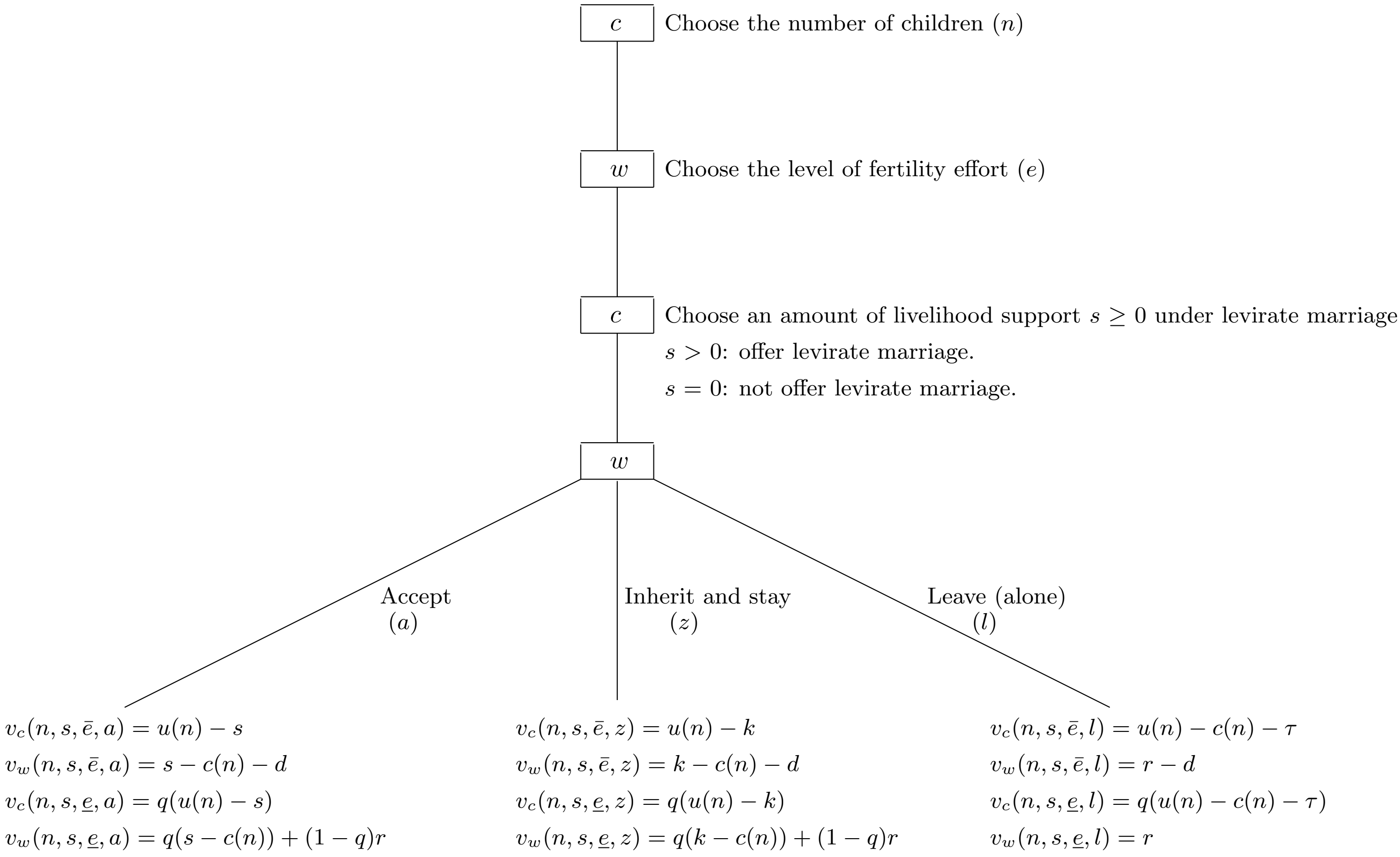

Figure 1: Levirate marriage game

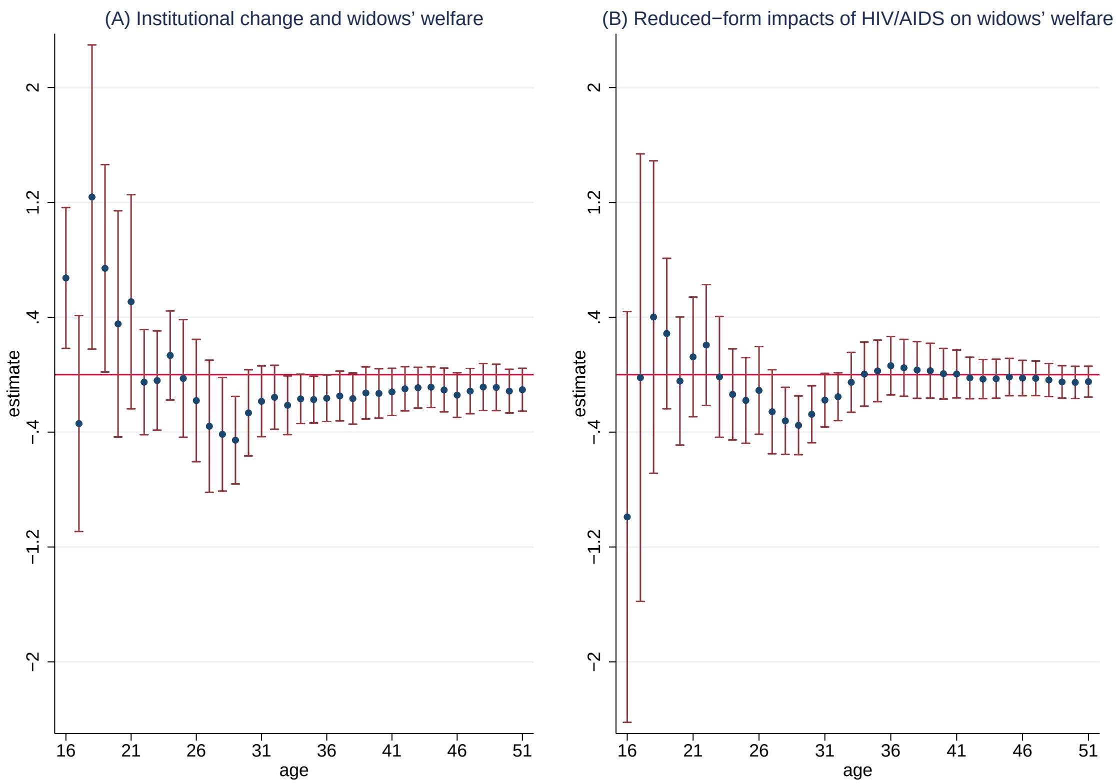

Figure 2: Age heterogeneity, consumption per adult equivalent (OLS)

Notes: (1) Panel (A) reports the estimated α_2 in equation (13) with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) After replacing D_{jt} in equation (13) with an HIV/AID indicator in each wave, panel (B) reports the estimated impacts of HIV/AIDS on widows' consumption per adult equivalent with 95% confidence intervals by changing the exploited sample by the respondents' age. (3) Age m in the horizontal axis means that the estimation uses data pertaining to female respondents aged 15 to $m - 1$.

Supplemental appendix

S.1 Benchmark model

S.1.1 Levirate marriage equilibrium

The proposition 1 is embedded in the following proposition:

Proposition S.1 *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 $(n^*, c(n^*)+\frac{d}{1-q}, \bar{e}, a)$ 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 $(n^*, c(n^*), \underline{e}, a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $r_0 = 0$.*

The $\frac{d}{1-q}$ is an incentive cost needed for a clan to encourage a woman's fertility effort. As this incentive cost increases, the "no-effort equilibrium" $(n^*, c(n^*), \underline{e}, a)$ 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, $\frac{qd}{1-q} = \frac{d}{1-q} - d$.

S.1.2 HIV/AIDS as an agent of institutional change

The proposition 2 is embedded in the following proposition:

Proposition S.2 *Assume that $r = r_1 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_1 < h_c + h_w \approx \infty$. Then,*

1. *When $k_1 - c(n^*) < k_1 < \frac{d}{1-q} + r_1$ (in this case, $n_1 < 0 < n^* < n_2$), the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$ (Case 1).*

2. *When $k_1 - c(n^*) \leq \frac{d}{1-q} + r_1 \leq k_1$ (in this case, $0 \leq n_1 \leq n^* < n_2$)*

   (a) *and $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$ (Case 2).*

   (b) *and $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_1 \leq n^*$ and a widow's payoff $r_1 + \frac{qd}{1-q} = r_1 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ (Case 3).*

3. *When $\frac{d}{1-q} + r_1 < k_1 - c(n^*) < k_1$ (in this case, $0 < n^* < n_1 < n_2$)*

(a) *and* $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$, *the strategy profile* $(n_2, 0, \underline{e}, z)$ *is subgame perfect, along with the equilibrium number of children* $n_2 > n^*$ *and a widow's payoff* $r_1 < 0 < \frac{qd}{1-q}$ *(Case 4).*

(b) *and* $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, *the strategy profile* $(n_1, 0, \bar{e}, z)$ *is subgame perfect, along with the equilibrium number of children* $n_1 > n^*$ *and a widow's payoff* $r_1 + \frac{qd}{1-q} = r_1 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ *(Case 5).*

Here, n_1 and n_2 satisfy $k_1 - c(n_1) = \frac{d}{1-q} + r_1$ and $k_1 - c(n_2) = r_1$.

The proposition S.2 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. In this example, an incentive cost needed for a clan to induce a woman's fertility effort is $\frac{d}{1-q} + r_1$.

When this incentive cost is very large (i.e., $k_1 < \frac{d}{1-q} + r_1$), a clan does not encourage a woman's fertility effort and attempts to raise the number of children to the level of $n_2 > n^*$ 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., $k_1 \geq \frac{d}{1-q} + r_1$), 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 $n_2 > n^*$, 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.

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., $k_1 - c(n^*) > \frac{d}{1-q} + r_1$), a clan encourages fertility to the level of $n_1 > n^*$ (i.e., Case 5). In contrast, if the amount of bequest is small (i.e., $k_1 - c(n^*) \leq \frac{d}{1-q} + r_1$), the clan decides to reduce the number of children to the level of $n_1 \leq n^*$ (i.e., Case 3).

In Case 3 and Case 5, a widow obtains reservation utility plus (net) information rent (i.e., $r_1 + \frac{qd}{1-q}$) 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 $r_1 + \frac{qd}{1-q}$. Otherwise, her welfare may increase or decrease from $r_0 = 0$ to $r_1 + \frac{qd}{1-q} = r_1 + \frac{d}{1-q} - d$. When $r_1 + \frac{d}{1-q} < d$ (i.e., very low incentive cost), widows' welfare decreases. When $r_1 + \frac{d}{1-q} \geq d$, 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., $k_1 \geq r_1 + \frac{d}{1-q}$) and particularly in Case 3, the reduced child-rearing cost.

In sum, 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, HIV/AIDS would raise the equilibrium number of children while decreasing widows' welfare. Importantly, in traditional agrarian societies, women are expected to have limited power to control fertility (i.e., large q). In addition, women's access to family planning methods was also limited during the investigation periods of the present study (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 $(n^*, c(n^*), \underline{e}, a)$ and $(n_2, 0, \underline{e}, z)$ (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.

S.1.3 Old-age security motive for fertility

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). As female reproductive rights are not entirely suppressed within a family, therefore, a woman may respond to the disappearance of levirate marriage by making more effort to produce children.

In the current model, it is 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 $\frac{d}{1-q} + r_1$ needed for a clan to induce women's fertility effort (more precisely, $\frac{d}{1-q}$ given r_1). If making fertility effort and having more children allow a woman to claim access to the deceased's property, 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 that women's 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.2, it can be shown that

Proposition S.3 *Assume that $r = r_1 < 0$, $k = k_0 \leq c(n^*)$, and the disease cost is high enough such that $\tau - r_1 < h_c + h_w \approx \infty$. Then, when $\frac{d}{1-q} + r_1 < k_0 - c(n^*) \leq 0$ (in this case, $n^* < n_6 < n_7$)*

1. *and $u(n_7) - k_0 \leq \frac{u(n_7) - u(n_6)}{1-q}$, the strategy profile $(n_7, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_7 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$ (Case 4b).*
2. *and $u(n_7) - k_0 > \frac{u(n_7) - u(n_6)}{1-q}$, the strategy profile $(n_6, 0, \bar{e}, z)$ is subgame perfect, along with the equilibrium number*

of children $n_6 > n^*$ *and a widow's payoff* $r_1 + \frac{qd}{1-q} = r_1 + \frac{d}{1-q} - d < \frac{qd}{1-q}$ *(Case 5b).*

Here, n_6 and n_7 satisfy $k_0 - c(n_6) = \frac{d}{1-q} + r_1$ and $k_0 - c(n_7) = r_1$.

Notably, the small $\frac{d}{1-q}$ makes $\frac{d}{1-q} + r_1 < k_0 - c(n^*)$ more likely as well as raises the level of n_6 (by construction), thereby making $u(n_7) - u(n_6)$ small owing to concavity of a clan's utility function. Since this small difference between $u(n_7)$ and $u(n_6)$ makes the case of $u(n_7) - k_0 > \frac{u(n_7)-u(n_6)}{1-q}$ more likely, a woman is expected to make fertility effort at equilibrium (i.e., Case 5b); as a result, the equilibrium number of children increases from n^* to n_6 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.2 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 $r_1 + \frac{d}{1-q}$ decreases due to HIV/AIDS so that $r_1 + \frac{d}{1-q} < d$. Therefore, once again, both the decline in widows' welfare and the increase in women's fertility are consistent with the HIV/AIDS-induced disappearance of levirate marriage.

S.2 Model extension

In this section, an attempt is made to ensure that the key theoretical implications are robust to several model extensions. To simplify the analysis, in this section, it is assumed that women have no power to control fertility, reducing the dimensions of the strategy profile from (n, s, e, m) to (n, s, m) along with the following payoff profiles,

$$v_c(n, s, a) = u(n) - s, \tag{S.2.1}$$

$$v_w(n, s, a) = s - c(n), \tag{S.2.2}$$

$$v_c(n, s, l) = u(n) - c(n) - \tau, \tag{S.2.3}$$

$$v_w(n, s, l) = r, \tag{S.2.4}$$

$$v_c(n, s, z) = u(n) - k, \tag{S.2.5}$$

$$v_w(n, s, z) = k - c(n). \tag{S.2.6}$$

S.2.1 Relocation cost and punishment

In the real world, several additional costs affect players' payoffs. 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.2.2 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

$$v_c(n,s,a) = u(n) - s, \tag{S.2.7}$$

$$v_w(n,s,a) = s - c(n), \tag{S.2.8}$$

$$v_c(n,s,l_1) = u(n) - c(n) - \tau, \tag{S.2.9}$$

$$v_w(n,s,l_1) = r - g, \tag{S.2.10}$$

$$v_c(n,s,l_2) = b, \tag{S.2.11}$$

$$v_w(n,s,l_2) = r - c(n) - b, \tag{S.2.12}$$

$$v_c(n,s,z) = u(n) - k, \tag{S.2.13}$$

$$v_w(n,s,z) = k - c(n), \tag{S.2.14}$$

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.[35] As seen from the 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, 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., $r - c(n) - b < k - c(n)$). 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.4 *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,*

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

along with the equilibrium number of children n^* and a widow's payoff $r_0 - g = -g$.

Next, 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 $r_1 < 0$. 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.5 *When $r = r_1 < 0$, $k = \hat{k}_1 > c(n^*) - g$, and the disease cost is high enough such that $\tau - r_1 + g < h_w + h_c$, the strategy profile $(n_9, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_9 > n^*$ and a widow's payoff $r_1 - g < -g$.*

Here, n_9 satisfies $\hat{k}_1 - c(n_9) = r_1 - g$.

The deterioration of levirate marriage is associated with an increase in the number of children (i.e., $n_9 > n^*$) as well as a decline in widows' welfare (i.e., $r_1 - g < -g$).

S.2.3 Uncertainty about a couple's death

In the real world, it is possible that a wife dies before a husband does. Defining a probability that a husband's dies first as $p \in (0, 1)$, the agents' expected payoffs can be characterized as

$$v_c(n, s, a) = u(n) - ps - (1 - p)(c(n) + \tau), \tag{S.2.15}$$

$$v_w(n, s, a) = p(s - c(n)), \tag{S.2.16}$$

$$v_c(n, s, l) = u(n) - c(n) - \tau, \tag{S.2.17}$$

$$v_w(n, s, l) = pr, \tag{S.2.18}$$

$$v_c(n, s, z) = u(n) - pk - (1 - p)(c(n) + \tau), \tag{S.2.19}$$

$$v_w(n, s, z) = p(k - c(n)), \tag{S.2.20}$$

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 $r = r_0 = 0$ and $k = k_0 \leq c(n^*)$. Then, it is easy to show that

Proposition S.6 *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 $r_1 < 0$. 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.7 *Assume that $r = r_1 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough such that $\tau - r_1 < h_w + h_c$. Then,*

1. *When $k_1 \leq c(n_p) + r_1$ (in this case, $n^* < n_2 \leq n_p$), the strategy profile $(n_2, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $pr_1 < 0$ (Case 1).*

2. *When $c(n_p) + r_1 < k_1 < c(n_p)$ (in this case, $n^* \leq n_p < n_2$), 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, $n^* \leq n_p < n_2$), 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_2 and n_p satisfy $k_1 - c(n_2) = r_1$ and $u'(n_p) = (1-p)c'(n_p)$.

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., $n_2 > n^*$ or $n_p \geq n^*$) as well as "either" a decrease or increase in widows' welfare. Several points deserve highlighting.

First, as the likelihood that a husband dies first goes up, n_p increases.[36] Then, given the values of r_0 $(= 0)$, r_1, and k_1, Case 1 (i.e., $c(n^*) < k_1 \leq c(n_p) + r_1$) is more likely to occur, as p increases. Consequently, when the value of p is large, the strategy profile $(n_2, 0, z)$ would arise at equilibrium.

Second, 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., $k_1 > c(n_p) + r_1$),[37] 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_2 and eventually choose $n_p < n_2$. In this case, widows' welfare may increase (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.

[36] 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 $n_p^1 \leq n_p^2$.

[37] For example, when $p \approx 0$, $n^* \approx n_p$ and so, $c(n_p) + r_1 \approx c(n^*) + r_1 < c(n^*) < k_1$.

S.2.4 Influence of HIV/AIDS on the probability of a husband's death

To consider the possibility that HIV/AIDS increases a probability of a young husband's death, 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 $n_\rho > n_{10}$, whereby n_ρ and n_{10} satisfy $u'(n_\rho) = \rho_0 c'(n_\rho)$ and $k_1 - c(n_{10}) = 0$.[38] As mentioned in subsection 4.1, the de facto amount of k bequeathed to widows tends to be large for elderly widows, i.e., those having adult children. Then, 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, the following holds:

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 $u(n_{10}) - u(n_0) \geq \rho_0(c(n_{10}) - c(n_0))$, the strategy profiles $(n_{10}, (c(n_{10}), a_y), (0, z_o))$ and $(n_{10}, (c(n_{10}), a_y), (c(n_{10}), a_o))$ are subgame perfect, along with the equilibrium number of children n_{10} and a widow's payoffs $v_w^y = v_w^o = r_0 = 0$ (Case 1).*

2. *When $u(n_{10}) - u(n_0) < \rho_0(c(n_{10}) - c(n_0))$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_{10}), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_{10}), a_o))$ are subgame perfect, along with the equilibrium number of children n_0 and a widow's payoffs $v_w^y = r_0 = 0$ and $v_w^o = c(n_{10}) - c(n_0) > 0$ (Case 2).*

Here, n_0 satisfies $k_0 - c(n_0) = 0$.

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 $u(n_{10}) - u(n_0) \geq \rho_0(c(n_{10}) - c(n_0))$), the amount k_1 ($= c(n_{10})$) primarily determines the number of children and otherwise, k_0 ($= c(n_0)$) does. 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 $k_0 - c(n_{10})$

[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 $n_\rho^1 \geq n_\rho^2$.

< 0. In my field survey in Rorya (see footnote 12 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.

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_1 while establishing their de facto property rights (i.e., always $k = k_1$). In addition, the probability of losing husbands early may also increase from ρ_0 to ρ_1. Then,

Proposition S.9 *Assume that $\rho = \rho_1 > \rho_0$, $r = r_1 < 0$, $k = k_1 > c(n^*)$ for a widow, whether early or late, who loses her husband, and the disease cost is high enough such that $\tau - r_1 < h_w + h_c$. Then, the strategy profile $(n_2, (0, z_y), (0, z_o))$ is subgame perfect, along with the equilibrium number of children $n_2 > n_{10} > n_0$ and a widow's payoffs $v_w^y = v_w^o = r_1 < 0$.*

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_2. For example, it can be presumed that the couple produces children at the (exogenous) level of $n = \bar{n} < n_2$ when a woman loses her husband early. In this case,

Proposition S.10 *Assume that $\rho = \rho_1 > \rho_0$, $r = r_1 < 0$, $k = k_1 > c(n^*)$ for a widow, whether early or late, who loses her husband, and the disease cost is high enough such that $\tau - r_1 < h_w + h_c$. When a woman loses her husband early, the couple produces $\bar{n} < n_2$ children. Then, the strategy profile $(n_2, (0, z_y), (0, z_o))$ is subgame perfect. In this case, the equilibrium number of children and a widow's payoff are $\bar{n}$ and $v_w^y = c(n_{10}) - c(\bar{n})$ when a woman loses her husband early, whereas the corresponding values are $n_2 > n_{10} > n_0$ and $v_w^o = r_1 < 0$ 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 $\bar{n} > n_{10}$. 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_2 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 are still consistent with the case of $\bar{n} > n_{10}$ 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_2), the situation $\bar{n} > n_{10}$ may be plausible even if a woman loses her husband early.

S.3 Detailed explanation on the triple-difference strategy

To facilitate an interpretation of the identification strategy explained in subsection 5.2.1, Figure S.1 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 (13) 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 villages (or triple difference).

Widows that were already in a levirate marriage in wave 1 are unlikely to have lost this 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 female respondents aged 15 to 28 years 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. 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 is further discussed in subsection 5.2.2.

Partially related to the point of the lower bound estimate, 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 (13) 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.

Furthermore, consumption enjoyed by "Other" females shown in Figure S.1 might also 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). This means that the current empirical approach comparing widows' consumption with that of "Other" females within the same village may also underestimate the negative correlation between the institutional change and widows' consumption.

S.4 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 S.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., $n_0 \leq n^*$. Also, find n_3 and n_4 satisfying $k_0 - c(n_3) = \frac{d}{1-q}$ and $k_0 - c(n_4) = d$. Since $\frac{d}{1-q} > d > 0$, it is the case that $n_3 < n_4 < n_0$. In addition, since $c(n_3) = k_0 - \frac{d}{1-q} < k_0 = c(n_0) \leq c(n^*)$, it is the case that $c(n_3) < c(n_0) \leq c(n^*)$, i.e., $n_3 < n_0 \leq n^*$. Since $c(n_4) = k_0 - d < k_0 = c(n_0) \leq c(n^*)$, it is the case that $c(n_4) < c(n_0) \leq c(n^*)$, i.e., $n_4 < n_0 \leq n^*$. Consequently, it becomes that $n_3 < n_4 < n_0 \leq n^*$.

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 $n \leq n_3$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_0 - c(n) - d \geq k_0 - c(n_3) - d > k_0 - c(n_4) - d = 0$, 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 $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), yielding $v_c = u(n_3) - k_0 = u(n_3) - c(n_3) - \frac{d}{1-q}$ as well as $v_w = k_0 - c(n_3) - d = \frac{d}{1-q} - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort for $n \leq n_3$, 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 $k_0 - c(n) - \frac{d}{1-q} = c(n_3) - c(n) \geq 0$, 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 $n = n_3$ (i.e., maximum in the domain of $n \leq n_3$), which results in $v_c = u(n_3) - s = u(n_3) - k_0 = u(n_3) - c(n_3) - \frac{d}{1-q}$ and $v_w = s - c(n_3) - d = k_0 - c(n_3) - d = \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \leq n_3$, 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 $\left(\frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n)\right) - \left(c(n) + \frac{d}{1-q}\right) = \frac{1}{q}\left(k_0 - c(n) - \frac{d}{1-q}\right) = \frac{1}{q}\left(c(n_3) - c(n)\right) \geq 0$, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_3$, the strategy profiles $(n_3, 0, \bar{e}, z)$ and $(n_3, c(n_3) + \frac{d}{1-q}, \bar{e}, a)$ provide a clan with maximum utility $u(n_3) - c(n_3) - \frac{d}{1-q}$.

Second, consider the case of $n_3 \leq n \leq n_0$. 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 $n_3 \leq n \leq n_0$, 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 $q(k_0 - c(n)) + c(n) + d - \left(c(n) + \frac{d}{1-q}\right) = q\left(k_0 - c(n) - \frac{d}{1-q}\right) = q(c(n_3) - c(n)) \leq 0$, the above conditions result in $s \geq c(n) + \frac{d}{1-q} \geq q(k_0 - c(n)) + c(n) + d$ for all $n_3 \leq n \leq n_0$. 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 $n_3 \leq n \leq n_0$, 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 $k_0 - \left(c(n) + \frac{d}{1-q}\right) = c(n_3) - c(n) \leq 0$, 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 $n_3 \leq n \leq n_0$, 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 $q\left(u(n) - c(n)\right)$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = q\left(u(n^*) - c(n^*)\right)$ 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 $(n^*, c(n^*) + \frac{d}{1-q}, \bar{e}, a)$ 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 $(n^*, c(n^*), \underline{e}, a)$ provides a clan with maximum utility $q(u(n^*) - c(n^*))$.

Now, compare maximum utility across cases. Note that $u(n_3) - c(n_3) - \frac{d}{1-q} < u(n^*) - c(n^*) - \frac{d}{1-q}$; $q(u(n_0) - c(n_0)) < q(u(n^*) - c(n^*))$; 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 $(n^*, c(n^*) + \frac{d}{1-q}, \bar{e}, a)$ 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 $(n^*, c(n^*), \underline{e}, a)$ 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 $(n^*, c(n^*) + \frac{d}{1-q}, \bar{e}, a)$ 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 $(n^*, c(n^*), \underline{e}, a)$ is subagme perfect. In this case, a widow obtains utility r_0 =0.

Proof of proposition S.2:

Find n_1, n_5, and n_2 satisfying $k_1 - c(n_1) = \frac{d}{1-q} + r_1$, $k_1 - c(n_5) = r_1 + d$, and $k_1 - c(n_2) = r_1$. Since $\frac{d}{1-q} + r_1 > d + r_1 > r_1$, it is the case that $n_1 < n_5 < n_2$. In addition, since $c(n_2) = k_1 - r_1 > k_1 > c(n^*)$, it is the case that $c(n_2) > c(n^*)$, i.e., $n_2 > n^*$.

Also, note that to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_1 - c(n) - d \geq q(k_1 - c(n)) + (1-q)r_1$, i.e., $k_1 - c(n) \geq \frac{d}{1-q} + r_1$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d - h_w \geq q(s - c(n) - h_w) + (1-q)r_1$, i.e., $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Now, two cases are considered, either $\frac{d}{1-q} + r_1 > 0$ or $\frac{d}{1-q} + r_1 \leq 0$.

Case 1: $\frac{d}{1-q} + r_1 > 0$.

Now, consider three subcases of either $k_1 < \frac{d}{1-q} + r_1$, $\frac{d}{1-q} + r_1 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_1$, and $k_1 > c(n^*) + \frac{d}{1-q} + r_1$.

Subcase 1: $k_1 < \frac{d}{1-q} + r_1$.

Since $k_1 < \frac{d}{1-q} + r_1 < c(n^*) + \frac{d}{1-q} + r_1$, it is the case that $c(n_1) = k_1 - \frac{d}{1-q} - r_1 < c(n^*)$, so $n_1 < n^*$. Consequently, $n_1 < 0 < n^* < n_2$. Also, note that in this case, a woman never makes fertility effort when she rejects leviraet marriage.

First, consider the case of $0 \leq n \leq n_2$. Since $q(k_1 - c(n)) + (1-q)r_1 \geq q(k_1 - c(n_2)) + (1-q)r_1 = r_1$, 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), yielding $v_c = q(u(n_2) - k_1) = q\,(u(n_2) - c(n_2) - r_1)$ as well as $v_w = q(k_1 - c(n_2)) + (1-q)r_1 = r_1$.

To encourage a widow to accept levirate marriage while making fertility effort for $0 \leq n \leq n_2$, it must be the case that $s - c(n) - d - h_w \geq q(k_1 - c(n)) + (1-q)r_1$ (i.e., $s \geq qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $(qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = q\left(k_1 - \frac{d}{1-q} - r_1 - c(n)\right) < 0$, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 > qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = c(n^*) + \frac{d}{1-q} + h_w + r_1 - c(n^*) - d - h_w = r_1 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $0 \leq n \leq n_2$, it must be case that $q(s - c(n) - h_w) + (1 - q)r_1 \geq q(k_1 - c(n)) + (1 - q)r_1$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_1 - \frac{d}{1-q} - r_1 - c(n) < 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in $v_c = q(u(n_2) - k_1 - h_w - h_c)$ $= q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ and $v_w = q(s - c(n_2) - h_w) + (1 - q)r_1 = r_1$.

Since $q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right) < q\left(u(n_2) - c(n_2) - r_1\right)$, the strategy profile $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_2) - c(n_2) - r_1) > u(n^*) - c(n^*) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $0 \leq n \leq n_2$, the strategy profile $(n_2, 0, \underline{e}, z)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - r_1)$.

Second, consider the case of $n \geq n_2$. Since $q(k_1 - c(n)) + (1 - q)r_1 \leq q(k_1 - c(n_2)) + (1 - q)r_1 = r_1$, 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* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), yielding $v_c = q(u(n_2) - c(n_2) - \tau)$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_2$, it must be the case that $s - c(n) - d - h_w \geq r_1$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq c(n) + d + h_w + r_1$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_2) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_2$, it must be the case that $q(s - c(n) - h_w) + (1 - q)r_1 \geq r_1$ (i.e., $s \geq c(n) + r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $c(n) + r_1 + h_w \leq s$ $\leq c(n) + \frac{d}{1-q} + h_w + r_1$. Then, a clan chooses $s = c(n) + r_1 + h_w$ and obtains utility $q\left(u(n) - c(n) - r_1 - h_w - h_c\right)$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ and $v_w = q(s - c(n_2) - h_w) + (1 - q)r_1 = r_1$. Since $q(u(n_2) - c(n_2) - \tau) > q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ due to $\tau - r_1 < h_w + h_c$ and $q(u(n_2) - c(n_2) - \tau) > u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$ due to an infinitely large disease cost, the strategy profiles $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ and $(n_2, c(n_2) + \frac{d}{1-q} + r_1 + h_w, \bar{e}, a)$ are not selected. Consequently, for $n \geq n_2$, the strategy profile $(n_2, 0, \underline{e}, l)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - \tau)$.

Now, compare utility $q(u(n_2) - c(n_2) - r_1)$ and $q(u(n_2) - c(n_2) - \tau)$. Since $q(u(n_2) - c(n_2) - r_1) > q(u(n_2) - c(n_2) - \tau)$, the strategy profile $(n_2, 0, \underline{e}, l)$ is not selected. As a result, the strategy profile $(n_2, 0, \underline{e}, z)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - r_1)$. In this case, a widow obtains utility r_1.

Subcase 2: $\frac{d}{1-q} + r_1 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_1$.

Since $k_1 \leq c(n^*) + \frac{d}{1-q} + r_1$, it is the case that $c(n_1) = k_1 - \frac{d}{1-q} - r_1 \leq c(n^*)$, so $n_1 \leq n^*$. Consequently, $0 \leq n_1 \leq n^* < n_2$.

First, consider the case of $n \leq n_1$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_1 - c(n) - d \geq k_1 - c(n_1) - d > k_1 - c(n_5) - d = r_1$. 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 $n = n_1$ (i.e., maximum in the domain of $n \leq n_1$), yielding $v_c = u(n_1) - k_1 = u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$ as well as $v_w = k_1 - c(n_1) - d = r_1 + \frac{qd}{1-q}$. 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* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_1 - c(n) - \frac{d}{1-q} - r_1 = c(n_1) - c(n) \geq 0$, the above conditions result in $s \geq k_1 + h_w \geq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_1$ (i.e., maximum in the domain of $n \leq n_1$), which results in $v_c = u(n_1) - k_1 - h_w - h_c = u(n_1) - c(n_1) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_1) - d - h_w = k_1 + h_w - c(n_1) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \geq k_1 - c(n) - d$ (i.e., $s \geq \frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $\left(\frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = \frac{1}{q}\left(k_1 - c(n) - \frac{d}{1-q} - r_1\right) = \frac{1}{q}(c(n_1) - c(n)) \geq 0$ for all $n \leq n_1$. Thus, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \leq n_1$, the strategy profile $(n_1, 0, \bar{e}, z)$ provides a clan with maximum utility $u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$.

Second, consider the case of $n_1 \leq n \leq n_2$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_1 - c(n)) + (1-q)r_1 \geq q(k_1 - c(n_2)) + (1-q)r_1 = r_1$, 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), yielding $v_c = q(u(n_2) - k_1) = q\left(u(n_2) - c(n_2) - r_1\right)$ as well as $v_w = q(k_1 - c(n_2)) + (1-q)r_1 = r_1$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_1 \leq n \leq n_2$, it must be the case that $s - c(n) - d - h_w \geq q(k_1 - c(n)) + (1-q)r_1$ (i.e., $s \geq qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $(qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = q\left(k_1 - \frac{d}{1-q} - r_1 - c(n)\right) = q(c(n_1) - c(n)) \leq 0$, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = c(n^*) + \frac{d}{1-q} + h_w + r_1 - c(n^*) - d - h_w = r_1 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_1 \leq n \leq n_2$, it must be case that $q(s - c(n) - h_w) + (1-q)r_1 \geq q(k_1 - c(n)) + (1-q)r_1$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_1 - \frac{d}{1-q} - r_1 - c(n) = c(n_1) - c(n) \leq 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in $v_c = q(u(n_2) - k_1 - h_w - h_c) = q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ and $v_w = q(s - c(n_2) - h_w) + (1-q)r_1 = r_1$.

Since $q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right) < q\left(u(n_2) - c(n_2) - r_1\right)$, the strategy profile $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_2) - c(n_2) - r_1) > u(n^*) - c(n^*) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n_1 \leq n \leq n_2$, the strategy profile $(n_2, 0, \underline{e}, z)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - r_1)$.

Third, consider the case of $n \geq n_2$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_1 - c(n)) + (1-q)r_1 \leq q(k_1 - c(n_2)) + (1-q)r_1 = r_1$, 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* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), yielding $v_c = q(u(n_2) - c(n_2) - \tau)$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_2$, it must be the case that $s - c(n) - d - h_w \geq r_1$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq c(n) + d + h_w + r_1$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_2) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_2$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \geq r_1$ (i.e., $s \geq c(n) + r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $c(n) + r_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Then, a clan chooses $s = c(n) + r_1 + h_w$ and obtains utility $q\left(u(n) - c(n) - r_1 - h_w - h_c\right)$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ and $v_w = q(s - c(n_2) - h_w) + (1-q)r_1 = r_1$. Since $q(u(n_2) - c(n_2) - \tau) > q\left(u(n_2) - c(n_2) - r_1 - h_w - h_c\right)$ due to $\tau - r_1 < h_w + h_c$, the strategy profile $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_2) - c(n_2) - \tau) > u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n \geq n_2$, the strategy profile $(n_2, 0, \underline{e}, l)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - \tau)$.

Now, compare utility $u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$, $q(u(n_2) - c(n_2) - r_1)$, and $q(u(n_2) - c(n_2) - \tau)$. Since $q(u(n_2) - c(n_2) - r_1) > q(u(n_2) - c(n_2) - \tau)$, the strategy profile $(n_2, 0, \underline{e}, l)$ is not selected. Here, note that $\left(u(n_1) - c(n_1) - \frac{d}{1-q} - r_1\right) - q(u(n_2) - c(n_2) - r_1) = (u(n_1) - k_1) - q(u(n_2) - k_1) = u(n_1) - u(n_2) + (1-q)(u(n_2) - k_1)$. Thus, when $u(n_2) - k_1 >$

$\frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect and a widow obtains utility $r_1 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect and a widow obtains utility r_1.

Subcase 3: $k_1 > c(n^*) + \frac{d}{1-q} + r_1$

Since $c(n_1) = k_1 - \frac{d}{1-q} - r_1 > c(n^*)$, $c(n_1) > c(n^*)$, so $n_1 > n^*$. Consequently, $n^* < n_1 < n_2$.

First, consider the case of $n \le n_1$. In this case, a woman has an incentive to make fertility effort when she chooses action z. Since $k_1 - c(n) - d \ge k_1 - c(n_1) - d > k_1 - c(n_5) - d = r_1$. 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 $n = n_1$ (i.e., maximum in the domain of $n \le n_1$), yielding $v_c = u(n_1) - k_1$ $= u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$ as well as $v_w = k_1 - c(n_1) - d = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort, it must be the case that $s - c(n) - d - h_w \ge k_1 - c(n) - d$ (i.e., $s \ge k_1 + h_w$) *and* $s \ge c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_1 - c(n) - \frac{d}{1-q} - r_1 = c(n_1) - c(n) \ge 0$, the above conditions result in $s \ge k_1 + h_w \ge c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_1$ (i.e., maximum in the domain of $n \le n_1$), which results in $v_c = u(n_1) - k_1 - h_w - h_c = u(n_1) - c(n_1) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_1) - d - h_w = k_1 + h_w - c(n_1) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \ge k_1 - c(n) - d$ (i.e., $s \ge \frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w$) *and* $s \le c(n) + \frac{d}{1-q} + h_w + r_1$. Since $\left(\frac{k_1}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = \frac{1}{q}\left(k_1 - c(n) - \frac{d}{1-q} - r_1\right)$ $= \frac{1}{q}(c(n_1) - c(n)) \ge 0$ for all $n \le n_1$. Thus, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \le n_1$, the strategy profile $(n_1, 0, \bar{e}, z)$ provides a clan with maximum utility $u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$.

Second, consider the case of $n_1 \le n \le n_2$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_1 - c(n)) + (1-q)r_1 \ge q(k_1 - c(n_2)) + (1-q)r_1 = r_1$, 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 $n = n_2$ (i.e., maximum in the domain of $n \le n_2$), yielding $v_c = q(u(n_2) - k_1) = q\left(u(n_2) - c(n_2) - r_1\right)$ as well as $v_w = q(k_1 - c(n_2)) + (1-q)r_1 = r_1$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_1 \le n \le n_2$, it must be the case that $s - c(n) - d - h_w \ge q(k_1 - c(n)) + (1-q)r_1$ (i.e., $s \ge qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$) *and* $s \ge c(n) + \frac{d}{1-q} + h_w + r_1$. Since $(qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = q\left(k_1 - \frac{d}{1-q} - r_1 - c(n)\right) = q(c(n_1) - c(n))$ ≤ 0, the above conditions result in $s \ge c(n) + \frac{d}{1-q} + h_w + r_1 \ge qk_1 + (1-q)c(n) + (1-q)r_1 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_1$ (corner solution), which results in $v_c = u(n_1) - c(n_1) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = c(n_1) + \frac{d}{1-q} + h_w + r_1 - c(n_1) - d - h_w = r_1 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_1 \leq n \leq n_2$, it must be case that $q(s - c(n) - h_w) + (1-q)r_1 \geq q(k_1 - c(n)) + (1-q)r_1$ (i.e., $s \geq k_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_1 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_1 - \frac{d}{1-q} - r_1 - c(n) = c(n_1) - c(n) \leq 0$, the above conditions result in $k_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in $v_c = q(u(n_2) - k_1 - h_w - h_c) = q\,(u(n_2) - c(n_2) - r_1 - h_w - h_c)$ and $v_w = q(s - c(n_2) - h_w) + (1-q)r_1 = r_1$.

Since $q\,(u(n_2) - c(n_2) - r_1 - h_w - h_c) < q\,(u(n_2) - c(n_2) - r_1)$, the strategy profile $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_2) - c(n_2) - r_1) > u(n_1) - c(n_1) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n_1 \leq n \leq n_2$, the strategy profile $(n_2, 0, \underline{e}, z)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - r_1)$.

Third, consider the case of $n \geq n_2$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_1 - c(n)) + (1-q)r_1 \leq q(k_1 - c(n_2)) + (1-q)r_1 = r_1$, 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* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), yielding $v_c = q(u(n_2) - c(n_2) - \tau)$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_2$, it must be the case that $s - c(n) - d - h_w \geq r_1$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq c(n) + d + h_w + r_1$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_2) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_2$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \geq r_1$ (i.e., $s \geq c(n) + r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $c(n) + r_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Then, a clan chooses $s = c(n) + r_1 + h_w$ and obtains utility $q\,(u(n) - c(n) - r_1 - h_w - h_c)$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = q\,(u(n_2) - c(n_2) - r_1 - h_w - h_c)$ and $v_w = q(s - c(n_2) - h_w) + (1-q)r_1 = r_1$. Since $q(u(n_2) - c(n_2) - \tau) > q\,(u(n_2) - c(n_2) - r_1 - h_w - h_c)$ due to $\tau - r_1 < h_w + h_c$, the strategy profile $(n_2, c(n_2) + r_1 + h_w, \underline{e}, a)$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_2) - c(n_2) - \tau) > u(n_2) - c(n_2) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n \geq n_2$, the strategy profile $(n_2, 0, \underline{e}, l)$ provides a clan with maximum utility $q(u(n_2) - c(n_2) - \tau)$.

Now, compare utility $u(n_1) - c(n_1) - \frac{d}{1-q} - r_1$, $q(u(n_2) - c(n_2) - r_1)$, and $q(u(n_2) - c(n_2) - \tau)$. Since $q(u(n_2) - c(n_2) - r_1)$

$> q(u(n_2) - c(n_2) - \tau)$, the strategy profile $(n_2, 0, \underline{e}, l)$ is not selected. Here, note that $\left(u(n_1) - c(n_1) - \frac{d}{1-q} - r_1\right) - q(u(n_2) - c(n_2) - r_1) = (u(n_1) - k_1) - q(u(n_2) - k_1) = u(n_1) - u(n_2) + (1-q)(u(n_2) - k_1)$. Thus, when $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect and a widow obtains utility $r_1 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect and a widow obtains utility r_1.

Case 2: $\frac{d}{1-q} + r_1 \leq 0$.

In this case, $k_1 > c(n^*) \geq c(n^*) + \frac{d}{1-q} + r_1$. Then, consider the case that $k_1 > c(n^*) + \frac{d}{1-q} + r_1$. Similar to the above Subcase 3, when $u(n_2) - k_1 > \frac{u(n_2)-c(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect and a widow obtains utility $r_1 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect and a widow obtains utility r_1.

Now, consider the Case 1 (including the Subcase 1 to Subcase 3) and Case 2 together. Then, assuming that $r = r_1 < 0$, $k = k_1 > c(n^*)$, and the disease cost is high enough in the sense that $\tau - r_1 < h_c + h_w \approx \infty$, we get

1. When $\frac{d}{1-q} + r_1 > 0$
   (a) and $k_1 < \frac{d}{1-q} + r_1$ (in this case, $n_1 < 0 < n^* < n_2$), the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$.
   (b) and $\frac{d}{1-q} + r_1 \leq k_1 \leq c(n^*) + \frac{d}{1-q} + r_1$ (in this case, $0 \leq n_1 \leq n^* < n_2$)
      i. and $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$.
      ii. and $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_1 \leq n^*$ and a widow's payoff $r_1 + \frac{qd}{1-q} < \frac{qd}{1-q}$.
   (c) and $k_1 > c(n^*) + \frac{d}{1-q} + r_1$ (in this case, $0 < n^* < n_1 < n_2$)
      i. and $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$.
      ii. and $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_1 > n^*$ and a widow's payoff $r_1 + \frac{qd}{1-q} < \frac{qd}{1-q}$.
2. When $\frac{d}{1-q} + r_1 \leq 0$ and thus, $k_1 > c(n^*) \geq c(n^*) + \frac{d}{1-q} + r_1$ (in this case, $0 < n^* < n_1 < n_2$)
   (a) and $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_2 > n^*$ and a widow's payoff $r_1 < 0 < \frac{qd}{1-q}$.

(b) and $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$, the strategy profile $(n_1, 0, \bar{e}, z)$ is subgame perfect, along with the equilibrium number of children $n_1 > n^*$ and a widow's payoff $r_1 + \frac{qd}{1-q} = r_1 + \frac{d}{1-q} - d < 0 < \frac{qd}{1-q}$.

Summarizing these more succinctly yields proposition S.2.

Proof of proposition S.3:

Find n_6, n_7, and n_8 satisfying $k_0 - c(n_6) = \frac{d}{1-q} + r_1$, $k_0 - c(n_7) = r_1$, and $k_0 - c(n_8) = r_1 + d$. Since $\frac{d}{1-q} + r_1 > d + r_1 > r_1$, it is the case that $n_6 < n_8 < n_7$. Since $c(n_6) = k_0 - \frac{d}{1-q} - r_1 > c(n^*)$ (by assumption), $c(n_6) > c(n^*)$, so $n_6 > n^*$. Consequently, $n^* < n_6 < n_7$.

Also, note that to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_0 - c(n) - d \geq q(k_0 - c(n)) + (1-q)r_1$, i.e., $k_0 - c(n) \geq \frac{d}{1-q} + r_1$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d - h_w \geq q(s - c(n) - h_w) + (1-q)r_1$, i.e., $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$.

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 $k_0 - c(n) - d \geq k_0 - c(n_6) - d > k_0 - c(n_8) - d = r_1$. 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 $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), yielding $v_c = u(n_6) - k_0 = u(n_6) - c(n_6) - \frac{d}{1-q} - r_1$ as well as $v_w = k_0 - c(n_6) - d = r_1 + \frac{qd}{1-q}$. 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* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_0 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_0 - c(n) - \frac{d}{1-q} - r_1 = c(n_6) - c(n) \geq 0$, the above conditions result in $s \geq k_0 + h_w \geq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_6$ (i.e., maximum in the domain of $n \leq n_6$), which results in $v_c = u(n_6) - k_0 - h_w - h_c = u(n_6) - c(n_6) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_6) - d - h_w = k_0 + h_w - c(n_6) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \geq k_0 - c(n) - d$ (i.e., $s \geq \frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $\left(\frac{k_0}{q} - \frac{d}{q} - \frac{1-q}{q}c(n) - \frac{1-q}{q}r_1 + h_w\right) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = \frac{1}{q}\left(k_0 - c(n) - \frac{d}{1-q} - r_1\right) = \frac{1}{q}(c(n_6) - c(n)) \geq 0$ 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 $(n_6, 0, \bar{e}, z)$ provides a clan with maximum utility $u(n_6) - c(n_6) - \frac{d}{1-q} - r_1$.

Second, consider the case of $n_6 \leq n \leq n_7$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) + (1-q)r_1 \geq q(k_0 - c(n_7)) + (1-q)r_1 = r_1$, 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 $n = n_7$ (i.e., maximum in the domain of $n \leq n_7$), yielding $v_c = q(u(n_7) - k_0) = q\left(u(n_7) - c(n_7) - r_1\right)$ as well as $v_w = q(k_0 - c(n_7)) + (1-q)r_1 = r_1$.

To encourage a widow to accept levirate marriage while making fertility effort for $n_6 \leq n \leq n_7$, it must be the case that $s - c(n) - d - h_w \geq q(k_0 - c(n)) + (1-q)r_1$ (i.e., $s \geq qk_0 + (1-q)c(n) + (1-q)r_1 + d + h_w$) *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $(qk_0 + (1-q)c(n) + (1-q)r_1 + d + h_w) - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = q\left(k_0 - \frac{d}{1-q} - r_1 - c(n)\right) = q(c(n_6) - c(n))$ ≤ 0, the above conditions result in $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq qk_0 + (1-q)c(n) + (1-q)r_1 + d + h_w$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility by selecting $n = n_6$ (corner solution), which results in $v_c = u(n_6) - c(n_6) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = c(n_6) + \frac{d}{1-q} + h_w + r_1 - c(n_6) - d - h_w = r_1 + \frac{qd}{1-q}$.

To encourage a widow to accept levirate marriage without making fertility effort for $n_6 \leq n \leq n_7$, it must be case that $q(s - c(n) - h_w) + (1-q)r_1 \geq q(k_0 - c(n)) + (1-q)r_1$ (i.e., $s \geq k_0 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Since $k_0 + h_w - \left(c(n) + \frac{d}{1-q} + h_w + r_1\right) = k_0 - \frac{d}{1-q} - r_1 - c(n) = c(n_6) - c(n) \leq 0$, the above conditions result in $k_0 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. 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 $n = n_7$ (i.e., maximum in the domain of $n \leq n_7$), which results in $v_c = q(u(n_7) - k_0 - h_w - h_c) = q\left(u(n_7) - c(n_7) - r_1 - h_w - h_c\right)$ and $v_w = q(s - c(n_7) - h_w) + (1-q)r_1 = r_1$.

Since $q\left(u(n_7) - c(n_7) - r_1 - h_w - h_c\right) < q\left(u(n_7) - c(n_7) - r_1\right)$, the strategy profile $(n_7, c(n_7) + r_1 + h_w, \underline{e}, a)$ is not selected. Given an infinitely large disease cost, it is also the case that $q(u(n_7) - c(n_7) - r_1) > u(n_6) - c(n_6) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n_6 \leq n \leq n_7$, the strategy profile $(n_7, 0, \underline{e}, z)$ provides a clan with maximum utility $q(u(n_7) - c(n_7) - r_1)$.

Third, consider the case of $n \geq n_7$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) + (1-q)r_1 \leq q(k_0 - c(n_7)) + (1-q)r_1 = r_1$, 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* $n \geq n_7 > n^*$. Then, a clan selects $n = n_7$ (corner solution), yielding $v_c = q(u(n_7) - c(n_7) - \tau)$ as well as $v_w = r_1$. To encourage a widow to accept levirate marriage while making fertility effort for $n \geq n_7$, it must be the case that $s - c(n) - d - h_w \geq r_1$ *and* $s \geq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $s \geq c(n) + \frac{d}{1-q} + h_w + r_1 \geq c(n) + d + h_w + r_1$. Then, a clan chooses $s = c(n) + \frac{d}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d}{1-q} - r_1 - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_7 > n^*$. Then, a clan selects $n = n_7$ (corner solution), which results in $v_c = u(n_7) - c(n_7) - \frac{d}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_7) - d - h_w = r_1 + \frac{qd}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \geq n_7$, it must be the case that $q(s - c(n) - h_w) + (1-q)r_1 \geq r_1$ (i.e., $s \geq c(n) + r_1 + h_w$) *and* $s \leq c(n) + \frac{d}{1-q} + h_w + r_1$, yielding $c(n) + r_1 + h_w \leq s \leq c(n) + \frac{d}{1-q} + h_w + r_1$. Then, a clan chooses

$s = c(n) + r_1 + h_w$ and obtains utility $q\,(u(n) - c(n) - r_1 - h_w - h_c)$. A clan can maximize this utility *subject to* $n \geq n_7 > n^*$. Then, a clan selects $n = n_7$ (corner solution), which results in $v_c = q\,(u(n_7) - c(n_7) - r_1 - h_w - h_c)$ and $v_w = q(s - c(n_7) - h_w) + (1-q)r_1 = r_1$. Since $q(u(n_7) - c(n_7) - \tau) > q\,(u(n_7) - c(n_7) - r_1 - h_w - h_c)$ due to $\tau - r_1 < h_w + h_c$, the strategy profile $(n_7, c(n_7) + r_1 + h_w, \underline{e}, a)$ is not selected. Due to an infinitely large disease cost, it is also the case that $q(u(n_7) - c(n_7) - \tau) > u(n_7) - c(n_7) - \frac{d}{1-q} - r_1 - h_w - h_c$. Consequently, for $n \geq n_7$, the strategy profile $(n_7, 0, \underline{e}, l)$ provides a clan with maximum utility $q(u(n_7) - c(n_7) - \tau)$.

Now, compare utility $u(n_6) - c(n_6) - \frac{d}{1-q} - r_1$, $q(u(n_7) - c(n_7) - r_1)$, and $q(u(n_7) - c(n_7) - \tau)$. Since $q(u(n_7) - c(n_7) - r_1) > q(u(n_7) - c(n_7) - \tau)$, the strategy profile $(n_7, 0, \underline{e}, .l)$ is not selected. Here, note that $\left(u(n_6) - c(n_6) - \frac{d}{1-q} - r_1\right) - q(u(n_7) - c(n_7) - r_1) = (u(n_6) - k_0) - q(u(n_7) - k_0) = u(n_6) - u(n_7) + (1-q)(u(n_7) - k_0)$. Thus, when $u(n_7) - k_0 > \frac{u(n_7) - u(n_6)}{1-q}$, the strategy profile $(n_6, 0, \bar{e}, z)$ is subgame perfect and a widow obtains utility $r_1 + \frac{qd}{1-q}$. Otherwise, the strategy profile $(n_7, 0, \underline{e}, z)$ is subgame perfect and a widow obtains utility r_1.

Proof of proposition S.4:

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 $-c(n) - b < \hat{k}_0 - c(n)$.

First, consider the case of $n \leq \hat{n}_0$. In this case, $\hat{k}_0 - c(n) \geq \hat{k}_0 - c(\hat{n}_0) = -g$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - \hat{k}_0$. A clan can maximize this utility by selecting $n = \hat{n}_0$ (i.e., maximum in the domain of $n \leq \hat{n}_0$), yielding $v_c = u(\hat{n}_0) - \hat{k}_0 = u(\hat{n}_0) - c(\hat{n}_0) + g$ as well as $v_w = \hat{k}_0 - c(\hat{n}_0) = -g$. To encourage a widow to accept levirate marriage for $n \leq \hat{n}_0$, it must be the case that $s - c(n) \geq \hat{k}_0 - c(n)$. Then, a clan chooses $s = \hat{k}_0$ and obtains utility $u(n) - \hat{k}_0$. A clan can maximize this utility by selecting $n = \hat{n}_0$ (i.e., maximum in the domain of $n \leq \hat{n}_0$), which results in $v_c = u(\hat{n}_0) - s = u(\hat{n}_0) - \hat{k}_0 = u(\hat{n}_0) - c(\hat{n}_0) + g$ and $v_w = s - c(\hat{n}_0) = \hat{k}_0 - c(\hat{n}_0) = -g$. Consequently, for $n \leq \hat{n}_0$, the strategy profiles $(\hat{n}_0, 0, z)$ and $(\hat{n}_0, c(\hat{n}_0) - g, a)$ provide a clan with maximum utility $u(\hat{n}_0) - c(\hat{n}_0) + g$.

In case of $n \geq \hat{n}_0$ (i.e., $\hat{k}_0 - c(n) \leq -g$), a widow chooses action l_1 when she rejects levirate marriage. Given the action l_1 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 $v_w = -g$. To encourage a widow to accept levirate marriage for $n \geq \hat{n}_0$, it must be the case that $s - c(n) \geq -g$. Then, a clan chooses $s = c(n) - g$ and obtains utility $u(n) - c(n) + g$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) + g$ and $v_w = s - c(n^*) = -g$. Consequently, for $n \geq \hat{n}_0$, the strategy profile $(n^*, c(n^*) - g, a)$ provides a clan with maximum utility $u(n^*) - c(n^*) + g$.

Since $u(n^*) - c(n^*) + g > u(\hat{n}_0) - c(\hat{n}_0) + g$, the strategy profile $(n^*, c(n^*) - g, a)$ is subgame perfect. In this case, a widows obtains utility $-g$.

Proof of proposition S.5:

Find n_9 satisfying $\hat{k}_1 - c(n_9) = r_1 - g$. Since $\hat{k}_1 > c(n^*) - g > c(n^*) + r_1 - g$ by assumption, it is the case that $c(n_9)$ $> c(n^*)$, i.e., $n_9 > n^*$. Also, note that a widow never chooses the action l_2 because $r_1 - c(n) - b < \hat{k}_1 - c(n)$.

First, consider the case of $n \leq n_9$. In this case, $\hat{k}_1 - c(n) \geq \hat{k}_1 - c(n_9) = r_1 - g$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - \hat{k}_1$. A clan can maximize this utility by selecting $n = n_9$ (i.e., maximum in the domain of $n \leq n_9$), yielding $v_c = u(n_9) - \hat{k}_1 = u(n_9) - c(n_9) - r_1 + g$ as well as $v_w = \hat{k}_1 - c(n_9) = r_1 - g$. To encourage a widow to accept levirate marriage for $n \leq n_9$, it must be the case that $s - c(n) - h_w \geq \hat{k}_1 - c(n)$. Then, a clan chooses $s = \hat{k}_1 + h_w$ and obtains utility $u(n) - \hat{k}_1 - h_w - h_c$. 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 $v_c = u(n_9) - s - h_c = u(n_9) - \hat{k}_1 - h_w - h_c = u(n_9) - c(n_9) - r_1 + g - h_w - h_c$ and $v_w = s - c(n_9) - h_w = \hat{k}_1 + h_w - c(n_9) - h_w = r_1 - g$. Consequently, for $n \leq n_9$, the strategy profile $(n_9, 0, z)$ provides a clan with maximum utility $u(n_9) - c(n_9) - r_1 + g$.

In case of $n \geq n_9$ (i.e., $\hat{k}_1 - c(n) \leq r_1 - g$), a widow chooses action l_1 when she rejects levirate marriage. Given the action l_1 taken by a widow, a clan obtains utility $u(n) - c(n) - \tau$. A clan can maximize this utility *subject to* n $\geq n_9 > n^*$. Then, a clan selects $n = n_9$ (corner solution), yielding $v_c = u(n_9) - c(n_9) - \tau$ as well as $v_w = r_1 - g$. To encourage a widow to accept levirate marriage for $n \geq n_9$, it must be the case that $s - c(n) - h_w \geq r_1 - g$. Then, a clan chooses $s = c(n) + r_1 - g + h_w$ and obtains utility $u(n) - c(n) - r_1 + g - h_w - h_c$. A clan can maximize this utility *subject to* $n \geq n_9 > n^*$. Then, a clan selects $n = n_9$, which results in $v_c = u(n_9) - c(n_9) - r_1 + g - h_w - h_c$ and v_w $= s - c(n_9) - h_w = r_1 - g$. Consequently, for $n \geq n_9$, the strategy profile $(n_9, 0, l_1)$ provides a clan with maximum utility $u(n_9) - c(n_9) - \tau$.

Since $u(n_9) - c(n_9) - r_1 + g > u(n_9) - c(n_9) - \tau$, the strategy profile $(n_9, 0, z)$ is subgame perfect. In this case, a widow obtains utility $r_1 - g$.

Proof of proposition S.6:

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 $n \le n_0$, it must be the case that $p(s - c(n)) \ge p(k_0 - c(n))$. 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 $n \le n_0$), 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 $n \le n_0$, 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 $n \ge n_0$ (i.e., $p(k_0 - c(n)) \le pr_0 = 0$), 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 $n \ge n_0$, it must be the case that $p(s - c(n)) \ge pr_0 = 0$. 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 $n \ge n_0$, 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.7:

Recall n_2 satisfying $k_1 - c(n_2) = r_1$. Since $k_1 > c(n^*) > c(n^*) + r_1$ by assumption, it is the case that $c(n_2) > c(n^*)$, i.e., $n_2 > n^*$. Also, recall n_p satisfying $u'(n_p) = (1-p)c'(n_p)$, whereby $n^* \le n_p$. Now, two cases are considered, either $k_1 \le c(n_p) + r_1$ (i.e., $c(n^*) < k_1 \le c(n_p) + r_1$) or $k_1 > c(n_p) + r_1$ (including both the cases of $k_1 > c(n^*) > c(n_p) + r_1$ and $k_1 > c(n_p) + r_1 > c(n^*)$).

Case 1: $k_1 \le c(n_p) + r_1$.

Since $c(n_2) = k_1 - r_1 \le c(n_p)$, it is the case that $n_2 \le n_p$. Consequently, $n^* < n_2 \le n_p$.

First, consider the case of $n \le n_2$. In this case, $p(k_1 - c(n)) \ge p(k_1 - c(n_2)) = pr_1$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - pk_1 - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_2$ (corner solution), yielding $v_c = u(n_2) - pk_1 - (1-p)c(n_2) - (1-p)\tau$ $= u(n_2) - c(n_2) - pr_1 - (1-p)\tau$ as well as $v_w = p(k_1 - c(n_2)) = pr_1$. To encourage a widow to accept levirate marriage for $n \le n_2$, it must be the case that $p(s - c(n) - h_w) \ge p(k_1 - c(n))$. 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 $n = n_2$ (corner solution), which results in $v_c = u(n_2) - pk_1 - ph_w - ph_c - (1-p)c(n_2) - (1-p)\tau = u(n_2) - c(n_2) - pr_1 - (1-p)\tau - ph_w - ph_c$ and $v_w = p(s - c(n_2) - h_w) = p(k_1 + h_w - c(n_2) - h_w) = pr_1$. Consequently, for $n \le n_2$, the strategy profile $(n_2, 0, z)$

provides a clan with maximum utility $u(n_2) - c(n_2) - pr_1 - (1-p)\tau$.

In case of $n \geq n_2$ (i.e., $p(k_1 - c(n)) \leq pr_1$), 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 *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), yielding $v_c = u(n_2) - c(n_2) - \tau$ as well as $v_w = pr_1$. To encourage a widow to accept levirate marriage for $n \geq n_2$, it must be the case that $p(s - c(n) - h_w) \geq pr_1$. Then, a clan chooses $s = c(n) + r_1 + h_w$ and obtains utility $u(n) - c(n) - pr_1 - ph_w - ph_c - (1-p)\tau$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - pr_1 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_2) - h_w) = pr_1$. Consequently, for $n \geq n_2$, the strategy profile $(n_2, 0, l)$ provides a clan with maximum utility $u(n_2) - c(n_2) - \tau$.

Since $u(n_2) - c(n_2) - pr_1 - (1-p)\tau > u(n_2) - c(n_2) - (1-p)\tau > u(n_2) - c(n_2) - \tau$, the strategy profile $(n_2, 0, z)$ is subgame perfect. In this case, a widow obtains utility pr_1.

Case 2: $k_1 > c(n_p) + r_1$.

Since $k_1 > c(n_p) + r_1$, $c(n_2) = k_1 - r_1 > c(n_p)$, so $n_2 > n_p$. Consequently, $n^* \leq n_p < n_2$.

First, consider the case of $n \leq n_2$. In this case, $p(k_1 - c(n)) \geq p(k_1 - c(n_2)) = pr_1$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - pk_1 - (1-p)c(n) - (1-p)\tau$. A clan can maximize this utility by selecting $n = n_p$, yielding $v_c = u(n_p) - pk_1 - (1-p)c(n_p) - (1-p)\tau = u(n_p) - pc(n_2) - (1-p)c(n_p) - pr_1 - (1-p)\tau$ as well as $v_w = p(k_1 - c(n_p)) = pr_1 + pc(n_2) - pc(n_p)$. To encourage a widow to accept levirate marriage for $n \leq n_2$, 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 $v_c = u(n_p) - pk_1 - ph_w - ph_c - (1-p)c(n_p) - (1-p)\tau = u(n_p) - pc(n_2) - (1-p)c(n_p) - pr_1 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_p) - h_w) = pr_1 + pc(n_2) - pc(n_p)$. Consequently, for $n \leq n_2$, the strategy profile $(n_p, 0, z)$ provides a clan with maximum utility $u(n_p) - pc(n_2) - (1-p)c(n_p) - pr_1 - (1-p)\tau$.

In case of $n \geq n_2$ (i.e., $p(k_1 - c(n)) \leq pr_1$), 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 *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), yielding $v_c = u(n_2) - c(n_2) - \tau$ as well as $v_w = pr_1$. To encourage a widow to accept levirate marriage for $n \geq n_2$, it must be the case that $s - c(n) - h_w \geq r_1$. Then, a clan chooses $s = c(n) + r_1 + h_w$ and obtains utility $u(n) - c(n) - pr_1 - ph_w - ph_c - (1-p)\tau$. A clan can maximize this utility *subject to* $n \geq n_2 > n^*$. Then, a clan selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - pr_1 - ph_w - ph_c - (1-p)\tau$ and $v_w = p(s - c(n_2) - h_w) = pr_1$. Note that $\tau < (1-p)\tau + pr_1 + ph_w + ph_c$ because $\tau - r_1 < h_w + h_c$ by assumption. Consequently, for $n \geq n_2$, the strategy profile $(n_2, 0, l)$ provides a clan with maximum utility $u(n_2) - c(n_2) - \tau$.

Now, compare utility $u(n_p)-pc(n_2)-(1-p)c(n_p)-pr_1-(1-p)\tau$ with $u(n_2)-c(n_2)-\tau$. Since $u(n_p)-(1-p)c(n_p)-pr_1 > u(n_p)-(1-p)c(n_p) > u(n_2)-(1-p)c(n_2)$, it becomes that $u(n_p)-pc(n_2)-(1-p)c(n_p)-pr_1 > u(n_2)-c(n_2)$, which indicates $u(n_p)-pc(n_2)-(1-p)c(n_p)-pr_1-(1-p)\tau > u(n_2)-c(n_2)-\tau$. Thus, the strategy profile $(n_p, 0, z)$ is subgame perfect. In this case, a widow obtains utility $pr_1 + pc(n_2) - pc(n_p)$.

Note that $pr_1 + pc(n_2) - pc(n_p) = pr_1 + p(k_1 - r_1 - c(n_p)) = p(k_1 - c(n_p))$. 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.8:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$ and find n_{10} satisfying $k_1 - c(n_{10}) = r_0 = 0$. Since $k_0 \leq c(n^*)$ by assumption, it is the case that $c(n_0) \leq c(n^*)$, i.e., $n_0 \leq n^*$. Since $k_1 > c(n^*)$ by assumption, it is the case that $c(n_{10}) > c(n^*)$, i.e., $n_{10} > n^*$, resulting in $n_0 \leq n^* < n_{10}$. 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 $n_\rho > n_{10}$ by assumption, therefore, it becomes $n_0 \leq n^* < n_{10} < n_\rho$. 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, $k_1 - c(n) \geq k_1 - c(n_0) > k_1 - c(n_{10}) = r_0 = 0$. 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 $v_c = u(n_0)-c(n_0)+(1-\rho_0)(c(n_0)-c(n_{10}))$. Consequently, for $n \leq n_0$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_{10}), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_{10}), a_o))$ provide a clan with maximum utility $u(n_0) - c(n_0) + (1-\rho_0)(c(n_0) - c(n_{10}))$.

Second, consider the case of $n_0 < n \leq n_{10}$. 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 $k_1 - c(n) \geq k_1 - c(n_{10}) = r_0 = 0$. To encourage w_y to accept levirate marriage when $n_0 < n \leq n_{10}$, 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 $n_0 < n \leq n_{10}$, 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* $n \leq n_{10} < n_\rho$, a clan selects $n = n_{10}$ (corner solution), which results in $v_c = u(n_{10})-c(n_{10})$. Consequently, when $n_0 < n \leq n_{10}$, the strategy profiles $(n_{10},(c(n_{10}),a_y),(0,z_o))$ and $(n_{10},(c(n_{10}),a_y),(c(n_{10}),a_o))$ provide a clan with maximum utility $u(n_{10})-c(n_{10})$.

Third, consider the case of $n \geq n_{10}$. In this case, $k_0-c(n) \leq k_0-c(n_{10}) < k_0-c(n_0) = r_0 = 0$. Also, $k_1-c(n) \leq k_1-c(n_{10}) = r_0 = 0$. 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 $n \geq n_{10}$, 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 $n \geq n_{10}$, 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* $n \geq n_{10} > n^*$, a clan selects $n = n_{10}$ (corner solution), which results in $v_c = u(n_{10})-c(n_{10})$. Consequently, when $n \geq n_{10}$, the strategy profile $(n_{10},(c(n_{10}),a_y),(c(n_{10}),a_o))$ provides a clan with maximum utility $u(n_{10})-c(n_{10})$.

Now, compare utility $u(n_{10})-c(n_{10})$ with $u(n_0)-c(n_0)+(1-\rho_0)(c(n_0)-c(n_{10}))$. When $u(n_{10})-u(n_0) \geq \rho_0(c(n_{10})-c(n_0))$, $u(n_{10})-c(n_{10}) \geq u(n_0)-c(n_0)+(1-\rho_0)(c(n_0)-c(n_{10}))$. In this case, the strategy profiles $(n_{10},(c(n_{10}),a_y),(0,z_o))$ and $(n_{10},(c(n_{10}),a_y),(c(n_{10}),a_o))$ are subgame perfect and $v_w^y = v_w^o = 0$. Otherwise, the strategy profiles $(n_0,(0,z_y),(0,z_o))$, $(n_0,(c(n_0),a_y),(0,z_o))$, $(n_0,(0,z_y),(c(n_{10}),a_o))$, and $(n_0,(c(n_0),a_y),(c(n_{10}),a_o))$ are subgame perfect and $v_w^y = r_0 = 0$ and $v_w^o = c(n_{10})-c(n_0) > 0$.

Proof of proposition S.9:

Recall n_2 satisfying $k_1-c(n_2) = r_1 < 0$, whereby $n_2 > n_{10} > n^*$ because $k_1-c(n_2) = r_1 < k_1-c(n_{10}) = r_0$ and so, $c(n_{10}) < c(n_2)$. As before, denote a woman who loses her husband early and late as w_y and w_o, respectively.

First, consider the case of $n \leq n_2$. In this case, $k_1-c(n) \geq k_1-c(n_2) = r_1$. 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 $n \leq n_2$, 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in $v_c = u(n_2) - c(n_2) - r_1$. Consequently, for $n \leq n_2$, the strategy profile $(n_2, (0, z_y), (0, z_o))$ provides a clan with maximum utility $u(n_2) - c(n_2) - r_1$.

Second, consider the case of $n \geq n_2$. In this case, $k_1 - c(n) \leq k_1 - c(n_2) = r_1$. 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 $n \geq n_2$, it must be the case that $s - c(n) - h_w \geq r_1$. Then, a clan chooses $s_y = s_o = c(n) + r_1 + h_w$.

Again, consider a clan's utility obtained in the aforementioned four subcases, which becomes $u(n) - c(n) - \tau$ in Case A; $\rho_1(u(n) - c(n) - r_1 - h_w - h_c) + (1 - \rho_1)(u(n) - c(n) - \tau)$ in Case B; $\rho_1(u(n) - c(n) - \tau) + (1 - \rho_1)(u(n) - c(n) - r_1 - h_w - h_c)$ in Case C; and $u(n) - c(n) - r_1 - h_w - h_c$ in Case D. Since $\tau - r_1 < h_w + h_c$, 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* $n \geq n_2 > n^*$ and then, selects $n = n_2$ (corner solution), which results in $v_c = u(n_2) - c(n_2) - \tau$. Consequently, when $n \geq n_2$, the strategy profile $(n_2, (0, l_y), (0, l_o))$ provides a clan with maximum utility $u(n_2) - c(n_2) - \tau$.

Since $u(n_2) - c(n_2) - r_1 > u(n_2) - c(n_2) - \tau$, the strategy profile $(n_2, (0, z_y), (0, z_o))$ is subgame perfect and $v_w^y = v_w^o = r_1$.

Proof of proposition S.10:

Recall n_2 satisfying $k_1 - c(n_2) = r_1 < 0$, whereby $n_2 > n_{10} > n^*$ because $k_1 - c(n_2) = r_1 < k_1 - c(n_{10}) = r_0$ and so, $c(n_{10}) < c(n_2)$. As before, denote a woman who loses her husband early and late as w_y and w_o, respectively. Since $k_1 - c(\bar{n}) > k_1 - c(n_2) = r_1$ 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 $n \leq n_2$. In this case, $k_1 - c(n) \geq k_1 - c(n_2) = r_1$. So, w_o chooses action z_o when she rejects levirate marriage. To encourage w_o to accept levirate marriage for $n \leq n_2$, 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 $n = n_2$ (i.e., maximum in the domain of $n \leq n_2$), which results in v_c $= \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - r_1$. Consequently, for $n \leq n_2$, the strategy profile $(n_2, (0, z_y), (0, z_o))$ provides a clan with maximum utility $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - r_1$.

Second, consider the case of $n \geq n_2$. In this case, $k_1 - c(n) \leq k_1 - c(n_2) = r_1$. So, w_o chooses action l_o when she rejects levirate marriage. To encourage w_o to accept levirate marriage for $n \geq n_2$, it must be the case that $s_o - c(n) - h_w \geq r_1$. Then, a clan chooses $s_o = c(n) + r_1 + h_w$.

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; $\rho_1(u(\bar{n}) - k_1) + (1 - \rho_1)(u(n) - c(n) - r_1 - h_w - h_c)$ in Case C; and $\rho_1(u(\bar{n}) - k_1 - h_w - h_c) + (1 - \rho_1)(u(n) - c(n) - r_1 - h_w - h_c)$ in Case D. Since $\tau - r_1 < h_w + h_c$, 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* $n \geq n_2 > n^*$ and then, selects $n = n_2$ (corner solution), which results in $v_c = \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - \rho_1 r_1 - (1 - \rho_1)\tau$. Consequently, when $n \geq n_2$, the strategy profile $(n_2, (0, z_y), (0, l_o))$ provides a clan with maximum utility $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - \rho_1 r_1 - (1 - \rho_1)\tau$.

Since $\rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - r_1 > \rho_1 u(\bar{n}) + (1 - \rho_1)u(n_2) - c(n_2) - \rho_1 r_1 - (1 - \rho_1)\tau$, the strategy profile $(n_2, (0, z_y), (0, z_o))$ is subgame perfect, along with $v_w^y = k_1 - c(\bar{n}) = c(n_{10}) - c(\bar{n})$ and $v_w^o = r_1$.

(For the supplemental appendix)

References

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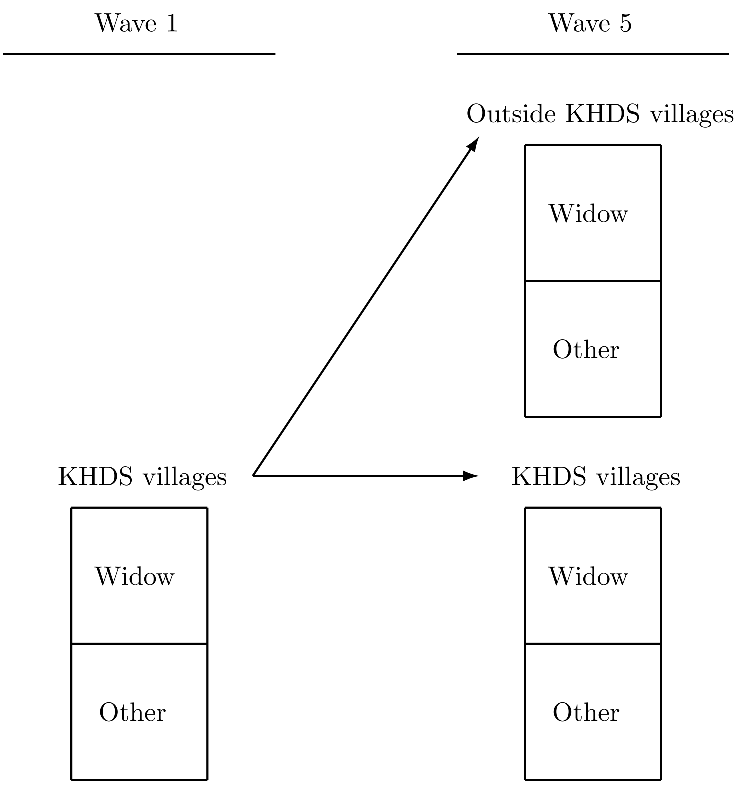
Table S.1: Parallel trend before wave 1 and a correlation between a household head and widowhood: females aged 15 to 28 years (OLS)

Sample:	Wave 1 only				Wave 1 and Wave 5		
Dependent variables:	Widow (dummy)		Log of consumption per adult equivalent (TSH)		Household head (dummy)		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Group A × Age	0.011	0.014	0.001	0.003	-	-	-
	(0.011)	(0.010)	(0.006)	(0.006)			
No levirate marriage × Widow	-	-	-	-	0.062	0.065	0.054
					(0.169)	(0.172)	(0.159)
No levirate marriage	-	-	-	-	-0.037***	-	-
					(0.014)		
Widow	-	-	-	-	0.299**	0.299*	0.255*
					(0.148)	(0.153)	(0.142)
Age (years)	0.003	-0.005	0.008***	0.008***	-	-	0.002***
	(0.006)	(0.005)	(0.003)	(0.003)			(0.001)
Education (years)	-	0.026***	-	0.002	-	-	-0.001
		(0.009)		(0.002)			(0.001)
Head's age (years)	-	-0.001	-	0.001	-	-	-0.002***
		(0.001)		(0.001)			(0.000)
Head male	-	0.066	-	-0.105***	-	-	-0.096***
		(0.084)		(0.031)			(0.016)
HH size	-	-0.038***	-	-0.001	-	-	-0.001
		(0.010)		(0.002)			(0.001)
HH land (acre)	-	0.020***	-	0.000	-	-	0.001
		(0.004)		(0.001)			(0.001)
Head's ethnicity	NO	YES	NO	YES	NO	NO	YES
Head's religion	NO	YES	NO	YES	NO	NO	YES
Village FE	YES	YES	YES	YES	YES	NO	NO
Wave FE	NO	NO	NO	NO	YES	NO	NO
Village time trend	NO	NO	NO	NO	NO	YES	YES
R-squared	0.356	0.412	0.106	0.189	0.086	0.104	0.269
No. of obs.	710	677	714	677	1770	1770	1553

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.



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

Figure S.1: Data structure and graphical representation of the identification strategy

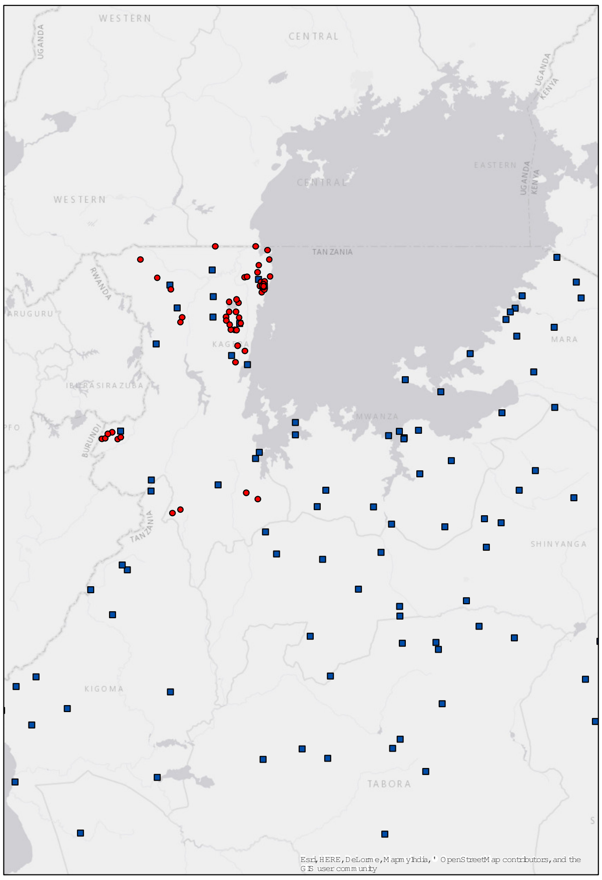


Figure S.2: Position of the KHDS (red circle) and 2003—04 THIS communities (blue square)