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

Yuya Kudo†

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Abstract

I examine whether and how HIV/AIDS leads to the deterioration of levirate marriage, which has anecdotally been viewed as an informal safety net for widows who have limited property rights. 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 declines in step with the disappearance of levirate marriage. In rural Tanzania, HIV/AIDS reduced levirate marriage and young widows' welfare while yielding a negative correlation between this institutional change and their welfare. These findings improve the understanding of the mechanisms responsible for the transformation of cultural institutions, highlighting the role of deadly infectious diseases (150 words).

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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) has been a common marital practice around the world (New World Encyclopedia, 2018). According to this practice, a widow is inherited by the brother or other male relative of her deceased husband. While the available data on its prevalence and trend is highly limited, this practice is still observed in present-day Africa (Potash, 1986; Radcliffe-Brown and Forde, 1987) such as Kenya (Agot, 2007), Nigeria (Doosuur and Arome, 2013), Sudan (Stern, 2012), Uganda (Ntozi, 1997), and Zambia (Malungo, 2001). However, prior case studies indicate that this century-old practice has recently begun to disappear because of the spread of HIV/AIDS (e.g., Malungo, 2001; Ntozi, 1997; Perry et al., 2014; see also the literature cited in Hosegood, 2009).

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

Second, in less developed societies, widows tend to comprise a significant proportion of the population because of their husbands' deaths being attributed to typical age differences between a couple. According to Potash (1986), a quarter of the adult female population is widowed in many African societies. Similar fractions of women also live in widowhood by age 55 based on Djuikom and van de Walle (2018), which analyzed data drawn from the Demographic and Health Surveys in 29 African countries. Traditionally, a widow has limited rights to the property of both her natal and husband's families. Nevertheless, owing to a customary system of exogamous and patrilocal marriage, a widow's close relatives (e.g., parents, siblings) often live outside her current residential village and, thus, cannot easily provide her with appropriate life protection. A relatively recent empirical study conducted in northern Tanzania also found that a large increase in the murder of "witches," typically elderly widowed women, is associated with their small contribution to a household's earning capacity (Miguel, 2005). Despite the evident vulnerability of widows' livelihood, their lives and survival strategies are insufficiently understood (e.g., Djuikom and van de Walle, 2018).

The present study attempts to fill these knowledge gaps by examining whether and how HIV/AIDS leads to the deterioration of levirate marriage both theoretically and empirically. To address this question, it first develops a theoretical framework wherein levirate marriage arises as a pure strategy subgame perfect equilibrium in an extensiveform game played by two agents, i.e., a widow and her husband's clan. This model assumes 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. The 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. Additionally, 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 (e.g., Dilger, 2006). Therefore, a husband's clan has a strong incentive to avoid this practice. Moreover, 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.[1]

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 third findings, and assessment of the importance of unobservables for the third finding (Oster, forthcoming). To shield young widows from HIV/AIDS, they may need social protection that increases their reservation payoffs (e.g., formal insurance, access to income-generating opportunities).

In prior qualitative studies including Lugalla et al. (2004) focusing on Kagera, it has already been observed that HIV/AIDS discourages levirate marriage. However, its mechanism and consequences on widows' welfare have not necessarily been clearly explained. The present study is the first endeavor to theoretically formalize and empirically

[1]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).

test them. Moreover, the developed theoretical model also provides a framework for thinking about whether and how the governmental intervention (e.g., formal insurance, property rights) as well as HIV/AIDS crowds out the informal insurance and affects widows' and social welfare. For example, simply making it possible for a widow to inherit her husband's property may discourage levirate marriage "without" increasing her welfare because a husband's clan consequently encourages her to have more children (Kudo, 2018). Additionally, it can reduce the clan's utility (so, the total welfare enjoyed by a clan and widows) because the amount of a husband's property increasingly bequeathed to widows is seen as a constraint which prevents a clan from choosing the desired number of children.[2]

This study also contributes to a rapidly growing body of economic research on culture and institutions (e.g., Alesina et al., 2013; Galor and Özak, 2016; Lowes et al., 2017; see also the literature cited in Alesina and Giuliano, 2015), particularly to studies examining the economic rationality of apparent anti-social marriage-related practices, such as dowry/bridewealth payments (e.g., Anderson and Bidner, 2015; Botticini and Siow, 2003), bride exchange (Jacoby and Mansuri, 2010), and polygyny (e.g., Jacoby, 1995; Tertilt, 2005).

The yielded findings would improve the general understanding of the conditions that facilitate the transformation of cultural institutions (e.g., Anderson, 2003; de la Croix and Mariani, 2015; Gould et al., 2008). Previous studies indicate that "positive" socioeconomic shocks (e.g., English-education or 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 groups' (e.g., widows') welfare.

The present study also encourages discussion of public policy relevant to widows' livelihood, which has surprisingly been given little attention on the development agenda compared with debates about "child" and "old-age" protection (e.g., Djuikom and van de Walle, 2018). It examines widows' informal insurance (e.g., Lambert and Rossi, 2016) and welfare (e.g., Chapoto et al., 2011; Milazzo and van de Walle, 2018; van de Walle, 2013). Further, it also relates to studies examining the impact of HIV/AIDS on fertility (e.g., Kalemli-Ozcan and Turan, 2011; Young, 2005).

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

[2] In contrast, raising widows' reservation payoffs increases this total welfare while discouraging levirate marriage (Kudo, 2018). From the perspective of the total and widows' welfare, therefore, empowering women "outside" a husband's clan (e.g., inherit parents' property, formal insurance, income-generating opportunities) may be preferred rather than doing so "within" it (e.g., inherit a husband's property) at least in the short term if the required policy cost is the same and the necessary budget is limited. However, since the greater value of the outside option increases women's bargaining power within a husband's family, it may make them less attractive in marriage markets and thus, the long-term welfare consequences of such policy prescriptions may be ambiguous (e.g., Anderson and Bidner, 2015).

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

Previous 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), Tanzania (e.g., Lugalla et al., 2004), 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.[3] The Luo is an ethnic group that has received much publicity for its practice of levirate marriage. In this survey, 80% (resp., 83%) of the interviewed females and 84% (90%) of their husbands "strongly agreed" (or "agreed") to the view that levirate marriage increased the risk of people being infected with HIV, respectively. Similarly, according to 4,500 interviews that Doosuur and Arome (2013) conducted in Benue state of Nigeria, more men than women perceived the practice of levirate marriage as a mode of HIV transmission. In Lugalla et al. (2004), which is most closely related to the present research, they conducted qualitative interviews in Bukoba, the regional capital of the Kagera region, and indicated that levirate marriage has declined as a result of HIV/AIDS.

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).

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

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 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 sketches a game-theoretic model that explains how HIV/AIDS prompts the deterioration of levirate marriage. Its formal demonstration is relegated to Section S.1 in the supplemental appendix. While the picture should not be over-simplified, the model builds upon several features of family relationships widely observed in sub-Saharan Africa, as noted in Caldwell and Caldwell (1987) and elsewhere (e.g., Tertilt, 2005). First, societies are often patrilineal; succession is passed down the male line.[4] Daughters, customarily, do not inherit their parents' property, and almost all females that reach marriageable age as determined by their respective societies, enter into

[4] Admittedly, matrilineal ethnic groups still exist (e.g., Malawi).

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) and an extended family of her deceased husband, called here a "clan." The sequence of actions taken by both agents is as follows. First, after marriage, a husband's clan (particularly, male members) chooses the number of children 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. Notably, this assumption does not necessarily mean that women have no control over fertility. In the present model, they do have by choosing the level of effort, which is unobserved by a husband's clan, to produce children during marriage (e.g., Ashraf et al., 2014). Such effort increases the probability of childbirth. After the husband's death, the clan chooses the amount of livelihood support 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 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, she has two choices. First, she can formally inherit her husband's property and live with her children. Else, she can leave her husband's home.

If the offered levirate marriage is accepted, the clan obtains positive utility by maintaining children of the deceased within its extended family. However, this utility can be achieved in exchange of (endogenously determined) material support (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. In case of the rejection or absence of the offered levirate marriage, a widow receives exogenously determined reservation utility when she leaves her husband's home. For instance, she may receive this reservation utility by remarrying or inheriting her parents' property. A widow can leave either with or without her children. If a widow leaves with her children, she incurs the child-rearing cost. 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. 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 transferred from a husband's clan to her (and measured by transferable utility), which enables her to be self-sufficient. For example, in a traditional society that does not allow a widow to inherit property of the deceased, this amount is expected to be zero.

3.1 Levirate marriage equilibrium

Assume that widows have limited independent livelihood means (i.e., negligible reservation utility). Additionally, widows' rights to inherit a husband's property are also highly limited. In this case, levirate marriage arises as a subgame perfect equilibrium. 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.

While a widow receives material support from her husband's clan by agreeing to a levirate marriage, its amount may not necessarily be large. This finding would be particularly salient in traditional agrarian societies, whereby women are expected to have limited power to control fertility and/or women's access to family planning methods are limited. In fact, this situation may not be implausible during the analyzed periods in Tanzania. For example, despite considerable increases in the use of injectables and pills for the period of 1991—2004, the respective prevalence rates in Tanzania 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).

In this particular case, a widow achieves equilibrium welfare equivalent to her reservation utility. Ethnographic studies (e.g., Doosuur and Arome, 2013; Luke, 2002; Nyanzi et al., 2009) show that material support provided by inheritors is typically minimal, because the inheritors normally have to take care of their wives and children at their original home in addition to the widows who continue to reside at their deceased husband's home (e.g., Ndisi, 1974). Thus, the model prediction is consistent with this finding.[5]

3.2 HIV/AIDS as an agent of institutional change

HIV/AIDS alters the underlying theoretical parameters from four perspectives, which are primarily 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,

[5]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.

an inheritor's wife) may contract HIV/AIDS. Additionally, 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 risks can be treated as additional costs (of both the clan and widows) needed to sustain levirate marriage.

In theory, a clan's members may avoid having such sexual intercourse with a likely HIV-positive widow even if they inherit her; however, levriate marriage typically follows sexual cleansing, as explained in Section 2. This cleansing cannot be separated from levirate marriage in traditional societies. Additionally, 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. Thus, a clan inheriting HIV-positive widows would have to increase the amount of livelihood support, which makes levirate marriage more costly to the clan even if sexual intercourse is avoided (e.g., Dilger, 2006).

Second, as described in Section 2, HIV/AIDS may also establish widows' de facto property rights; 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, for example (e.g., Goldstein and Udry, 2008).

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.

Fourth, HIV/AIDS may also increase women's expected gain arising from making fertility effort relative to its cost because in the present model, such effort is presumed to increase the probability of childbirth, which in turn decreases the probability that a woman has to leave her husband's home after his death (e.g., Hoddinott, 1992; Rwebangira, 1996).

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.[6][7] First, a clan becomes reluctant to offer levirate marriage as the corresponding expected infection risk 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 of her expected infection risk, which further discourages a clan from continuing this practice. Third, securing a widow's right to inherit her husband's property increases her utility obtained outside a levirate marriage. To encourage such widows to remain in this traditional marriage, a clan must also increase the amount of material

[6] In contrast, the infection costs of HIV/AIDS do not necessarily make widows avoid levirate marriage. First, the infection risk of a husband's clan does not affect a widow's decision to accept levirate marriage. Second, a widow still has an incentive to follow levirate marriage as long as her husband's clan compensates for her infection risk by increasing the material support given to her.

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

support, which makes this practice costly.

The disappearance of levirate marriage coincides with a decrease in widows' welfare. Intuitively, 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, her welfare declines in step with the deterioration of levirate marriage. The number of children is also likely to increase. First, increases in the amount of a husband's property bequeathed to widows allow them to afford many children. Accordingly, a clan attempts to increase its number. Additionally, women's widowhood security concern also contributes to this fertility increase. However, this fertility response depends upon whether and how strongly these two factors play a role. For example, when a widow's reservation payoffs decline with no changes in the bequest amount and her expected gain arising from making fertility effort, another equilibrium may arise. In this equilibrium, the number of children remains unchanged, and a widow may leave her husband's home while again receiving lower utility than before (Kudo, 2018). Therefore, compared to that of fertility, the empirical exploration of widows' welfare is more useful to explore the role of HIV/AIDS in discouraging levirate marriage.

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. 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 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.[8] 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 Young cohort as a primary sample

This study primarily focuses on the sample females aged 15 to 28 years because HIV/AIDS primarily increased prime-age adult mortality in Kagera (e.g., 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). Since women tend to be younger than their husbands, therefore, young married women seem to have more severely suffered from HIV/AIDS-induced deaths of their husbands than elderly ones, at least during the analyzed periods in the present context. Table 1 provides summary statistics pertaining to this young cohort for the wave 1 [panel (A)] and wave 5 [panel (B)] surveys.

[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 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

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

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. Additionally, 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 et al., 2008).[9] 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. Exploiting this information, this study creates a time-varying indicator, called "HIV/AIDS indicator" hereinafter, for villages that referred to HIV/AIDS as the most or second-most important health problem in a community. The number of villages that admitted this health problem increased from 18 in wave 1 to 32 in wave 5.

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 comprehensive survey carried out on HIV/AIDS in Tanzania from December 2003 to March 2004,[10] whereas Killewo et al. (1990) estimated the district-level infection rate based on a population-based survey conducted in Kagera in 1987. The estimates provided by two "independent" data sources are not temporally comparable due to the methodological differences, 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 know the "trend" of HIV/AIDS based on these estimates as well as to use them in a rigorous empirical analysis directly. Nevertheless, these estimates are still useful to assess the accuracy of the HIV/AIDS indicator (i.e., "level") in each wave of the KHDS.

[9] 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).

[10] 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.

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.3 in the supplemental appendix for the position of the KHDS and THIS communities).[11] Second, the district-level values of the infection rate reported in Killewo et al. (1990) were also assigned to each KHDS community.

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 this indicator's utilization in the empirical analysis that follows.

[Here, Table 2]

4.4 Measurement of marital status

This study also 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, household members in the KHDS are defined as including "all people who normally sleep and eat their meals together in the household during at least three of the twelve months preceding the interview." 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 5). Additionally, an inherited widow does not share a household budget with her inheritor's family when purchasing food and other items. Therefore, the enumerators are likely to have identified females in levirate marriage as "widowed" in the survey. Nevertheless, this study will return to this issue in subsection 5.2.2.

5 Empirical findings

This section demonstrates three pieces of empirical evidence that is consistent with the HIV/AIDS-induced deterioration of levirate marriage: a negative impact of HIV/AIDS on levirate marriage (subsection 5.1), a negative correlation

[11] 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.

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 wave 1 and wave 5, this study examined the impact of the aforementioned HIV/AIDS indicator on the village-level prevalence of levirate marriage (i.e., D_{jt}) at the bottom panel of Table 2. Importantly, levirate marriage is often blamed for facilitating the sexual transmission of HIV/AIDS (e.g., Malungo, 2001; Okeyo and Allen, 1994). Therefore, to address this reverse causality, this study used as an instrumental variable an indicator for communities to which temporal migrants come to find jobs from Uganda located immediately to the north of Kagera, and conducted two-stage least-squares (2SLS) estimations. The first- and second-stage estimation results are reported in columns (g) and (h), respectively. Since this job-related in-migration dummy, although the relevant information is available from each wave, had little time-variation within a village, these estimations excluded the village-fixed effects to avoid multicollinearity (and computational difficulty).

Two reasons explain the choice of this instrument. First, 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 (see the literature cited in Oster, 2012). Second, however, because they are "temporary," they do not directly enter into levirate marriage. One concern for this instrument 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. Additionally, widows who avoided levirate marriage might also have migrated into urban centers because jobs are available. To mitigate these concerns, the 2SLS estimations were performed with a control of an indicator for communities located in urban areas (although excluding this urban control did not alter the obtained implications).

As the results show, the in-migration dummy significantly increased the prevalence of HIV/AIDS, which discouraged the practice of leviratte marriage. The instrument is strong as seen from the F-statistics of the first-stage estimations, reported at the bottom of this table. In column (i), this study additionally controlled for the interaction term of the urban indicator with the wave 5 dummy, which controls for the time-varying urban effects. It further controlled for age, years of living in a village, and gender of the person responsible for providing information on customary practices in community surveys, which may mitigate concerns over the potential noise in the measured levirate marriage. HIV/AIDS is still responsible for the disappearance of levirate marriage.

For the sake of comparison, the corresponding ordinary least-squares (OLS) estimate was reported in column (j). It is smaller than the 2SLS estimates. This finding is plausible because in the OLS, the aforementioned reverse causality might have attenuated the discouraging effect of HIV/AIDS on levirate marriage. Additionally, this study also estimated a reduced-form equation of levirate marriage with respect to the in-migration and urban dummies in column (k). The job-related in-migration significantly discouraged levirate marriage, however, the magnitude of the estimate declines and its statistical significance disappears once the HIV/AIDS indicator is additionally controlled for in column (l). Admittedly, the last exercise is a rough test of the overidentification restriction, as done elsewhere (e.g., Fenske, 2014, p. 637). Nevertheless, these findings still suggest that the in-migration discouraged levirate marriage only through its influence on HIV/AIDS, which may support 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 widows' welfare (recall Section 3). In this subsection, it is attempted to verify this negative "correlation." However, exploring a simple correlation is not useful because it is attributable to many confounding factors. Thus, 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.

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

$$y_{ijt} = \alpha_1 + \alpha_2 D_{jt} \cdot w_{ijt} + \alpha_3 w_{ijt} + \alpha_4 \mathbf{x_{ijt}} + v_{jt} + \epsilon_{ijt}, \tag{1}$$

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 time-varying village effects v_{jt} subsume the level effects of D_{jt}. 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.[12] Additionally, unlike the wave 5 survey, an effort to trace the wave 1 respondents appears to be limited in the wave 2 to 4 surveys. Therefore, following Beegle et al. (2011), this study uses wave 1 as baseline data to minimize potential influence arising from the sample attrition. 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 (1) compares changes in women's consumption from wave 1 to wave 5 between villages where levirate marriage grew less customary during the sample periods (16 villages) and all other villages. 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.[13] 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}).

The above empirical approach exploits the the KHDS 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) and allows the current study to exploit data variations fully. 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

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

[13] 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.

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 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. These checks, though not sufficient, may 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 (recall subsection 4.1), 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 1 (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 in columns (d) through (i) in Table 3. 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,[14] 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).

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

[14]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 deterioration of levirate marriage in that village. In this case, such migrants should be included in the estimated sample; for such migrants in wave 5, D_{jt} reflects the situation in their original villages. See also Section S.3 in the supplemental appendix.

number of people who died in the past 12 month in each KHDS village divided by its village population.[15]

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., Baez, 2011; Jean-François and Verwimp, 2014). The analysis in column (f) controlled for the (time-invariant) number of refugee camps established within a 25 km radius from each KHDS village during the relevant time frames.[16]

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 (1) in columns (h) and (i). The significantly negative correlation between the disappearance of levirate marriage and young widows' welfare still existed in all these exercises.

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 young widows' welfare is more clearly observed in villages more severely affected by HIV/AIDS from 1991 (wave 1) to 2004 (wave 5).

In columns (c) to (f) in Table 4, this study also estimated as an alternative welfare measure an indicator of one if the respondents' body mass index (BMI) belongs to its normal range between 18.5 and 25 (e.g., Milazzo and van de Walle, 2018). Similar to previous findings, only young widows' BMI is negatively associated with the disappearance of levirate marriage, and this tendency is more pronounced in the HIV/AIDS-affected villages. Estimating in columns (g) and (h) an indicator for BMI less than 18.5, which may reflect undernourishment, also yielded a similar implication.

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. In contrast, in villages where levirate marriage

[15]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, the number was assumed to take the value of the sample average.

[16]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.

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 1]

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 (1) with the HIV/AIDS indicator in the respective wave (which again means triple difference), the impacts of HIV/AIDS on widows' welfare are investigated in Table 5. Importantly, this study does not claim that only the proposed mechanism links HIV/AIDS to widows' welfare. However, together with the findings reported in previous subsections, it may be difficult to consider that this mechanism does not play a role at all if the coefficients reveal the expected sign.

As the result in column (a) shows, HIV/AIDS reduced the consumption of widows aged 15 to 28. This effect is less clearly observed for the elderly cohort (29—50), as seen in column (b). Estimating the aforementioned BMI indicators in columns (c) to (f) also yielded a similar implication. However, the estimates' statistical significance is marginal. Unlike the information on D_{jt} that was recalled by a group of village leaders in the wave 5 survey, the community-level information pertaining to HIV/AIDS was available in every wave of the KHDS. Therefore, in columns (g) and (h), the relevant observations recorded in all the five waves were alternatively exploited to increase the power of the statistical test. The negative impacts on young widows' consumption are found with strong statistical significance.

Taking a similar approach to that for the estimations performed in the left-hand panel of Figure 1, 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. In this figure, the full sample drawn from all the five waves was exploited. As the results demonstrate, HIV/AIDS significantly reduced the consumption of young widows. This finding is consistent with the fact that the negative correlation between institutional change and widows' welfare is more clearly observed for young widows. As discussed in subsection 4.1, the influence of HIV/AIDS was apparently less pronounced for elderly (married) women during the analyzed periods in Kagera. Therefore, the absences of the significant correlation (left-hand panel) and of the reduced-form impact (right-hand panel) for the elderly cohort may be seen as a result of the relevant falsification test.

However, the estimation results exploiting the full sample may more seriously suffer from the sample attrition that existed in the wave 2 to 4 surveys (as well as the wave 5 survey). Particularly, if HIV/AIDS-induced deaths (so, sample attrition) begin with poor widows, the negative impact on widows' welfare would be biased upward. Further, this upward bias may also occur 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. Therefore, following Oster (forthcoming), this study estimated and reported a coefficient of proportionality on selection assumptions at the bottom of Table 5, as denoted as δ, for the coefficients on the interaction term between a widow dummy and the HIV/AIDS indicator.[17] The reported negative δ values indicate that the aforementioned HIV/AIDS impacts appear to be attenuated if any causality bias exists.

[Here, Table 5]

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 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.

Notably, female empowerment as a source of improved women's property rights (e.g., increases in the amount of bequest provided by the deceased husband or own parents) can also make levirate marriage obsolete (Kudo, 2018). In this mechanism, however, widows' welfare does "not" decline in step with this institutional change. This mechanism also appears to be inconsistent with the swift transformation of levirate marriage; in the KHDS data, this centuries-

[17]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.

long practice has started to disappear only during the past 20 years. 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, according to Greif and Iyigun (2013), "social institutions are ... all but absent from our analyses of economic growth and development." Additionally, 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. Together, the findings of this study may still provide a valuable lesson applicable in other development settings, particularly when considering the vulnerability or resistance of non-market institutions to deadly communicable diseases.

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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
Normal BMI (dummy)	0.73	0.44	629	0.75	0.43	937	-0.009	0.045	1566
BMI < 18.5 (dummy)	0.16	0.37	629	0.14	0.35	937	0.042	0.040	1566
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

Note: 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). *** denotes significance at 1%. Standard errors are robust to heteroskedasticity and clustered residuals within each village.

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:	HIV/AIDS indicator	No levirate marriage	No levirate marriage	No levirate marriage	No levirate marriage	No levirate marriage
	OLS	2SLS	2SLS	OLS	OLS	OLS
	(g)	(h)	(i)	(j)	(k)	(l)
HIV/AIDS indicator (KHDS)	-	0.419***	0.410**	0.154**	-	0.147**
		(0.124)	(0.184)	(0.071)		(0.073)
Temporary job in-migration from Uganda (indicator)	0.551***	-	-	-	0.231**	0.150
	(0.120)				(0.111)	(0.102)
Urban village (indicator)	0.142	0.080	0.073	0.114	0.140*	0.119
	(0.127)	(0.096)	(0.155)	(0.077)	(0.075)	(0.077)
Urban village × Wave 5	-	-	0.022	-	-	-
			(0.197)			
Wave FE	YES	YES	YES	YES	YES	YES
Village leader characteristics	NO	NO	YES	NO	NO	NO
F-statistics of the 1st stage	-	21.12	22.35	-	-	-
R-squared	0.110	0.072	0.126	0.173	0.145	0.176
No. of villages	102	102	100	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 in columns (a) to (e) and further clustered residuals within each village in columns (f) to (l). (3) A village leader's characteristics include age, years of living in a village, and gender of the person responsible for providing information on customary practices in community surveys.

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 alternative welfare measures (OLS)

Dependent variables:	Log of consumption per adult equivalent (TSH)		One if normal BMI				One if BMI < 18.5	
Sample:	Aged 15 to 28		Aged 15 to 28	Aged 29 to 50	Aged 15 to 28		Aged 15 to 28	
	Δ HIV/AIDS indicator				Δ HIV/AIDS indicator		Δ HIV/AIDS indicator	
	Positive	Non-positive			Positive	Non-positive	Positive	Non-positive
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Widow								
× No levirate marriage	-1.294***	-0.205	-0.240**	0.047	-0.457***	-0.153	0.268**	0.153
	(0.230)	(0.148)	(0.102)	(0.095)	(0.139)	(0.111)	(0.121)	(0.129)
Widow	0.825***	0.151*	0.180***	-0.055	0.266***	0.171**	-0.108*	-0.060
	(0.083)	(0.083)	(0.062)	(0.088)	(0.087)	(0.073)	(0.059)	(0.068)
Age (years)	0.002	0.005	0.017***	-0.008***	0.021**	0.015***	-0.030***	-0.022***
	(0.007)	(0.004)	(0.004)	(0.003)	(0.007)	(0.005)	(0.005)	(0.003)
Education (years)	0.034***	0.033***	0.010**	-0.015**	0.015	0.008	-0.019***	-0.013***
	(0.007)	(0.006)	(0.005)	(0.006)	(0.009)	(0.006)	(0.005)	(0.005)
Head's age (years)	-0.003	-0.001	-0.000	-0.001	0.002	-0.001	-0.001	0.001
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Head male	0.125	0.129**	-0.002	0.045	0.014	-0.014	0.038	0.006
	(0.072)	(0.060)	(0.028)	(0.042)	(0.042)	(0.037)	(0.033)	(0.033)
HH size	-0.033**	-0.047***	0.003	0.000	-0.001	0.004	0.002	-0.006*
	(0.013)	(0.008)	(0.003)	(0.006)	(0.007)	(0.004)	(0.008)	(0.003)
HH land (acre)	0.020*	0.017***	-0.007*	0.000	-0.008	-0.006	-0.000	0.005
	(0.010)	(0.004)	(0.004)	(0.003)	(0.007)	(0.004)	(0.006)	(0.003)
Head's ethnicity	YES	YES	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES	YES	YES
Village time trend	YES	YES	YES	YES	YES	YES	YES	YES
R-squared	0.353	0.406	0.123	0.177	0.110	0.136	0.174	0.222
No. of women	520	1033	1398	993	462	936	462	936

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

Table 5: Reduced-form impacts of HIV/AIDS (OLS)

Dependent variable:	Log of consumption per adult equivalent (TSH)		One if normal BMI		One if BMI < 18.5		Log of consumption per adult equivalent (TSH)	
Sample:	Wave 1 and Wave 5		Wave 1 and Wave 5		Wave 1 and Wave 5		All waves	
	Aged 15 to 28	Aged 29 to 50	Aged 15 to 28	Aged 29 to 50	Aged 15 to 28	Aged 29 to 50	Aged 15 to 28	Aged 29 to 50
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Widow								
× HIV/AIDS indicator	-0.184	-0.017	-0.123	0.075	0.187*	-0.098	-0.353***	0.024
	(0.201)	(0.091)	(0.144)	(0.100)	(0.108)	(0.082)	(0.101)	(0.057)
Widow	0.000	-0.123*	0.089	-0.050	-0.060	0.134**	0.082	-0.167***
	(0.176)	(0.067)	(0.107)	(0.078)	(0.057)	(0.063)	(0.077)	(0.058)
Age (years)	0.004	0.004	0.017***	-0.008***	-0.025***	0.005**	0.006***	0.005*
	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)
Education (years)	0.034***	0.035***	0.010**	-0.015***	-0.015***	-0.000	0.033***	0.038***
	(0.005)	(0.007)	(0.005)	(0.005)	(0.003)	(0.004)	(0.004)	(0.006)
Head's age (years)	-0.002	-0.001	-0.000	-0.001	0.001	0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head male	0.122**	0.101*	-0.003	0.044	0.020	0.003	0.110***	0.082
	(0.046)	(0.051)	(0.028)	(0.043)	(0.024)	(0.027)	(0.037)	(0.051)
HH size	-0.044***	-0.053***	0.003	0.000	-0.004	-0.007	-0.039***	-0.051***
	(0.007)	(0.008)	(0.003)	(0.006)	(0.003)	(0.004)	(0.004)	(0.006)
HH land (acre)	0.019***	0.021***	-0.007*	0.000	0.003	-0.003	0.001*	0.025***
	(0.004)	(0.005)	(0.004)	(0.003)	(0.003)	(0.002)	(0.000)	(0.003)
Head's ethnicity	YES	YES	YES	YES	YES	YES	YES	YES
Head's religion	YES	YES	YES	YES	YES	YES	YES	YES
Village time trend	YES	YES	YES	YES	YES	YES	YES	YES
Oster (forthcoming)'s δ								
(1) $R_{max} = 1.3\tilde{R}$	-1.139	-	-4.248	-	-3.553	-	-10.859	-
(2) $R_{max} = 1.0$	-0.209	-	-0.176	-	-0.268	-	-2.033	-
R-squared	0.380	0.403	0.122	0.178	0.199	0.184	0.382	0.423
No. of women	1553	1063	1398	993	1398	993	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.

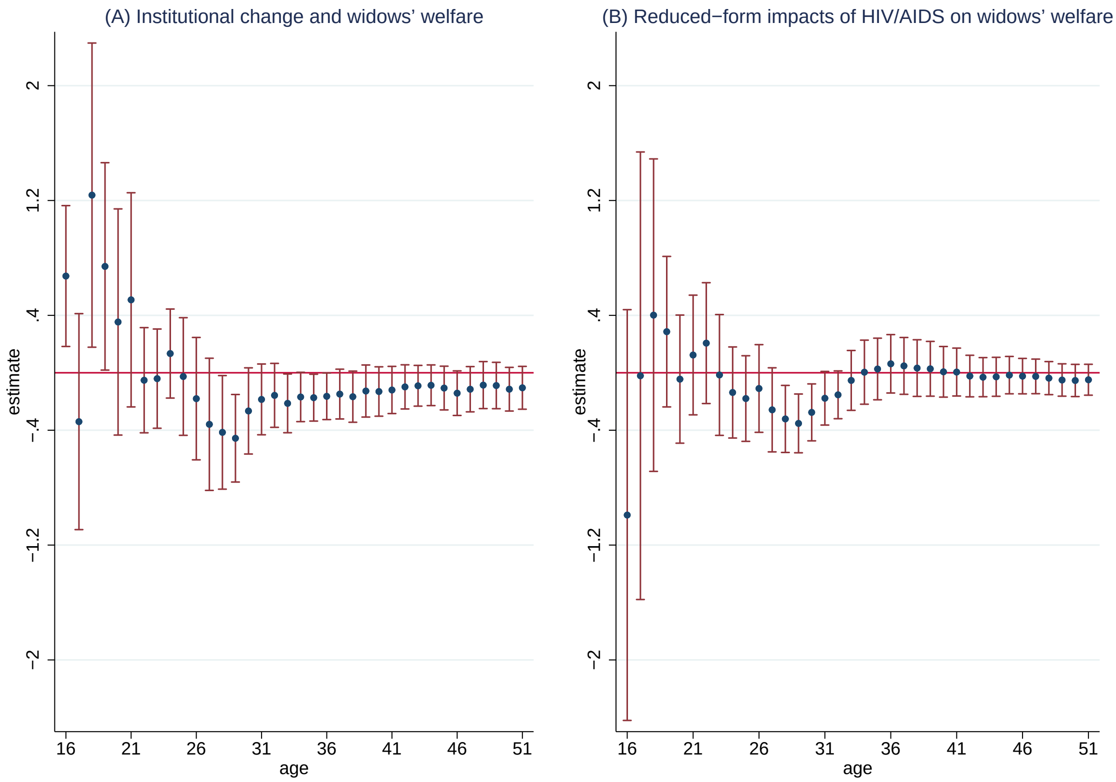

Figure 1: Age heterogeneity, consumption per adult equivalent (OLS)

Notes: (1) Panel (A) reports the estimated α_2 in equation (1) with 95% confidence intervals by changing the exploited sample by the respondents' age. (2) After replacing D_{jt} in equation (1) with an HIV/AIDS 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 $m-1$. (4) Standard errors are robust to heteroskedasticity and clustered residuals within each village.

Supplemental appendix

S.1 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 often patrilineal; succession is passed down the male line.[18] 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 S.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. Notably, this assumption does not necessarily mean that women have no control over fertility. In the present model, during marriage, a woman can either expend effort e, which is unobserved by a husband's clan, to produce children or not (e.g., Ashraf et al., 2014). 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 $d > 0$. Therefore, women can also affect the number of children by choosing the level of this effort. 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

[18] Admittedly, matrilineal ethnic groups still exist (e.g., Malawi).

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 $c(0) = 0$.[19] 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:

$$
\begin{aligned}
v_c(n, s, \bar{e}, a) &= u(n) - s, && \text{(S.1.1)}\\
v_c(n, s, \underline{e}, a) &= q(u(n) - s), && \text{(S.1.2)}\\
v_w(n, s, \bar{e}, a) &= s - c(n) - d, && \text{(S.1.3)}\\
v_w(n, s, \underline{e}, a) &= q(s - c(n)) + (1-q)r, && \text{(S.1.4)}\\
v_c(n, s, \bar{e}, l) &= u(n) - c(n) - \tau, && \text{(S.1.5)}\\
v_c(n, s, \underline{e}, l) &= q(u(n) - c(n) - \tau), && \text{(S.1.6)}\\
v_w(n, s, \bar{e}, l) &= r - d, && \text{(S.1.7)}\\
v_w(n, s, \underline{e}, l) &= r, && \text{(S.1.8)}\\
v_c(n, s, \bar{e}, z) &= u(n) - k, && \text{(S.1.9)}\\
v_c(n, s, \underline{e}, z) &= q(u(n) - k), && \text{(S.1.10)}\\
v_w(n, s, \bar{e}, z) &= k - c(n) - d, && \text{(S.1.11)}\\
v_w(n, s, \underline{e}, z) &= q(k - c(n)) + (1-q)r. && \text{(S.1.12)}
\end{aligned}
$$

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

In case of the rejection or absence of the offered levirate marriage, a widow receives exogenously determined

[19] 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.

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.[20] 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.[21]

Notably, in the present model, widows' reservation utility does not depend upon the number of children. Given this assumption, a widow 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 $v_w(n, s, \bar{e}, l) = r - d$. This assumption generating this consequence appears to be contrary to women's old-age security motive for fertility (e.g., Hoddinott, 1992). However, this assumption does not necessarily mean that a widow prefers to leave alone rather than to stay with children in general (e.g., action a, action z). Additionally, this assumption also does not prevent this benchmark model from analyzing the influence of HIV/AIDS on women's widowhood security motive for fertility, as explained in subsection S.1.2. Therefore, it is made to illustrate the model's nature of the forces at work in a simpler way. Nevertheless, this assumption is relaxed in the extended model, as analyzed in subsection S.2.3.[22]

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

In the real world, widows who leave alone may emotionally suffer from separation from children.[23] Similarly, community members may impose the cost on widows not following the traditional custom of levirate marriage. Further, a widow leaving her husband's home would also incur the relocation cost. These additional costs are disregarded in

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

[21]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.

[22]However, the extended model allowed widows' reservation utility to depend upon the number of children only after assuming that women have no control over fertility; notably, unifying these two perspectives into a single framework results in specifying sixteen different payoffs, and doing so requires much more algebra without altering the main theoretical implications. Additionally, different people tend to see different values and limitations in the model. For example, in Kudo (2018), women's fertility effort was considered only in the extended model, but the present manuscript incorporated this perspective in the main framework because one may disagree with the assumption that women have no control over fertility. In contrast, this assumption may be acceptable by others, but they may instead see it important to consider the influence of HIV/AIDS on the probability of a husband's death in the benchmark model (see subsection S.2.2). Since addressing all potential perspectives simultaneously in a single model not only makes it mathematically less tractable (without producing a significant gain) but also makes its key mechanisms difficult to understand, this study decided to select the present assumptions after pondering over the best choice of them.

[23]However, a widow's separation from her own children is not uncommon in rural Africa. Additionally, women may not suffer much emotionally from leaving alone. For example, widows 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).

the present model because they only reduce widows' reservation utility and thus, inclusion of them does not change the model's implications.

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 her to be self-sufficient. For example, in a traditional society that does not allow a widow to inherit property of the deceased, this amount is expected to be zero. These yield the payoff profiles $v_c(n, s, \bar{e}, z) = u(n) - k$ and $v_w(n, s, \bar{e}, z) = k - c(n) - d$.

Regardless of whether the taken action is 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 $v_c(n, s, \underline{e}, l) = q(u(n) - c(n) - \tau)$.

S.1.1 Levirate marriage equilibrium

Assume that widows have limited independent livelihood means such that $r = r_0 = 0$. Additionally, widows' rights to inherit a husband's property are also highly limited in the sense that $k = k_0 \leq c(n^*)$, whereby n^* satisfies $u'(n^*) = c'(n^*)$. Further, $d = d_0$. Then, it is easy to verify that

Proposition S.1 *Assume that $r = r_0 = 0$, $k = k_0 \leq c(n^*)$, and $d = d_0$. Then, when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d_0}{1-q}$, the strategy profile $(n^*, c(n^*) + \frac{d_0}{1-q}, \bar{e}, a)$ is subgame perfect, along with the equilibrium number of children n^* and a widow's payoff $\frac{qd_0}{1-q}$. When $(1-q)(u(n^*) - c(n^*)) < \frac{d_0}{1-q}$, 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 $r_0 = 0$.*

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.

The $\frac{d_0}{1-q}$ is an incentive cost needed for a clan to encourage a woman's fertility effort. When a clan decides to prompt a woman's fertility effort (i.e., "effort equilibrium"), she obtains a payoff greater than her reservation utility by an amount of (net) information rent, $\frac{qd_0}{1-q} = \frac{d_0}{1-q} - d_0$. 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). Both these factors generate a large incentive cost.[24] As a result, the "no-effort equilibrium" $(n^*, c(n^*), \underline{e}, a)$ is

[24] 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.

more likely to arise in such societies than the effort equilibrium. In fact, this situation may not be implausible during the analyzed periods in Tanzania. For example, despite considerable increases in the use of injectables and pills for the period of 1991—2004, the respective prevalence rates in Tanzania 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).

In this no-effort equilibrium, a widow receives material support (i.e., $s = c(n^*)$) from her husband's clan by agreeing to a levirate marriage. As the equilibrium payoffs indicate, however, this amount is not necessarily large. Ethnographic studies (e.g., Doosuur and Arome, 2013; Luke, 2002; Nyanzi et al., 2009) show that material support provided by inheritors is typically minimal, because the inheritors normally have to take care of their wives and children at their original home in addition to the widows who continue to reside at their deceased husband's home (e.g., Ndisi, 1974). Thus, the model prediction may be consistent with this finding.[25] 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., $c(n) < c(n) + \tau$.

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

HIV/AIDS alters the underlying theoretical parameters from four perspectives, which are primarily 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. Additionally, 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, a clan's members may avoid having such sexual intercourse with a likely HIV-positive widow even if they inherit her; however, levriate marriage typically follows sexual cleansing, as explained in Section 2. This cleansing cannot be separated from levirate marriage 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

[25] 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.

have to increase the amount of livelihood support s, which makes levirate marriage more costly to the clan even if sexual intercourse is avoided (e.g., Dilger, 2006).

Second, as described in Section 2, 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.[26]

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

Fourth, HIV/AIDS may also increase women's expected gain arising from making fertility effort relative to its cost $\frac{1-q}{d}$ because in the present model, such effort is presumed to increase the probability of childbirth (from q to 1), which in turn decreases the probability that a woman has to leave her husband's home after his death (e.g., Hoddinott, 1992; Rwebangira, 1996). One simple way to include this possibility in the model is to assume that women's perceived cost of fertility effort declines from d_0 to $d_1 \approx 0$. Consequently,

Proposition S.2 *Assume that* $r = r_1 < 0$, $k = k_1 > c(n^*)$, $d = d_1 \approx 0 < d_0$ *(consequently,* $\frac{d_1}{1-q} + r_1 < k_1 - c(n^*) < k_1$ *and so,* $n^* < n_1 < n_2$*), and the disease cost is high enough such that* $\tau - r_1 < h_c + h_w \approx \infty$*. Then, 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, along with the equilibrium number of children* $n_1 > n^*$ *and a widow's payoff* $r_1 + \frac{qd_1}{1-q} \approx r_1 < 0$*. When* $u(n_2) - k_1 \leq \frac{u(n_2)-u(n_1)}{1-q}$*, 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* $r_1 < 0$*.*

Here, n_1 and n_2 satisfy $k_1 - c(n_1) = \frac{d_1}{1-q} + r_1$ and $k_1 - c(n_2) = r_1$.[27]

As a result of HIV/AIDS, levirate marriage disappears and a widow makes a living with her children by inheriting her husband's property. Notably, the small d_1 raises the level of n_1 by construction, thereby making $u(n_2) - u(n_1)$ small owing to concavity of a clan's utility function. Since this small difference between $u(n_1)$ and $u(n_2)$ makes the case of $u(n_2) - k_1 > \frac{u(n_2)-u(n_1)}{1-q}$ more likely, the strategy profile $(n_1, 0, \bar{e}, z)$ (i.e., effort equilibrium) is more likely to arise than the no-effort equilibrium $(n_2, 0, \underline{e}, z)$. Presuming that the no-effort equilibrium $(n^*, c(n^*), \underline{e}, a)$ existed previously (recall subsection S.1.1), thus, women become to make fertility effort in step with this institutional change.

This institutional change occurs in step with the increasing number of children ($n_1 > n^*$) and the declining widows'

[26] 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.

[27] If the value of d_1 is not specified, three cases are considered: $k_1 - c(n^*) < k_1 < \frac{d_1}{1-q} + r_1$ (in this case, $n_1 < 0 < n^* < n_2$); $k_1 - c(n^*) \leq \frac{d_1}{1-q} + r_1 \leq k_1$ (in this case, $0 \leq n_1 \leq n^* < n_2$); and $\frac{d_1}{1-q} + r_1 < k_1 - c(n^*) < k_1$ (in this case, $0 < n^* < n_1 < n_2$). The proposition S.2 corresponds to the last case. The full description of the equilibria in the remaining cases are available upon request. In all the cases, however, the theoretical implications on widows' welfare, as explained below, hold true; see Kudo (2018).

welfare ($r_1 + \frac{qd_1}{1-q} \approx r_1 < r_0 = 0$). An intuitive explanation of this prediction is as follows; first, increases in bequest amounts allow widows to afford many children. Accordingly, a clan increases the number of children.[28] Additionally, women's widowhood security concern also contributes to this fertility increase. Second, 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 lower utility after the deterioration of levirate marriage than that obtained under the levirate marriage equilibrium.

Notably, this decline in widows' welfare holds true even if the amount of k does not increase owning to HIV/AIDS. For example, assume that a widow's reservation payoffs decline to the level of r_1 with no changes in the values of k (i.e., $k = k_0$) and d (i.e., $d = d_0$). When the amount of τ is small, then, another equilibrium may arise. In this equilibrium, the number of children remains unchanged from the levirate marriage equilibrium, and a widow leaves her husband's home while receiving lower utility than before (Kudo, 2018). Thus, compared to that of fertility, the empirical exploration of widows' welfare is more useful to explore the role of HIV/AIDS in discouraging levirate marriage.

As analyzed in Section S.2, the theoretical prediction pertaining to widows' welfare is robust to several model extensions considering (a) a possibility of a woman passing away before her husband's death, (b) influence of HIV/AIDS on the probability of a husband's death, and (c) widows' reservation utility that depends upon the number of children.

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, which reduces the dimensions of the strategy profile from (n, s, e, m) to (n, s, m) along with the following payoff profiles,

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

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

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

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

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

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

[28] 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.

Kudo (2018) analyzes levirate marriage equilibrium and how increases in r and k as well as HIV/AIDS affect this practice in this framework.

S.2.1 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

$$
\begin{aligned}
v_c(n,s,a) &= u(n) - ps - (1-p)(c(n)+\tau), && \text{(S.2.7)}\\
v_w(n,s,a) &= p(s-c(n)), && \text{(S.2.8)}\\
v_c(n,s,l) &= u(n) - c(n) - \tau, && \text{(S.2.9)}\\
v_w(n,s,l) &= pr, && \text{(S.2.10)}\\
v_c(n,s,z) &= u(n) - pk - (1-p)(c(n)+\tau), && \text{(S.2.11)}\\
v_w(n,s,z) &= p(k-c(n)), && \text{(S.2.12)}
\end{aligned}
$$

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

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

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

Next, assume that HIV/AIDS hits a society that practices levirate marriage, while establishing widows' de facto property rights $k = k_1 > c(n^*)$ as well as reducing r to the level of $r_1 < 0$. 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.4 *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_p satisfies $u'(n_p) = (1-p)c'(n_p)$.

When there is a possibility that a wife dies first, the disappearance of levirate marriage coincides with an increase in the number of children (i.e., $n_2 > n^*$ 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.[29] 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., $k_1 > c(n_p) + r_1$),[30] 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.

S.2.2 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 $n_\rho > n_6$, whereby n_ρ and n_6 satisfy $u'(n_\rho) = \rho_0 c'(n_\rho)$ and $k_1 - c(n_6) = 0$.[31] According to my questionnaire-based field survey conducted in 2012 in Karagwe, a

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

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

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

district in Kagera (Kudo, 2015), the de facto amount of k bequeathed to widows tends to be large for elderly ones, likely, having adult children. This is because adult children who inherit the deceased father's property can provide their widowed mother with livelihood support (e.g., Rwebangira, 1996). 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.5 *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 $u(n_6) - u(n_0) \geq \rho_0(c(n_6) - c(n_0))$, the strategy profiles $(n_6, (c(n_6), a_y), (0, z_o))$ and $(n_6, (c(n_6), a_y), (c(n_6), a_o))$ are subgame perfect, along with the equilibrium number of children n_6 and a widow's payoffs $v_w^y = v_w^o = r_0 = 0$ (Case 1).*

2. *When $u(n_6) - u(n_0) < \rho_0(c(n_6) - c(n_0))$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_6), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_6), a_o))$ are subgame perfect, along with the equilibrium number of children n_0 and a widow's payoffs $v_w^y = r_0 = 0$ and $v_w^o = c(n_6) - c(n_0) > 0$ (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 $u(n_6) - u(n_0) \geq \rho_0(c(n_6) - c(n_0))$), the amount k_1 ($= c(n_6)$) 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. In contrast, 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 $k_0 - c(n_6) < 0$. In my field survey in Rorya (see footnote 25 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 $k = k_1$). Additionally, the probability of losing husbands early may also increase from ρ_0 to ρ_1. Then,

Proposition S.6 *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 $n_2 > n_6 > n_0$ and a widow's payoffs $v_w^y = v_w^o = r_1 < 0$.*

Compare the proposition S.6 with (particularly Case 1 of) the proposition S.5. 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.

S.2.3 Widows' reservation utility that depends upon the number of 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). A widow taking the action l_2 obtains utility $r(n)$ such that $r'(n) > 0$, $r''(n) < 0$, and $r(0) = 0$ while incurring the child-rearing cost $c(n)$. Assume that $u'(n) > r'(n)$ for all values of n because rearing children outside their father's family is likely to reduce their mother's utility.[32] However, this reduction may not be remarkably large in the sense that $n^* \leq n_7$, whereby n_7 satisfies $r(n_7) = c(n_7)$ and $n_7 > 0$. The relevant payoff profiles can be summarized as

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

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

$$v_c(n, s, l_1) = u(n) - c(n) - \tau, \tag{S.2.15}$$

$$v_w(n, s, l_1) = r, \tag{S.2.16}$$

$$v_c(n, s, l_2) = 0, \tag{S.2.17}$$

$$v_w(n, s, l_2) = r(n) - c(n), \tag{S.2.18}$$

$$v_c(n, s, z) = u(n) - k, \tag{S.2.19}$$

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

[32]For example, traditionally, receiving bride prices is often a father's role and thus, widows who do not have socially recognized partners may have difficulty in marrying off their children.

First, consider a case that $r = r_0 = 0$ and $k = \hat{k}_0 \leq r(n_7)$. Then,

Proposition S.7 *When $r = r_0 = 0$ and $k = \hat{k}_0 \leq r(n_7)$, the strategy profile $(n_7, c(n_7), a)$ is subgame perfect, along with the equilibrium number of children n_7 and a widow's payoff $r_0 = 0$.*

Next, assume that HIV/AIDS strikes a society sustaining levirate marriage while establishing widows' de facto property rights $k = \hat{k}_1 > r(n_7)$ as well as reducing r to the level of $r_0 - \eta$ whereby $\eta > 0$ (i.e., $v_w(n, s, l_1) = r_0 - \eta = -\eta$). Additionally, a widow taking the action l_2 may also suffer from HIV/AIDS-related stigma, yielding $v_w = r(n) - c(n) - \eta$. Now, it is also the case that $v_c(n, s, a) = u(n) - s - h_c$ and $v_w(n, s, a) = s - c(n) - h_w$. Then, the following proposition holds:

Proposition S.8 *When HIV/AIDS reduces widows' reservation utility by the amount of $\eta > 0$, $k = \hat{k}_1 > r(n_7)$, and the disease cost is high enough such that $\tau + \eta < h_w + h_c$, the strategy profile $(n_{10}, 0, z)$ is subgame perfect, along with the equilibrium number of children $n_{10} > n_7$ and a widow's payoff $-\eta < 0$.*

Here, n_{10} satisfies $\hat{k}_1 - c(n_{10}) = -\eta$.

The deterioration of levirate marriage is associated with an increase in the number of children (i.e., $n_{10} > n_7$) as well as a decline in widows' welfare (i.e., $-\eta < 0$).

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.2 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) and allows the current study to exploit data variations fully.

As the figure shows, in wave 1, all female respondents resided in the KHDS villages and some of them were widowed. In contrast, 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 (1) 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.

Additionally, 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 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. In contrast, 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.

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. Additionally, by interacting D_{jt} with w_{ijt}, the specification (1) 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.2 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 $k_0 - c(n_3) = \frac{d_0}{1-q}$ and $k_0 - c(n_4) = d_0$. Since $\frac{d_0}{1-q} > d_0 > 0$, it is the case that $n_3 < n_4 < n_0$. In addition, since $c(n_3) = k_0 - \frac{d_0}{1-q} < k_0 = c(n_0) \leq c(n^*)$, it is the case that $c(n_3) < c(n_0) \leq c(n^*)$, i.e., $n_3 < n_0 \leq n^*$. Since $c(n_4) = k_0 - d_0 < k_0 = c(n_0) \leq c(n^*)$, 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 $k_0 - c(n) - d_0 \geq q(k_0 - c(n)) + (1-q)r_0$, i.e., $k_0 - c(n) \geq \frac{d_0}{1-q}$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d_0 \geq q(s - c(n)) + (1-q)r_0$, i.e., $s \geq c(n) + \frac{d_0}{1-q}$. Now, two cases are considered, either $k_0 \geq \frac{d_0}{1-q}$ or $k_0 < \frac{d_0}{1-q}$.

Case 1: $k_0 \geq \frac{d_0}{1-q}$.

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 $k_0 - c(n) - d_0 \geq k_0 - c(n_3) - d_0 > k_0 - c(n_4) - d_0 = 0$, 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 $v_c = u(n_3) - k_0 = u(n_3) - c(n_3) - \frac{d_0}{1-q}$ as well as $v_w = k_0 - c(n_3) - d_0 = \frac{d_0}{1-q} - d_0 = \frac{qd_0}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort for $n \leq n_3$, it must be the case that $s - c(n) - d_0 \geq k_0 - c(n) - d_0$ (i.e., $s \geq k_0$) *and* $s \geq c(n) + \frac{d_0}{1-q}$. Since $k_0 - c(n) - \frac{d_0}{1-q} = c(n_3) - c(n) \geq 0$, the above conditions result in $s \geq k_0 \geq c(n) + \frac{d_0}{1-q}$. 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 $v_c = u(n_3) - s = u(n_3) - k_0 = u(n_3) - c(n_3) - \frac{d_0}{1-q}$ and

$v_w = s - c(n_3) - d_0 = k_0 - c(n_3) - d_0 = \frac{qd_0}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n \le n_3$, it must be the case that $q(s - c(n)) \ge k_0 - c(n) - d_0$ (i.e., $s \ge \frac{k_0}{q} - \frac{d_0}{q} - \frac{1-q}{q}c(n)$) *and* $s \le c(n) + \frac{d_0}{1-q}$. Since $\left(\frac{k_0}{q} - \frac{d_0}{q} - \frac{1-q}{q}c(n)\right) - \left(c(n) + \frac{d_0}{1-q}\right) = \frac{1}{q}\left(k_0 - c(n) - \frac{d_0}{1-q}\right) = \frac{1}{q}\left(c(n_3) - c(n)\right) \ge 0$, it is not possible to encourage a widow to accept levirate marriage without making fertility effort. Consequently, for $n \le n_3$, the strategy profiles $(n_3, 0, \bar{e}, z)$ and $(n_3, c(n_3) + \frac{d_0}{1-q}, \bar{e}, a)$ provide a clan with maximum utility $u(n_3) - c(n_3) - \frac{d_0}{1-q}$.

Second, consider the case of $n_3 \le n \le n_0$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) \ge q(k_0 - c(n_0)) = 0$, 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 $n \le n_0$), 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 $n_3 \le n \le n_0$, it must be the case that $s - c(n) - d_0 \ge q(k_0 - c(n))$ (i.e., $s \ge q(k_0 - c(n)) + c(n) + d_0$) *and* $s \ge c(n) + \frac{d_0}{1-q}$. Since $q(k_0 - c(n)) + c(n) + d_0 - \left(c(n) + \frac{d_0}{1-q}\right) = q\left(k_0 - c(n) - \frac{d_0}{1-q}\right) = q(c(n_3) - c(n)) \le 0$, the above conditions result in $s \ge c(n) + \frac{d_0}{1-q} \ge q(k_0 - c(n)) + c(n) + d_0$ for all $n_3 \le n \le n_0$. Then, a clan chooses $s = c(n) + \frac{d_0}{1-q}$ and obtains utility $u(n) - c(n) - \frac{d_0}{1-q}$. In this case, a clan can maximize utility by selecting $n = n_0$ (corner solution), which results in $v_c = u(n_0) - c(n_0) - \frac{d_0}{1-q}$ and $v_w = s - c(n_0) - d_0 = \frac{qd_0}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort for $n_3 \le n \le n_0$, it must be the case that $q(s - c(n)) \ge q(k_0 - c(n))$ (i.e., $s \ge k_0$) *and* $s \le c(n) + \frac{d_0}{1-q}$. Since $k_0 - \left(c(n) + \frac{d_0}{1-q}\right) = c(n_3) - c(n) \le 0$, the above conditions result in $k_0 \le s \le c(n) + \frac{d_0}{1-q}$. 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 $n \le n_0$), 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 $n_3 \le n \le n_0$, either of $q(u(n_0) - c(n_0))$ or $u(n_0) - c(n_0) - \frac{d_0}{1-q}$ provides a clan with maximum utility, depending upon the relevant functional forms and parameter values.

Third, consider the case of $n \ge n_0$. In this case, a woman has no incentive to make fertility effort when she chooses action z. Since $q(k_0 - c(n)) \le q(k_0 - c(n_0)) = 0$, 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 $n \ge n_0$, it must be the case that $s - c(n) - d_0 \ge 0$ *and* $s \ge c(n) + \frac{d_0}{1-q}$, namely $s \ge c(n) + \frac{d_0}{1-q} > c(n) + d_0$. Then, a clan chooses $s = c(n) + \frac{d_0}{1-q}$ and obtains utility $u(n) - c(n) - \frac{d_0}{1-q}$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = u(n^*) - c(n^*) - \frac{d_0}{1-q}$ and $v_w = s - c(n^*) - d_0 = \frac{qd_0}{1-q}$. 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* $s \leq c(n) + \frac{d_0}{1-q}$, namely $c(n) \leq s \leq c(n) + \frac{d_0}{1-q}$. Then, a clan chooses $s = c(n)$ and obtains utility $q\,(u(n) - c(n))$. A clan can maximize this utility by selecting $n = n^*$, which results in $v_c = q\,(u(n^*) - c(n^*))$ and $v_w = q(s - c(n^*)) = 0$. Consequently, for $n \geq n_0$, when $(1-q)(u(n^*) - c(n^*))$ $\geq \frac{d_0}{1-q}$, it becomes that $u(n^*) - c(n^*) - \frac{d_0}{1-q} \geq q(u(n^*) - c(n^*)) > q(u(n^*) - c(n^*) - \tau)$. In this case, the strategy profile $(n^*, c(n^*) + \frac{d_0}{1-q}, \bar{e}, a)$ provides a clan with maximum utility $u(n^*) - c(n^*) - \frac{d_0}{1-q}$. When $(1-q)(u(n^*) - c(n^*))$ $< \frac{d_0}{1-q}$, it becomes $q(u(n^*) - c(n^*)) > u(n^*) - c(n^*) - \frac{d_0}{1-q}$ 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 $u(n_3) - c(n_3) - \frac{d_0}{1-q} < u(n^*) - c(n^*) - \frac{d_0}{1-q}$; $q(u(n_0) - c(n_0))$ $< q(u(n^*) - c(n^*))$; and $u(n_0) - c(n_0) - \frac{d_0}{1-q} < u(n^*) - c(n^*) - \frac{d_0}{1-q}$. Thus, when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d_0}{1-q}$, the strategy profile $(n^*, c(n^*) + \frac{d_0}{1-q}, \bar{e}, a)$ is subagme perfect. In this case, a widow obtains utility $\frac{qd_0}{1-q}$. When $(1-q)(u(n^*) - c(n^*))$ $< \frac{d_0}{1-q}$, the strategy profile $(n^*, c(n^*), \underline{e}, a)$ is subagme perfect. In this case, a widow obtains utility $r_0 = 0$.

Case 2: $k_0 < \frac{d_0}{1-q}$.

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 $(n^*, c(n^*) + \frac{d_0}{1-q}, \bar{e}, a)$ is subagme perfect when $(1-q)(u(n^*) - c(n^*)) \geq \frac{d_0}{1-q}$. In this case, a widow obtains utility $\frac{qd_0}{1-q}$. When $(1-q)(u(n^*) - c(n^*)) < \frac{d_0}{1-q}$, 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 $k_1 - c(n_1) = \frac{d_1}{1-q} + r_1$, $k_1 - c(n_5) = r_1 + d_1$, and $k_1 - c(n_2) = r_1$. Since $\frac{d_1}{1-q} + r_1$ $> d_1 + r_1 > r_1$, it is the case that $n_1 < n_5 < n_2$. Additionally, since $c(n_2) = k_1 - r_1 > k_1 > c(n^*)$, it is the case that $c(n_2) > c(n^*)$, i.e., $n_2 > n^*$. Since $c(n_1) = k_1 - \frac{d_1}{1-q} - r_1 \approx k_1 - r_1 > k_1 > c(n^*)$, $c(n_1) > c(n^*)$, so $n_1 > n^*$. Consequently, $n^* < n_1 < n_2$.

Also, note that to prompt a woman's fertility effort when she chooses action z, it must be the case that $k_1 - c(n) - d_1$ $\geq q(k_1 - c(n)) + (1-q)r_1$, i.e., $k_1 - c(n) \geq \frac{d_1}{1-q} + r_1$. Similarly, to prompt a woman's fertility effort when she chooses action a, it must be the case that $s - c(n) - d_1 - h_w \geq q(s - c(n) - h_w) + (1-q)r_1$, i.e., $s \geq c(n) + \frac{d_1}{1-q} + h_w + r_1$.

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 $k_1 - c(n) - d_1 \geq k_1 - c(n_1) - d_1 > k_1 - c(n_5) - d_1 = r_1$. 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 $v_c = u(n_1) - k_1$ $= u(n_1) - c(n_1) - \frac{d_1}{1-q} - r_1$ as well as $v_w = k_1 - c(n_1) - d_1 = r_1 + \frac{qd_1}{1-q}$. To encourage a widow to accept levirate marriage while making fertility effort, it must be the case that $s-c(n)-d_1-h_w \geq k_1-c(n)-d_1$ (i.e., $s \geq k_1+h_w$) *and* $s \geq c(n)+\frac{d_1}{1-q}+h_w+r_1$. Since $k_1+h_w-\left(c(n)+\frac{d_1}{1-q}+h_w+r_1\right)=k_1-c(n)-\frac{d_1}{1-q}-r_1=c(n_1)-c(n) \geq 0$, the above conditions result in $s \geq k_1+h_w \geq c(n)+\frac{d_1}{1-q}+h_w+r_1$. 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 $v_c=u(n_1)-k_1-h_w-h_c=u(n_1)-c(n_1)-\frac{d_1}{1-q}-r_1-h_w-h_c$ and $v_w=s-c(n_1)-d_1-h_w=k_1+h_w-c(n_1)-d_1-h_w=r_1+\frac{qd_1}{1-q}$. To encourage a widow to accept levirate marriage without making fertility effort, it must be the case that $q(s-c(n)-h_w)+(1-q)r_1 \geq k_1-c(n)-d_1$ (i.e., $s \geq \frac{k_1}{q}-\frac{d_1}{q}-\frac{1-q}{q}c(n)-\frac{1-q}{q}r_1+h_w$) *and* $s \leq c(n)+\frac{d_1}{1-q}+h_w+r_1$. Since $\left(\frac{k_1}{q}-\frac{d_1}{q}-\frac{1-q}{q}c(n)-\frac{1-q}{q}r_1+h_w\right)-\left(c(n)+\frac{d_1}{1-q}+h_w+r_1\right)=\frac{1}{q}\left(k_1-c(n)-\frac{d_1}{1-q}-r_1\right)$ $=\frac{1}{q}(c(n_1)-c(n)) \geq 0$ 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 $u(n_1)-c(n_1)-\frac{d_1}{1-q}-r_1$.

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 $s-c(n)-d_1-h_w \geq q(k_1-c(n))+(1-q)r_1$ (i.e., $s \geq qk_1+(1-q)c(n)+(1-q)r_1+d_1+h_w$) *and* $s \geq c(n)+\frac{d_1}{1-q}+h_w+r_1$. Since $(qk_1+(1-q)c(n)+(1-q)r_1+d_1+h_w)-\left(c(n)+\frac{d_1}{1-q}+h_w+r_1\right)=q\left(k_1-\frac{d_1}{1-q}-r_1-c(n)\right)=q(c(n_1)-c(n))$ ≤ 0, the above conditions result in $s \geq c(n)+\frac{d_1}{1-q}+h_w+r_1 \geq qk_1+(1-q)c(n)+(1-q)r_1+d_1+h_w$. Then, a clan chooses $s=c(n)+\frac{d_1}{1-q}+h_w+r_1$ and obtains utility $u(n)-c(n)-\frac{d_1}{1-q}-r_1-h_w-h_c$. A clan can maximize this utility by selecting $n=n_1$ (corner solution), which results in $v_c=u(n_1)-c(n_1)-\frac{d_1}{1-q}-r_1-h_w-h_c$ and $v_w=c(n_1)+\frac{d_1}{1-q}+h_w+r_1-c(n_1)-d_1-h_w=r_1+\frac{qd_1}{1-q}$.

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* $s \leq c(n)+\frac{d_1}{1-q}+h_w+r_1$. Since $k_1+h_w-\left(c(n)+\frac{d_1}{1-q}+h_w+r_1\right)=k_1-\frac{d_1}{1-q}-r_1-c(n)=c(n_1)-c(n) \leq 0$, the above conditions result in $k_1+h_w \leq s \leq c(n)+\frac{d_1}{1-q}+h_w+r_1$. 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 $q(u(n_2) - c(n_2) - r_1) > u(n_1) - c(n_1) - \frac{d_1}{1-q} - r_1 - h_w - h_c$. 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 $s - c(n) - d_1 - h_w \geq r_1$ *and* $s \geq c(n) + \frac{d_1}{1-q} + h_w + r_1$, yielding $s \geq c(n) + \frac{d_1}{1-q} + h_w + r_1 \geq c(n) + d_1 + h_w + r_1$. Then, a clan chooses $s = c(n) + \frac{d_1}{1-q} + h_w + r_1$ and obtains utility $u(n) - c(n) - \frac{d_1}{1-q} - r_1 - h_w - h_c$. 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 $v_c = u(n_2) - c(n_2) - \frac{d_1}{1-q} - r_1 - h_w - h_c$ and $v_w = s - c(n_2) - d_1 - h_w = r_1 + \frac{qd_1}{1-q}$. 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* $s \leq c(n) + \frac{d_1}{1-q} + h_w + r_1$, yielding $c(n) + r_1 + h_w \leq s \leq c(n) + \frac{d_1}{1-q} + h_w + r_1$. 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 $q(u(n_2) - c(n_2) - \tau) > u(n_2) - c(n_2) - \frac{d_1}{1-q} - r_1 - h_w - h_c$. 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 $u(n_1) - c(n_1) - \frac{d_1}{1-q} - r_1$, $q(u(n_2) - c(n_2) - r_1)$, 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 $\left(u(n_1) - c(n_1) - \frac{d_1}{1-q} - r_1\right) - q(u(n_2) - c(n_2) - r_1) = (u(n_1) - k_1) - q(u(n_2) - k_1) = u(n_1) - u(n_2) + (1-q)(u(n_2) - k_1)$. 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 $r_1 + \frac{qd_1}{1-q}$. Otherwise, the strategy profile $(n_2, 0, \underline{e}, z)$ is subgame perfect and a widow obtains utility r_1.

Proof of proposition S.3:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$. Since $k_0 \leq c(n^*)$ by assumption, it is the case that $c(n_0) \leq c(n^*)$, i.e., $n_0 \leq n^*$. Also, find n_p satisfying $u'(n_p) = (1-p)c'(n_p)$. Note that $n^* \leq n_p$, which can be proved as follows; suppose $n^* > n_p$, $u'(n_p) > u'(n^*) = c'(n^*) > c'(n_p)$, which is a contradiction to $u'(n_p) = (1-p)c'(n_p)$. Therefor, it becomes $n_0 \leq n^* \leq n_p$.

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

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

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

Proof of proposition S.4:

Recall n_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 $n^* \leq n_p$. Now, two cases are considered, either $k_1 \leq c(n_p) + r_1$ (i.e., $c(n^*) < k_1 \leq c(n_p) + r_1$) 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: $k_1 \leq c(n_p) + r_1$.

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

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 $n = n_2$ (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 $n \leq n_2$, 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 $n = n_2$ (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 $n \leq n_2$, 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 $v_w = p(s - c(n_2) - h_w) = pr_1$. 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 $u(n_2) - c(n_2) - \tau$.

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.5:

Recall n_0 satisfying $k_0 - c(n_0) = r_0 = 0$ and find n_6 satisfying $k_1 - c(n_6) = r_0 = 0$. 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 $c(n_6) > c(n^*)$, i.e., $n_6 > n^*$, resulting in $n_0 \leq n^* < n_6$. 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 $n_\rho > n_6$ by assumption, therefore, it becomes $n_0 \leq n^* < n_6 < n_\rho$. 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, $k_1 - c(n) \geq k_1 - c(n_0) > k_1 - c(n_6) = r_0 = 0$. 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 $v_c = u(n_0) - c(n_0) + (1-\rho_0)(c(n_0) - c(n_6))$. Consequently, for $n \leq n_0$, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_6), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_6), a_o))$ provide a clan with maximum utility $u(n_0) - c(n_0) + (1-\rho_0)(c(n_0) - c(n_6))$.

Second, consider the case of $n_0 < n \leq n_6$. 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 $k_1 - c(n) \geq k_1 - c(n_6) = r_0 = 0$. To encourage w_y to accept levirate marriage when $n_0 < n \leq n_6$, 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 $n_0 < n \leq n_6$, 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* $n \leq n_6 < n_\rho$, a clan selects $n = n_6$ (corner solution), which results in $v_c = u(n_6) - c(n_6)$. Consequently, when $n_0 < n \leq n_6$, the strategy profiles $(n_6, (c(n_6), a_y), (0, z_o))$ and $(n_6, (c(n_6), a_y), (c(n_6), a_o))$ provide a clan with maximum utility $u(n_6) - c(n_6)$.

Third, consider the case of $n \geq n_6$. In this case, $k_0 - c(n) \leq k_0 - c(n_6) < k_0 - c(n_0) = r_0 = 0$. Also, $k_1 - c(n) \leq k_1 - c(n_6) = r_0 = 0$. 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 $n \geq n_6$, 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 $n \geq n_6$, 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* $n \geq n_6 > n^*$, a clan selects $n = n_6$ (corner solution), which results in $v_c = u(n_6) - c(n_6)$. Consequently, when $n \geq n_6$, the strategy profile $(n_6, (c(n_6), a_y), (c(n_6), a_o))$ provides a clan with maximum utility $u(n_6) - c(n_6)$.

Now, compare utility $u(n_6) - c(n_6)$ with $u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_6))$. When $u(n_6) - u(n_0) \geq \rho_0(c(n_6) - c(n_0))$, $u(n_6) - c(n_6) \geq u(n_0) - c(n_0) + (1 - \rho_0)(c(n_0) - c(n_6))$. In this case, the strategy profiles $(n_6, (c(n_6), a_y), (0, z_o))$ and $(n_6, (c(n_6), a_y), (c(n_6), a_o))$ are subgame perfect and $v_w^y = v_w^o = 0$. Otherwise, the strategy profiles $(n_0, (0, z_y), (0, z_o))$, $(n_0, (c(n_0), a_y), (0, z_o))$, $(n_0, (0, z_y), (c(n_6), a_o))$, and $(n_0, (c(n_0), a_y), (c(n_6), a_o))$ are subgame perfect and $v_w^y = r_0 = 0$ and $v_w^o = c(n_6) - c(n_0) > 0$.

Proof of proposition S.6:

Recall n_2 satisfying $k_1 - c(n_2) = r_1 < 0$, whereby $n_2 > n_6 > n^*$ because $k_1 - c(n_2) = r_1 < k_1 - c(n_6) = r_0$ and so, $c(n_6) < c(n_2)$. 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.7:

Find n_7 and n_8 satisfying $r(n_7) - c(n_7) = r_0 = 0$ and $\hat{k}_0 - c(n_8) = r(n_8) - c(n_8)$. Since $\hat{k}_0 = r(n_8) \leq r(n_7)$ by assumption, $n_8 \leq n_7$. Here, $n_7 \geq n^*$ by assumption. Also, note that $r(n) - c(n) \geq r(n_7) - c(n_7) = 0$ for all $n \leq n_7$, and vice versa. Then, two cases are considered: $n_8 \leq n^* \leq n_7$ and $n^* < n_8 \leq n_7$. The following proof applies to both the cases.

First, consider the case of $n \leq n_8$. In this case, $\hat{k}_0 - c(n) = r(n_8) - c(n) \geq r(n) - c(n) \geq r(n_7) - c(n_7) = r_0 = 0$. So, a widow chooses action z when she rejects levirate marriage. Given the action z taken by a widow, a clan obtains utility $u(n) - \hat{k}_0$. A clan can maximize this utility by selecting $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), yielding $v_c = u(n_8) - \hat{k}_0 = u(n_8) - r(n_8)$ as well as $v_w = \hat{k}_0 - c(n_8) = r(n_8) - c(n_8)$. To encourage a widow to accept levirate marriage for $n \leq n_8$, 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 $n = n_8$ (i.e., maximum in the domain of $n \leq n_8$), which results in $v_c = u(n_8) - s = u(n_8) - \hat{k}_0 = u(n_8) - r(n_8)$ and $v_w = s - c(n_8) = \hat{k}_0 - c(n_8) = r(n_8) - c(n_8)$. Consequently, for $n \le n_8$, the strategy profiles $(n_8, 0, z)$ and $(n_8, r(n_8), a)$ provide a clan with maximum utility $u(n_8) - r(n_8)$.

Second, consider the case of $n_8 \le n \le n_7$. In this case, $r(n) - c(n) \ge r(n_7) - c(n_7) = r_0 = 0$ and $r(n) - c(n) \ge r(n_8) - c(n) = \hat{k}_0 - c(n)$. So, a widow chooses action l_2 when she rejects levirate marriage. Given the action l_2 taken by a widow, a clan obtains utility 0. To encourage a widow to accept levirate marriage for $n_8 \le n \le n_7$, it must be the case that $s - c(n) \ge r(n) - c(n)$. Then, a clan chooses $s = r(n)$ and obtains utility $u(n) - r(n)$. A clan can maximize this utility by selecting $n = n_7$ (corner solution) because $u'(n) > r'(n)$, which results in $v_c = u(n_7) - s = u(n_7) - r(n_7) > 0$ and $v_w = s - c(n_7) = r(n_7) - c(n_7) = r_0 = 0$. Consequently, for $n_8 \le n \le n_7$, the strategy profile $(n_7, c(n_7), a)$ provides a clan with maximum utility $u(n_7) - r(n_7) = u(n_7) - c(n_7)$.

Third, consider the case of $n \ge n_7$. In this case, $r_0 = r(n_7) - c(n_7) \ge r(n) - c(n) > r(n_8) - c(n) = \hat{k}_0 - c(n)$. So, 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 $n = n_7$ (corner solution), yielding $v_c = u(n_7) - c(n_7) - \tau$ as well as $v_w = r_0 = 0$. To encourage a widow to accept levirate marriage for $n \ge n_7$, it must be the case that $s - c(n) \ge r_0$. Then, a clan chooses $s = c(n) + r_0 = c(n)$ and obtains utility $u(n) - c(n)$. A clan can maximize this utility by selecting $n = n_7$ (corner solution), which results in $v_c = u(n_7) - c(n_7)$ and $v_w = s - c(n_7) = r_0 = 0$. Consequently, for $n \ge n_7$, the strategy profile $(n_7, c(n_7), a)$ provides a clan with maximum utility $u(n_7) - c(n_7)$.

Since $u'(n) > r'(n)$ and $n_8 \le n_7$, $u(n_8) - r(n_8) \le u(n_7) - r(n_7) = u(n_7) - c(n_7)$. Therefore, the strategy profile $(n_7, c(n_7), a)$ is subgame perfect. In this case, a widows obtains utility $r_0 = 0$.

Proof of proposition S.8:

Find n_9 and n_{10} satisfying $\hat{k}_1 - c(n_9) = r(n_9) - c(n_9) - \eta$ and $\hat{k}_1 - c(n_{10}) = -\eta$. Also, recall n_7 satisfying $r(n_7) = c(n_7)$ (i.e., $r(n_7) - c(n_7) - \eta = -\eta$). Since $\hat{k}_1 = r(n_9) - \eta > r(n_7)$ (by assumption), $r(n_9) > r(n_7) + \eta > r(n_7)$, so $n_9 > n_7$. Since $\hat{k}_1 - c(n_{10}) = (r(n_9) - \eta) - c(n_{10}) = -\eta$ and $r(n_7) - c(n_7) - \eta = -\eta$ (by definition), $r(n_9) - c(n_{10}) - \eta = r(n_7) - c(n_7) - \eta$, i.e., $r(n_9) - r(n_7) = c(n_{10}) - c(n_7)$. Since $r(n_9) - r(n_7) > 0$ because $n_9 > n_7$, $c(n_{10}) - c(n_7) > 0$, so $n_{10} > n_7$. Also, note that $r(n) - c(n) - \eta \ge r(n_7) - c(n_7) - \eta = -\eta$ for all $n \le n_7$, and vice versa. Since $\hat{k}_1 = r(n_9) - \eta = c(n_{10}) - \eta$, $r(n_9) = c(n_{10})$. Then, two cases are considered: $n^* \le n_7 < n_9 \le n_{10}$ and $n^* \le n_7 < n_{10} < n_9$. The following proof applies to both the cases.

First, consider the case of $n \le n_7$. In this case, $\hat{k}_1 - c(n) = r(n_9) - c(n) - \eta > r(n_7) - c(n) - \eta \ge r(n) - c(n) - \eta \ge -\eta$. 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 $n = n_7$ (i.e., maximum in the domain of $n \le n_7$), yielding $v_c = u(n_7) - \hat{k}_1 = u(n_7) - c(n_{10}) + \eta$ as well as $v_w = \hat{k}_1 - c(n_7) = c(n_{10}) - c(n_7) - \eta$. To encourage a widow to accept levirate marriage for $n \le n_7$, it must be the case that $s - c(n) - h_w \ge \hat{k}_1 - c(n)$. 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 $n = n_7$ (i.e., maximum in the domain of $n \leq n_7$), which results in $v_c = u(n_7) - s - h_c = u(n_7) - \hat{k}_1 - h_w - h_c = u(n_7) - c(n_{10}) + \eta - h_w - h_c$ and $v_w = s - c(n_7) - h_w = \hat{k}_1 + h_w - c(n_7) - h_w = c(n_{10}) - c(n_7) - \eta$. Consequently, for $n \leq n_7$, the strategy profile $(n_7, 0, z)$ provides a clan with maximum utility $u(n_7) - c(n_{10}) + \eta$.

Second, consider the case of $n_7 \leq n \leq n_{10}$. In this case, $\hat{k}_1 - c(n) = c(n_{10}) - c(n) - \eta \geq -\eta \geq r(n) - c(n) - \eta$. 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 $n = n_{10}$ (i.e., maximum in the domain of $n_7 \leq n \leq n_{10}$), yielding $v_c = u(n_{10}) - \hat{k}_1 = u(n_{10}) - c(n_{10}) + \eta$ as well as $v_w = \hat{k}_1 - c(n_{10}) = -\eta$. To encourage a widow to accept levirate marriage for $n_7 \leq n \leq n_{10}$, 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 $n = n_{10}$ (i.e., maximum in the domain of $n_7 \leq n \leq n_{10}$), which results in $v_c = u(n_{10}) - s - h_c = u(n_{10}) - \hat{k}_1 - h_w - h_c = u(n_{10}) - c(n_{10}) + \eta - h_w - h_c$ and $v_w = s - c(n_{10}) - h_w = \hat{k}_1 + h_w - c(n_{10}) - h_w = -\eta$. Consequently, for $n_7 \leq n \leq n_{10}$, the strategy profile $(n_{10}, 0, z)$ provides a clan with maximum utility $u(n_{10}) - c(n_{10}) + \eta$.

Third, consider the case of $n \geq n_{10}$. In this case, $\hat{k}_1 - c(n) = c(n_{10}) - c(n) - \eta \leq -\eta$. Also, $r(n) - c(n) - \eta \leq -\eta$. So, 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* $n \geq n_{10} > n^*$. Then, a clan selects $n = n_{10}$ (corner solution), yielding $v_c = u(n_{10}) - c(n_{10}) - \tau$ as well as $v_w = -\eta$. To encourage a widow to accept levirate marriage for $n \geq n_{10}$, it must be the case that $s - c(n) - h_w \geq -\eta$. Then, a clan chooses $s = c(n) + h_w - \eta$ and obtains utility $u(n) - c(n) - h_w - h_c + \eta$. A clan can maximize this utility *subject to* $n \geq n_{10} > n^*$. Then, a clan selects $n = n_{10}$ (corner solution), which results in $v_c = u(n_{10}) - c(n_{10}) - h_w - h_c + \eta$ and $v_w = s - c(n_{10}) - h_w = -\eta$. Consequently, for $n \geq n_{10}$, the strategy profile $(n_{10}, 0, l_1)$ provides a clan with maximum utility $u(n_{10}) - c(n_{10}) - \tau$.

Note $u(n_7) - c(n_{10}) + \eta < u(n_{10}) - c(n_{10}) + \eta$. Also, $u(n_{10}) - c(n_{10}) - \tau < u(n_{10}) - c(n_{10}) + \eta$. Therefore, the strategy profile $(n_{10}, 0, z)$ is subgame perfect. In this case, a widow obtains utility $-\eta$.

(For the supplemental appendix)

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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.

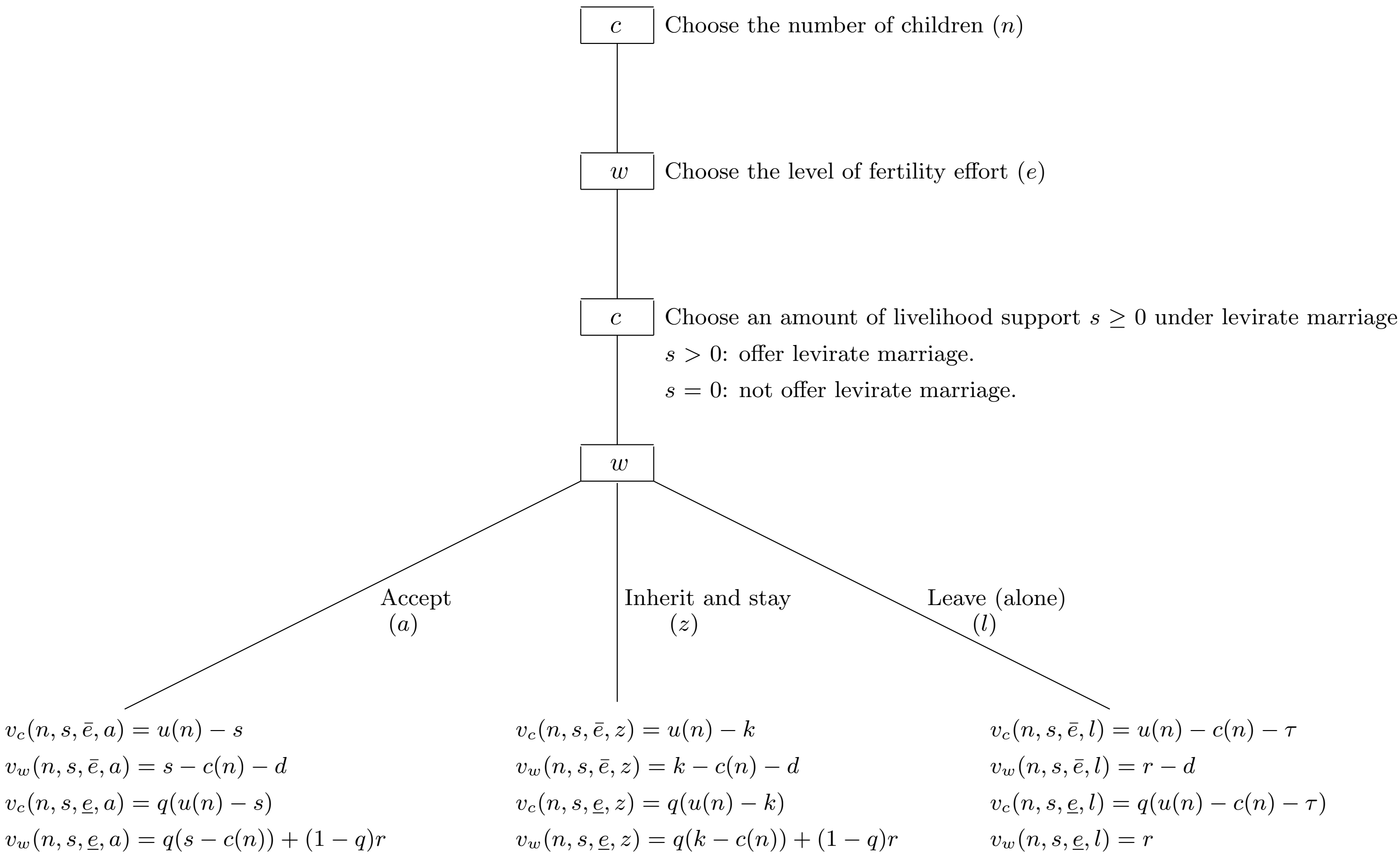
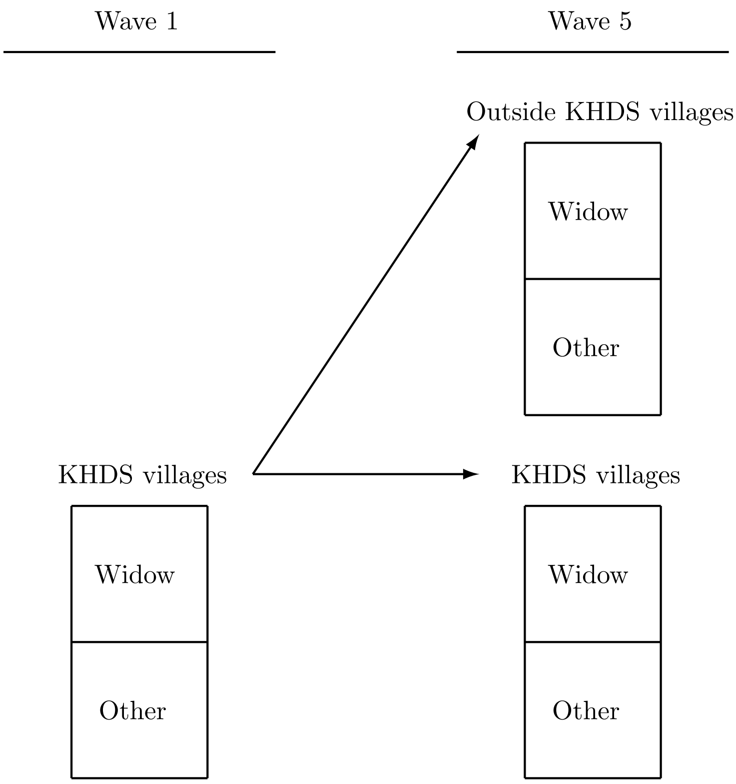


Figure S.1: Levirate marriage game



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

Figure S.2: Data structure and graphical representation of the identification strategy

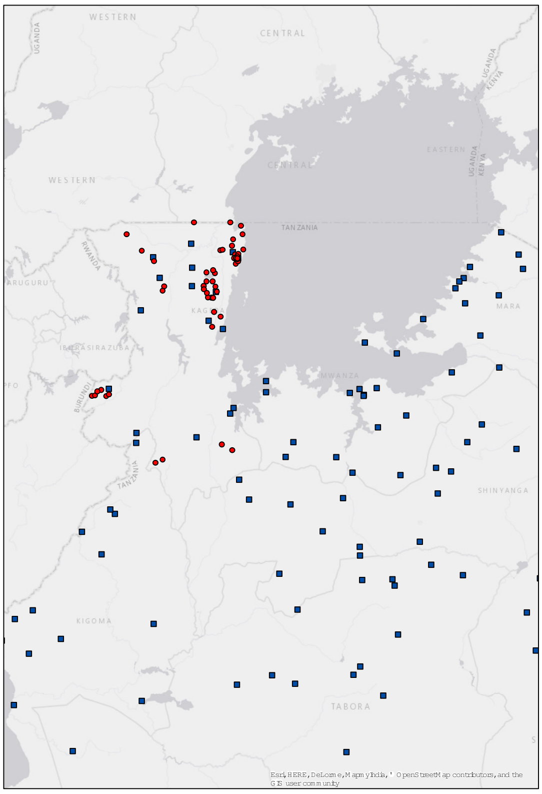


Figure S.3: Position of the KHDS (red circle) and 2003—04 THIS communities (blue square)