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Mortality at Mesopotamia, a Jamaican sugar estate, 1762 - 1832

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Abstract

We use survival analysis to study the mortality experience of 1111 slaves living on the British West Indian sugar plantation of Mesopotamia for seven decades prior to the Emancipation Act of 1833. Using three different concepts of analysis time and employing non-parametric and semi-parametric models, our results suggest that female slaves first observed under Joseph Foster Barham II's period of ownership (1789-1832) faced an increased hazard of death compared with those first observed during his predecessor's tenure. We find no such relationship for males. We cite as a possible explanation the employment regime operated by Foster Barham II, which allocated increasing numbers of females to gang labour in the cane fields. A G-estimation model used to compensate for the 'healthy worker survivor effect' estimates that continuous exposure to such work reduced survival times by between 20 and 40 per cent. Our findings are compared with previous studies of Mesopotamia and related to the wider literature investigating the roles of fertility and mortality in undermining the sustainability of Caribbean slave populations.

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1 Introduction

Abolition of the trans-Atlantic slave trade in 1807 and the passing of the Emancipation Act of 1833 are landmark events in British imperial history and a large historical literature documents and debates the demography of slavery in Britannia's far-flung dominions. Yet hindering two centuries-worth of research is the scarcity of high quality data with which to investigate the impact that the plantation system had on the health and survival prospects of a slave population which, at its greatest extent, numbered in excess of three quarters of a million people.

During the late eighteenth and early nineteenth century, statistical issues, as well as moral, played a central role in the debate over abolition. Prior to 1807, abolitionists contrasted Africa's burgeoning slave population with the failure of slaves to reproduce in the West Indies, citing the latter as evidence of a cruel regime, perpetuated by the ready availability of fresh African imports. In response, planters argued that the Caribbean's harsh climate and the sexual immorality of Africans raised mortality while depressing fertility (Higman, 1976, p 99-101). Post-1807, the black population in most Caribbean colonies continued to suffer a surplus of deaths over births, in stark contrast to North America where, from the early eighteenth century onwards, slave populations achieved natural increase (Engerman, 1976; Tadman, 2000). A revived anti-slavery campaign then called for immediate emancipation during the 1820s on humanitarian grounds, attributing slavery's demographic failure to brutality, over-work, and nutritional deprivation. Again, the pro-slavery lobby struck back: conditions in the Caribbean, they argued, were improving as planters embraced an amelioration agenda that sought to moderate work intensity and punishment, while encouraging family formation and natalism. Both sides of the dispute analysed official surveys of the enslaved population (the 'Registration Returns', official documents designed to police abolition of the Atlantic slave trade by monitoring the numbers of slaves owned by West Indian planters), to gain support from neutrals and discredit the arguments of their opponents (Higman, 1976, 1984; Lewis, 1983, p 106-13; Luster, 1995 p 1-10).

In this paper, we use survival analysis to study the mortality experience of over one thousand slaves whose lives are documented in annual inventories taken between 1762 and 1832 on the British West Indian estate of Mesopotamia. Mesopotamia was a sugar plantation of 2,448 acres, located in Westmoreland Parish, along the Cabrita River, approximately five miles inland from the small port town of Savanna la Mar (Dunn, 1977, p 37; Dunn, 1987, p 797). Established circa 1700, it was absentee-owned from 1736 onwards by the Barham family, in common with other large estates (Burnard, 2004; Higman, 2005). Its workforce consisted overwhelmingly of enslaved workers of Afro-Caribbean origin, supplemented by small numbers of white managers, hired white artisans, and jobbing slave labour. In terms of area and population the property probably ranked in the top third of the island's sugar estates (Higman, 1976, 1987). Economically and organisationally, however, Mesopotamia shared features characteristic of the rest of Jamaica's sugar industry. The estate specialised in cultivating cane and processing sugar and rum on a central works. These products were exported to London for sale and earned most of the property's annual revenue.

The continuity of Mesopotamia's inventories render the estate unique: on no other British West Indian property can the relationship between slave labour, health, and mortality be investigated with the same level of detail. Further, Mesopotamia is of particular interest because its owner between 1789 and 1832, Joseph Foster Barham II, voluntarily withdrew from the trans-Atlantic slave trade fifteen years early, choosing, on moral grounds, to stop importing new African slaves and instead rely on transfers from existing estates within Jamaica. As a result, Mesopotamia allows researchers a longer period with which to examine the implications of abandoning the trans-Atlantic slave trade on plantation management (Dunn, 1987).

As far as we are aware, this paper is the first to apply survival analysis techniques to the determinants of slave mortality. Our models, which use different concepts of analysis time, adjust for left-truncation and right-censoring of survival times, allowing us to analyse the fortunes of almost all of the slaves who worked at Mesopotamia between 1762 and 1832. In addition, we apply techniques previously used in areas such as epidemiology and occupational health to try to overcome the problem of the 'healthy worker survivor effect', in which estimates of the effect of exposure to a health-damaging occupation on mortality risk can be biased in the presence of a variable, such as health status, which is both a time-varying confounder and an intermediate variable on the pathway between the exposure and mortality risk.

The existing historical and statistical literature, together with our study questions, are presented in section 2. Sources of data are described in section 3 and methods in section 4. Results are presented in section 5 and discussed in section 6. An appendix contains additional technical material.

2 Fertility and mortality in slave populations

Two centuries after 1807, historians continue to debate whether slaves in the West Indies failed to emulate the natural increase of their counterparts in the United States because of a low birth rate or high mortality. Attempts have been made to link reduced fertility with an economy reliant on slave imports and sugar cultivation, since these features are shared both by estates in the Caribbean and Louisiana, one of the few areas of the United States where the enslaved population failed to reproduce itself. Curtin (1969) argues that access to the slave trade unbalanced sex ratios in the Caribbean, leading to a shortage of females and delaying the emergence of a Creole majority. Klein and Engerman (1978) argue that the continuation of slave imports may also have established African lactation practices within the population, further lowering fertility by widening birth spacing. It is also contended that sugar cultivation's extensive use of female gang labour impaired the reproductive capacity of women by delaying menarche and weakening their ability to conceive (Higman, 1979; Follett, 2003). Additional explanations of unsuccessful child rearing, drawn primarily from qualitative accounts of plantation slavery, emphasise factors such as cruelty of treatment, malnourishment and disease, an unwillingness of women to bear children, and opposition by some planters to slave procreation (Morgan, 2006).

Data limitations make it difficult to test such hypotheses. Further, the core assumption of a low birth rate is, itself, open to challenge: the Registration Returns and other contemporary data sources badly under-state infant mortality and usually fail to record still-births entirely (Higman, 1984). Critics of the fertility rate explanation argue, therefore, that the chief difference between the slave regimes of the Caribbean and the United States resides in the mortality rate. An adverse tropical disease climate, combined with malnutrition of mothers, are adduced as probable causes of heavy infant and child mortality (Kiple, 1984). Yet regional differences within the Caribbean and changes in the demographic regimes of specific colonies, such as Barbados, render the search for mono-causal explanations an elusive quest (Craton, 1978; Higman, 1984).

Instead of seeking to establish the primacy of fertility or mortality, an alternative approach is to subject available, high quality, data sources to close scrutiny using inferential methods. Yet inferential statistical studies of Caribbean slave data remain rare. Meredith-John (1988) uses two surveys of the plantations of Trinidad, carried out in 1813 and 1816, to derive period life-tables and estimate logit models of the probability of survival from one survey to the next as a function of various explanatory variables. She finds the survival prospects of those imported from Africa to be lower than Creoles and that working on a sugar plantation, relative to other plantations (such as cotton and cocoa), damaged survival prospects (Meredith-John, 1988a, p 174-5). However, Meredith-John does not have information on the dates of death of slaves, ruling out survival analysis, nor is she able to adjust her analysis for health status, ruling out analyses which take into account the potential interrelationships between slaves' health, work status and mortality risk.

The largest existing study of Mesopotamia may be found in the works of Dunn (1977, 1987, 1993, 1996, 2007), who carries out descriptive analyses of sub-samples of the estate's population between 1762 and 1832. In his 1977 paper, he analyses data for around 550 slaves present on the estate between 1799 and 1818; in his 1987 paper, he studies those 538 slaves present on the estate between 1762 and 1831 whose 'adult' careers can be reconstructed completely (Dunn, 1987, p 802-3). Both of his studies examine around half of the population present on the estate during the period in question.

Dunn (1977) contrasts Mesopotamia with Mount Airey estate, a Virginia tobacco plantation. He concludes that fertility formed the main difference between the two populations, describing the birth rate on Mesopotamia as 'feeble', with half of all women in his sample failing to become mothers (Dunn, 1977, p 43, 58, 59). However, as Dunn acknowledges, evidence for fertility on Mesopotamia is deficient, since stillborn babies and infants dying shortly after birth are only rarely recorded.

Dunn (1987) attributes reproductive failure on the estate to a low birth rate, despite a shift in the male:female ratio from 153:100 in 1762 to 88:100 in 1834 (Dunn, 1987, p 812) and a female age structure conducive to high fecundity. He notes that more than half of all women were childless, while around sixty percent of mothers bore fewer than four children. He further suggests that nutritional deprivation and sexual abstinence were likely causes of low fertility, since he reports little difference between the fertility of Africans and non-Africans or the occupational histories of mothers and non-mothers (Dunn, 1977, p 41, 43, 45, 58-63). Further, he argues that health and life expectancy differ according to both gender and occupation: among his sample, more women than men performed the strenuous, manual labour in the cane fields, whilst men monopolised skilled crafts, transportation, and work with animals. Among males, he reports that the mean age at death of workers assigned to fieldwork was less than those of drivers, craftworkers and stockkeepers and that the health of male workers 'broke down rapidly' when they joined the field gangs. Dunn argues that the fieldwork carried out by women 'clearly affected their health and probably damaged their reproductive capability' (Dunn, 1987, p 806-12).

Dunn (2007, p 48) describes how British-born Joseph Foster Barham II made only one visit to Jamaica, in 1778-81, when he was revolted by cargoes unloaded by the slave ships. Upon assuming ownership of the estate, he continued to buy slaves, although he voluntarily withdrew from the trans-Atlantic slave trade in 1792, relying instead on the transfer of slaves from within Jamaica to replenish his stock. Dunn finds that these 'Jamaican transfers' were older, less healthy, less functional and less durable than the Africans and concludes therefore that Foster Barham II's decision to withdraw from the slave trade fifteen years early was a mistake:

> 'When he added large numbers of overaged and unhealthy slaves from neighbouring Jamaican estates to his workforce, he unwittingly pushed the death rate at Mesopotamia above the median level for sugar estates in Westmoreland parish.' (Dunn, 1987, p 816).

In 1793, upon becoming MP for Stockbridge, Foster Barham II voted with Wilberforce to abolish the slave trade (Dunn 1987, 798; 2007, 48) and during the 1790s he adopted a policy of amelioration, informing his agents that he wished for three slaves to assume the work formerly borne by two, with adequate respite at weekends. Attorneys were also urged to give pregnant women special care, including light work duties (Dunn 1987, p 798-9). By the 1820s, however, the continued failure of the estate's population to become self-sustaining caused Foster Barham II to become disillusioned with amelioration and natalism and led him to support emancipation, provided planters received adequate compensation. He complained that slaves were 'dreadful idlers', incapable of productive endeavour because of moral failings (Dunn 1987, 800; 2007, p 49):

> 'The negro race is so averse to labour, that without force we have hardly anywhere been able to obtain it, even from those who had been trained to work' (Foster Barham II, 1823, p 8).

Black women were blamed for the estate's poor demographic performance, and in 1829 Foster Barham II threatened to cut the food rations of females who failed to produce children and to hire out as jobbers those miscarrying or suspected of aborting babies. At least two slaves who miscarried were sent to the workhouse (Dunn 1987, p 820; Dunn 1993, p 56).

Dunn's research provides far-reaching insights into life at Mesopotamia and the foundations upon which our work builds. We address the following study questions: do the data support Dunn's (1987) contention that the labour system at Mesopotamia had 'a large and quantifiable impact upon the slaves' health and life expectancy'?; do the data support Dunn's (1987) contention that Foster Barham II's decision to stop importing Africans after 1792 was a mistake because it forced him to transfer to Mesopotamia older and weaker slaves from neighbouring Jamaican estates who were at a higher risk of dying?; are there alternative explanations for the continued failure of the Mesopotamian slaves to achieve natural increase under the ownership of Foster Barham II?

3 Sources of data

Analysis is based on a panel data set constructed by the authors which tracks the fortunes of the enslaved population of Mesopotamia across annual inventories compiled between 10 July 1762 and 1 January 1832. Of these inventories, six (at three year intervals, starting in 1817 and finishing in 1832) form part of the Registration Returns preserved in The National Archives (London) and the remaining sixty-nine are preserved among the Clarendon Papers in the collections of the Bodleian Library, University of Oxford. A further inventory, for 1833, is preserved in the Jamaica Archives in Spanishtown, Jamaica.

Inventories in the Clarendon Papers were compiled for the benefit of absentee owners Joseph Foster Barham I (born 1729, died 21 July 1789) and his son, Joseph Foster Barham II (born 1759, died 1832),[1] who took over the ownership of the estate upon the death of his father. In addition to listing slaves on the estate, the inventory manuscripts record details of the livestock on the plantation, an account of expenditure incurred by the managers of Mesopotamia, details of sugar production and sale, and other sources of estate income.

Generally, for each year, the inventories in the Clarendon Papers record information about a slave's name, age, occupation, and health status. There are, however, exceptions:

1. two inventories survive for 1763 (taken on 1 January and 31 December);
2. there is virtually no information for the health and work status of slaves in the inventories for 1763 and 1764;
3. only a partial inventory survives for the year 1778;
4. no inventory survives for the year 1821.

Missing data between 1768 and 1777 is partially bridged using a separate list of deaths occurring on the estate during these years. Missing data for 1821 is bridged using the Jamaican Registration Return for 1823, which records population additions and losses between 21 June 1820 and 28 June 1823. Selected inventories in the Clarendon Papers identify whether slaves were purchased from ships importing Africans into Jamaica or were purchased as transfers from other estates within the island and the Registration Return of 20 June 1817 provides information about the origins and colour of all individuals living on Mesopotamia.[2] The Clarendon Papers include inventories compiled prior

[1] Hereafter we refer to Joseph Foster Barham I as JFB I and Joseph Foster Barham II as JFB II.

[2] Clarendon Papers, Dep.b.37.2; NA:PRO, T71/178, 79-82; T71/180, 21-22.

to 1762, but these do not record the ages of slaves, nor do they include a register of births and deaths. Consequently, the starting point for our study is the inventory taken on 10 July 1762. The only use we make of inventories taken prior to 1762 is to estimate, for those present on the estate on 10 July 1762, the time spent on the estate prior to this date. The inventory for 1833, compiled by the executors of JFB II (deceased), is of a different format to the inventories held in the Clarendon Papers and does not record births and deaths, so our study ends with the inventory of 1 January 1832.[3]

Modern research has established that the standard of bookkeeping on sugar plantations was high (Oldroyd et al., 2004) and there is no reason to doubt that the accounts were intended to provide an accurate account of the slaves on the property. Study of the inventories is complicated, however, by the variable standard of their preservation and legibility. Inventories are scattered in eight boxes of archival material and mixed with those of the Barhams' other Jamaican property, the Island Estate. Information about age, occupation, and health does, however, enable the great majority of individuals to be name-matched uniquely from inventory-to-inventory (Dunn 1977, p 39).

The most problematic element of the inventories relates to the recorded ages of slaves. Slaves can be divided into three main groups:

1. those born on the estate for whom a date of birth is known;
2. those born on the estate for whom a date of birth is not known (this includes those recorded in the inventory of 10 July 1762 and some born on the estate subsequent to this date and for whom a date of birth is not recorded);
3. those transferred to the estate either from Africa or Jamaica who were assigned an age upon arrival by the census compilers using procedures that are not always enumerated. The stated ages of those transferred from other Jamaican estates were supplied by the previous owners Dunn (1987, p 801-802).

Inspection of the raw data reveals evidence of 'heaping' of slaves' ages at five and ten year points in the inventory of 10 July, 1762 and that the ages of a majority of slaves were subject to some form of alteration during their time on the estate. For individuals born on the estate and for whom a date of birth is known, we ignored subsequent revisions to their age. For other slaves, investigations showed that the majority of ages were adjusted by only small amounts, whereas a small minority were adjusted by larger amounts, which we attribute to confusion of slaves across inventories. For example, a bookkeeper

[3] Jamaica Archives, Spanish Town, IB/11/3 vol. 150, p.25ff.

Total number of slaves identified	1148
Slaves removed, together with reason:	
not exposed to estate environment	
- never came to the estate	4
- still births	8
- runaway in all years	2
observed in one inventory only	18
date of birth and age not known	4
no information at all on slave	1
Total slaves removed	37
Total remaining for analysis	1111

Table 1: Total number of slaves identified, removed and remaining for analysis.

could confuse two slaves, both of whom are called Nancy, one aged 31 and one aged 51, by adding 20 years to Nancy Jr.'s age and subtracting 20 years from Nancy Sr.'s age. We attribute errors falling into the middle ground (such as misreading the primary digit of a person's age or misreading of end-digits) to slips of the pen.

Our conclusion from our examination of age revisions supports that of Dunn, which is that the age statements contained within the inventories are 'as accurate as such data can ever be' (Dunn, 1987, p 802).

3.1 Subjects identified, excluded and comparison with Dunn

Table 1 shows that 1148 slaves were identified and that, prior to carrying out any analysis, 37 were removed for the reasons listed, leaving 1111 slaves. Dunn (1987, p 796) identifies 1103 slaves, eight fewer than do we.

Table 2 shows that comparison of our summary statistics with those of Dunn (1987, p 797, Table 1) shows close agreement. We record 258 slaves present on the estate on 10 July 1762 (Dunn records 270 on 31 December 1761) and 329 on 1 January 1832 (Dunn records 328). We record the total number of slaves purchased by the estate to be 423, the same number as Dunn. Our data suggest that 17 slaves were imported from Africa after 1793, the year in which JFB II is said to have stopped buying from the slave ships (Dunn,

	Total	Female	Male
Population on 10 July 1762	258 (270)	112 (118)	146 (152)
Increase:			
Born on estate, date of birth known	390	199	189
Born on estate, date of birth not known	40	18	22
Born on estate (total)	430 (410)	217 (206)	211 (204)
Africans (pre-31/12/1792)	122	29	93
Africans (post-31/12/1792)	17	13	4
Africans (total)	139 (138)	42 (42)	97 (96)
Jamaican transfers	284 (285)	136 (138)	148 (147)
Decrease:			
Recorded deaths	714 (749)	301 (320)	411 (429)
Manumitted	5 (15)	3 (11)	2 (4)
Escaped	6 (7)	2 (2)	4 (5)
Sold	4 (4)	0 (0)	4 (4)
‘Right-censored’ (fate not recorded)	53	29	24
Population on 1st January 1832	329 (328)	172 (171)	157 (157)

NOTES
Nearest comparable figures of Dunn (1987), for 31 December 1761, in parentheses.
Total column for Born on estate includes two slaves for whom gender is not known.

Table 2: Population changes at Mesopotamia, 10 July 1762 - 1st January 1832.

NOTES
Estate slave stock is divided by 10.

Figure 1: Estate stocks, births and deaths by calendar year.

1987, p 797). All arrived prior to 1807, the year of abolition of the trans-Atlantic slave trade. We record 430 live births compared with Dunn's 410, possibly because we include births of infants who died soon after. We record 714 deaths compared with Dunn's 749. 53 slaves were classified as having 'right-censored' survival times, because their fate was not recorded, although the most likely reason for their exit is death.

Descriptive and non-parametric survival analyses are carried out using all 1111 subjects (21492 person-years), 1109 for analyses splitting by gender because gender is not recorded for two subjects. The Cox regressions use fewer subjects and observations because of missing values for time-varying covariates for some subjects.

Figure 1 shows how the stock of slaves on the estate changed during the study period (the estate total is divided by 10 in this figure), together with the number of births and deaths by calendar year. The stock shows an upward trend, with variation due to the flows in to and out of the estate for the reasons listed in Table 2. Recorded deaths exceed recorded births for the majority of years. Notable peaks in deaths occur in 1767/8 (28 deaths, many due to smallpox), 1777 (20 deaths, during the American War of Independence), the years including and surrounding 1816 (there were 75 deaths between 1st

January 1815 and 31 December 1819, around half of which were due to infectious/parasitic disease) and 1830 (20 deaths).

4 Survival analysis and the healthy worker survivor effect

Our methods follow the approach of Tunali and Pritchett (1997), who analysed the mortality experience of residents of New Orleans during the yellow fever epidemic of 1853. We consider three concepts of analysis time: 1. calendar time (the number of days elapsed from 9 July 1762, the day prior to the date of the first inventory, non-parametric analysis only), 2. time spent on the estate and 3. slave's age. The survival analysis accounts for left-truncation (not all subjects are under observation from the origin time) and right-censoring (not all subjects are observed to fail) and failure, left-truncation and right-censoring times are dependent upon the analysis time used. Dates used to define analysis time are measured to the day, that is, DD/MM/YYYY, subsequently rescaled so that analysis time is measured in years. Section A.1 describes in detail how each analysis time is calculated and how risk sets are affected.

Regardless of the concept of analysis time used, for $i = 1, \dots, n$ subjects, define the random vector (L_i, Y_i, δ_i), comprising:

1. $Y_i = \min(T_i, C_i)$, the analysis time, the minimum of $T_i \in \mathbb{R}_+$, the failure (or survival) time, and $C_i \in \mathbb{R}_+$, the time of right-censoring. Right-censored survival times exist for slaves present on the estate when the final inventory was taken, slaves who ran away from the estate never to return, slaves freed or sold, and slaves whose fate is unknown;

2. $L_i \in [0, Y_i)$, the left-truncation time;

3. δ_i, an indicator variable equal to one if the subject dies and zero otherwise.

Following Tunali and Pritchett, conditioning on the explanatory variables used by us to affect survival time, we treat (L_i, Y_i, δ_i) as representing random draws from an unobserved population of slaves, about which we make inferences.

Putting aside those subjects for which the reason for having a right-censored survival time is known, our analysis assumes that, conditional upon the values of the explanatory variables, a subject with right-censoring time c is representative of all other subjects surviving to time c (Cox and Oakes, 1984, p 5). This assumption might be broken if, for example, poor record-keeping at Mesopotamia meant that those subjects with right-censored survival times for reasons unknown died soon after the censoring time. Although it is not possible to test nonparametrically whether T_i and C_i are independent (realisations of only one or the other are observed), we did test whether the right-censoring process is 'noninformative', by estimating logit models of whether the probability of having a right-censored survival time for a reason unknown is correlated with any of the main measured explanatory variables (which, in turn, could be correlated with failure time). We also checked how sensitive our main results were to reclassifying such right-censored failure times as actual failure times (as suggested by Collett (2003, p 318-320)).

Further, given that Keiding (1992) shows that, when L and T are dependent, the standard, delayed-entry approach to constructing risk sets for non-parametric and semi-parametric survival analysis yields biased estimates of the hazard function, we used the nonparametric method suggested by Tsai (1990) to test for so-called 'quasi-independence' between L and T. Section A.2 defines quasi-independence and outlines the intuition behind Tsai's test.

4.1 Survival analysis

Nonparametric, exploratory, survival analysis of the data was useful in summarising the survival experience of different groups of slaves and potentially non-proportional relationships between hazard functions, and allowed us to make comparisons with Dunn's (1987) descriptive analysis. Our main semi-parametric analysis consisted of unstratified and stratified Cox regression models for females and males, using time on the estate and age as the analysis time.

The hazard function - or age-specific failure rate - defines the probability of failing at t conditional upon surviving until at least t:

$$h(t) = \lim_{\Delta t \to 0+} \frac{\Pr(t \leq T < t + \Delta t | t \leq T)}{\Delta t}, \tag{1}$$

and the survival function $S(t)$, is defined as $S(t) = \Pr(T \geq t)$ (Cox and Oakes, 1984).

Let there be $j = 1, \ldots, m$ failures ($m < n$) with failure times $T_{(j)}$. Order the failure times from lowest to highest: $T_{(1)} < T_{(2)} \ldots < T_{(m)}$. At each failure time, define the number of failures as $D_{(j)} \geq 1$ and the number 'at risk' of failing as $R_{(j)}$, the number of elements of the 'risk set' $\mathcal{R}_{(j)}$, the set of all subjects at risk of failing at $T_{(j)}$ ($\mathcal{R}_{(j)} = \{i : L_i < T_{(j)} \leq Y_i\}$). Assuming that deaths occur independently, the Kaplan-Meier estimator of the survival function is $\hat{S}(t) = 1$ for $t < t_{(1)}$ and:

$$\hat{S}(t) = \prod_{j=1}^{k} \left(1 - \frac{d_{(j)}}{r_{(j)}}\right), \quad t \in [t_{(k)}, t_{(k+1)}), k = 1, \ldots, m.$$

We also obtained Kernel-smoothed estimates of the hazard function, derived from the Nelson-Aalen estimator of the cumulative hazard function (Nelson (1972) and Aalen (1978)) using the Epanechnikov kernel smoother (Klein and Moeschberger, 1998, p 152-9).

In Cox regression with time-dependent covariates, define t to be the support on which the hazard function is defined and let the observations on subjects consist of $(L_i, Y_i, \delta_i, [\mathbf{x}_i(t), L_i \leq t \leq Y_i])$, where $\mathbf{x}_i(t)$ is a column vector of time invariant and time-varying covariates, including measurements of time-varying covariates taken at baseline, fixed factors (such as gender) and the number of years of exposure to fieldwork and the number of years spent in good health. The Cox regression model (Cox, 1972) assumes that the hazard function for subject i is the product of a non-specified 'baseline hazard function', $h_0(t)$, and a proportionality factor $\exp(\boldsymbol{\beta}'\mathbf{x}_i(t))$:

$$h_i(t; \mathbf{x}_i(t)) = h_0(t) \exp(\boldsymbol{\beta}'\mathbf{x}_i(t)), \tag{2}$$

where $\boldsymbol{\beta}$ is a column vector of parameters.

The probability that j fails at t, conditional upon being at risk, is:

$$\frac{h_j(t; \mathbf{x}_j(t))}{\sum_{k \in \mathcal{R}_{(j)}} h_k(t; \mathbf{x}_k(t))} = \frac{h_0(t) \exp(\boldsymbol{\beta}'\mathbf{x}_j(t))}{\sum_{k \in \mathcal{R}_{(j)}} h_0(t) \exp(\boldsymbol{\beta}'\mathbf{x}_k(t))}.$$

Since information is only provided at distinct failure times, the partial likelihood function is given by:

$$\mathcal{L}(\boldsymbol{\beta}) = \prod_{j=1}^{m} \left(\frac{\exp(\boldsymbol{\beta}'\mathbf{x}_j(t))}{\sum_{k \in \mathcal{R}_{(j)}} \exp(\boldsymbol{\beta}'\mathbf{x}_k(t))} \right). \tag{3}$$

The estimator of $\boldsymbol{\beta}$ arising from maximising the logarithm of (3) is asymptotically normal, and the standard results from maximum likelihood estimation concerning the derivation of the variance-covariance matrix and likelihood ratio tests apply (Cox (1975) and Collett (2003, p 67 - 69)).[4]

To allow for non-proportional relationships between hazard functions according to the source of slave, we also estimated stratified proportional hazards models. Let there be three strata denoted $y = 1, \ldots, 3$ representing, respectively, slaves imported from Africa, slaves transferred from Jamaica and slaves born on the estate. Then the hazard function for individual i in the yth stratum becomes (Klein and Moeschberger, 1997, p 282):

$$h_i(t; \mathbf{x}_i(t)) = h_{0iy}(t) \exp(\boldsymbol{\beta}'\mathbf{x}_i(t)), \ \ y = 1, \ldots, 3. \tag{4}$$

[4] We have assumed no ties between failure times. In estimating, we used Breslow's method to deal with tied failure times.

We carried out sensitivity analysis of one of our main results - the association between mortality risk and estate ownership - by running alternative Cox models which made different assumptions about the treatment of controlling for elapsed calendar time, right-censoring, left-truncation and the definition of estate ownership.

Baseline health status and/or fieldwork was set to the value of the nearest non-missing value. Values of the main time-varying covariates were assumed to apply retrospectively: denoting the set of inventories by $\mathcal{S} = \{1, 2, \ldots, 69\}$, a covariate's value in inventory $s \in \mathcal{S}$ was assumed to hold between inventory $s - 1$ and s. The only exception to this rule occurs for the period between the last inventory in which a slave appears and the slave's death, in which case the values recorded in the final inventory are carried forward. Because of a large number of missing values on health and work status in the inventory immediately prior to the deaths of slaves, we carried forward the most recent non-missing value if it was recorded in one of the three inventories prior to the slave's death. Some missing values on health status and work status remained, as did some slaves who ran away from the estate only to return to it later. These were classed as being 'interval truncated' between inventory $s - 1$ and s (Cleves et al., 2008, p 36).

4.2 The healthy worker survivor effect

Cox regressions can yield biased estimates of the effect of working in strenuous occupations such as fieldwork on mortality risk in the presence of what is known as the 'healthy worker survivor effect'. In our study, this could occur if: (a) a slave's work status ('exposure') at t is, in part, determined by the slave's state of health at, and/or prior to, t and health status itself is correlated with mortality risk and (b) health status at t is influenced by the subject's exposure history prior to t (Robins, 1986, 1992). In such a situation, health status is a time-varying confounder for the relationship between exposure and mortality risk and is also an 'intermediate variable' on the causal pathway between exposure and mortality risk, since part of the detrimental impact on mortality risk of being exposed is transmitted via health. To control for time-varying confounding, health status should be included in the Cox regressions, but in doing so, only the direct impact of work status on mortality risk (the element that is not transmitted through its effect on health) can then be estimated (Robins et al., 1992, Witteman et al., 1998).

To obtain an unbiased estimate of the effect of fieldwork on all-cause mortality risk and survival time, we use the method of 'G-estimation' (Robins, 1986, Robins et al., 1992). Consider a set of 'counterfactual failure times', which define the time subject i would spend on the estate, were they to work in fieldwork for a defined period. Within this set, define N_i as the counterfactual failure time if i is never exposed to fieldwork and W_i as the counterfactual survival time if i is continuously exposed. Define the relationship between the two as:

$$W_i = N_i \exp(-\psi_0), \tag{5}$$

where $\psi_0 \in \mathbb{R}$ is an unknown parameter to be estimated. If $\psi_0 = 0$, being exposed has no impact on survival time; if $\psi_0 < 0$, exposure increases it and if $\psi_0 > 0$, it decreases it. Let T_i be the actual failure time for subject i. The counterfactual failure time function $G_i(\psi)$ is:

$$G_i(\psi) = \int_0^{T_i} \exp(\psi.\text{fieldwork}_i(t))dt, \tag{6}$$

where $\text{fieldwork}_i(t)$ is an indicator variable equal to one if the subject is exposed and zero otherwise.

Assume no right-censoring of failure times and no competing risks of death. Further assume that, at each inventory point, we include in our model all variables which confound the relationship between exposure to fieldwork and survival time. If the null hypothesis $\psi_0 = 0$ is true, for subjects with identical histories and controlling for all confounding variables, exposure at each inventory will be independent of the *observed* survival times for these subjects. Denote $\mathbf{W}_{it}$ as the column vector of the exposure variable history and all baseline and time-varying confounding variables, including their histories, and γ as the related column vector of parameters. A test of the null hypothesis that $\psi_0 = 0$ is a test that $\gamma_G = 0$ in the model:

$$\text{logit}(\text{fieldwork}_{it} = 1|\mathbf{W}_{it}, G_i(\psi), T_i > t) = \alpha_k + \boldsymbol{\gamma}'\mathbf{W}_{it} + \gamma_G G_i(\psi), \tag{7}$$

where $\psi = 0$ in (6), that is, $G_i(\psi) \equiv T_i$ in (7). If the null is rejected, the 'G-estimate' $\bar{\psi}$ of ψ_0 is obtained by varying ψ in (6), estimating (7) with the appropriate values of $G_i(\psi)$, and choosing the value of ψ which yields a p-value equal to 1 for the test $\gamma_G = 0$ (Witteman, 1998; we used a threshold of 0.999 or greater for the p-value). A 95% confidence interval for ψ_0 covers the values of ψ which fail to reject the null hypothesis that $\gamma_G = 0$ at the 5% level, that is, the interval for which the p-values for the Wald test of this null are greater than 0.05 (Robins, 1992).

We chose to estimate ψ for the cohort of adult slaves present on the estate on 31 December 1766, allowing us to follow-up all subjects in the cohort until they died. We estimated separate models for females and males and a model which included both. As regressors we included the source of the slave, gender (pooled model only), a dummy variable for whether the subject was risk during JFB II's period of ownership, current health status, baseline health and work status and cumulative person-years spent in good health and in fieldwork, lagged by one inventory. We used the stgest STATA program, written by Sterne and Tilling (2002), to carry out G-estimation. Our program used a grid search for ψ and we chose the value of $\bar{\psi}$ which corresponded to a p-value of 0.999 or greater.

5 Results

5.1 Descriptive analysis

Table 3 reports descriptive statistics for the main time-invariant variables, comparing the non-parametric and Cox regression samples. 647 (58%) of the 1111 slaves were born on the estate and 465 were transfers to the estate, either prior to the first inventory (purchased from the slave ships) or during the observation period (purchased from the slave ships and transferred from within Jamaica). The 284 slaves transferred from within Jamaica came from the estates of Three Mile River (in 1786), Southfield Pen (1791), Cairncurran (1814), Springfield (1819) and estates owned by a neighbouring estate owner, John Wedderburn (1792/3). Table 3 shows little evidence that any of the time-invariant variables are under- or over-represented in the Cox regression samples.

As Table 4 shows, the sample is split quite evenly between subjects first observed during JFB I's period of ownership and JFB II's. A total of 521 subjects were first observed under JFB I and 588 under JFB II. Those born on the estate are almost equally split (322 and 323). The table highlights the switch from African imports to Jamaican transfers with the change of ownership and the higher number of women transferred to the estate during JFB II's period of ownership.

For time-varying covariates, inventories categorised the health status of slaves as follows: 'able/healthy', 'unhealthy', 'disabled', 'not stated' (treated as a missing value for health), 'other' and 'disabled and unhealthy'. We defined the binary variable 'Good health', equal to one if health status was able/healthy and zero if it was not. Table 5 presents the number of years spent in the health state able/healthy for the full sample. It shows that both male slaves and female slaves spent just under half their respective total number of person years in an able/healthy state, figures which are comparable with Dunn's (1987, Table 4, p809)

The inventories measured the work status of slaves using the categories

	Nonparametric survival analysis				Cox regression sample			
	Female		Male		Female		Male	
	n	Proportion	n	Proportion	n	Proportion	n	Proportion
Gender								
Male	-	-	602	-	-	-	564	1.00
Female	507	-	-	-	466	1.00	-	-
Transfers to estate								
African imports	54	0.106	126	0.209	54	0.116	120	0.213
Jamaican transfers	136	0.269	148	0.246	136	0.292	145	0.257
Born on estate	317	0.625	328	0.545	276	0.592	299	0.530
Estate owner								
First observed under JFB I	210	0.419	311	0.511	191	0.410	286	0.507
First observed under JFB II	291	0.581	297	0.488	275	0.590	278	0.493

Table 3: Descriptive statistics for time-invariant variables.

	JFB I		JFB II	
	Female	Male	Female	Male
African imports	40	120	14	6
Jamaican transfers	15	24	121	124
Born on the estate	155	167	162	161
Total	210	311	297	291

Table 4: Sources and gender of slaves first observed during JFB I's and II's period of ownership.

listed in Table 6. Where an inventory recorded more than one job for a slave, the higher status job was used to classify the slave's occupation. Estate journals for other plantations make clear that slaves did not always have one occupation throughout the season (Dunn, 1977 p 56-7; Roberts, 2006). For example, 1st and 2nd gangs might be merged for part of the year and/or fieldworkers re-assigned to the works. Some of the original classifications, such as 'boiler and field', or 'jobber and field', reflect this (Dunn, 1987, p 806). Assigning one employment category to a slave is, therefore, a simplification.

To create a manageable, parsimonious, variable to classify slaves' work status, we defined the variable 'Active work' to denote a slave in an active occupation, equal to one if the slave was employed in any of the categories up to and including domestics in Table 6 and zero otherwise. We also created the variable Fieldwork, equal to one if the slave was employed in any of the fieldwork categories listed in Table 6 and zero otherwise. According to Dunn (1987, p 805), those members of the field first gang 'performed the hardest physical labour by far'. Table 5 presents the number of person-years spent in these categories. It reveals that male and female slaves spent just over 50% of their total person-years in active occupations. The table highlights the major role played by women in fieldwork: for females, 54% of total person-years were spent in fieldwork, compared with 36% for men.

5.1.1 Causes of death

The Jamaican Consolidated Slave Law of 1792 required a doctor to give, on oath, 'an account of slaves dying, with, to the best of his judgement, the causes thereof, under penalty of £100 for each neglect' (Edwards, 1806: iv, p 389). Causes of death were written up by the white overseers of the estate based

	Full sample				Cox regression sample			
	Female		Male		Female		Male	
	Person-years	Proportion	Person-years	Proportion	Person-years	Proportion	Person-years	Proportion
Health								
Full sample								
Good health	4999	0.529	5556	0.547	4933	0.533	5472	0.549
Not good health	4452	0.471	4610	0.453	4318	0.467	4496	0.451
Missing	775	-	1100	-	-	-	-	-
Total	10226	1.000	11266	1.000	9251	1.000	9968	1.000
Work								
Active work	5103	0.516	6345	0.585	-	-	-	-
Not active work	4795	0.484	4502	0.415	-	-	-	-
Fieldwork	5275	0.533	3851	0.355	5062	0.547	3594	0.361
Not fieldwork	4623	0.467	6997	0.645	4189	0.453	6374	0.639
Missing	328	-	419	-	-	-	-	-
Total	10226	-	11266	-	9251	-	9968	-

Table 5: Person-years spent in various health states and work categories: full sample and Cox regression sample.

Classification	Description
Drivers and 'head people'	Drivers directed the field gangs. Head people supervised (e.g. 'head cooper' and 'head watchman').
Craftworkers	Skilled artisans including carpenters, coopers, blacksmiths, masons, distillers and boilers.
Stockkeepers and transport	Slaves working with animals, including herders, and/or in the transportation of plantation produce, including penkeepers, stable hands, mulemen and carters.
Fieldworkers	Slaves carrying out agricultural tasks on the estate. Divided into different gangs, of which 1st and 2nd gang carried out the most strenuous tasks, including holing and harvesting, and the 3rd gang lighter tasks (such as weeding).
Fieldworker, children's gang	Provided young slaves with an introduction to agricultural work, including tasks such as weeding and gathering fodder.
Domestics	Included housekeepers, grooms, and other attendants of white overseers and missionaries.
Marginal workers	Carried out miscellaneous tasks including ratcatching, fence lopping, jobbing, gardening, fishing, water carrying and field cooking.
Watchmen and nurses	Nurses and older and/or infirm slaves who watched crops (for security purposes).
Not stated	Children too young to be in active occupations or adults in poor health and not in active occupations.
Not working	Not working in an occupation classified by the census enumerators. These individuals may, nevertheless, have worked to support themselves in subsistence cultivation or related activities.

Table 6: Slave occupations.

(a) (b)

Figure 2: (a) Changes in stocks children, females and males actively employed; (b) Ratio of women to men in fieldwork.

on this information, which is problematic for many reasons: not all deaths are recorded, especially for babies and young infants, and when a death is recorded, the cause death is not always stated. We listed causes of death using contemporary descriptors (67 separate descriptors were found). Deaths were then re-classified using ICD-10 (World Health Organisation, 2007). Analysis of the major causes of death on the estate showed them to be due to infectious/parasitic diseases (around 39%), senility (17%) and 'general debility' (13%).

5.1.2 Estate profile over time

The inventory of 10 July 1762, records 258 slaves present on the estate, no runaways, 57% of whom were male, the youngest individual having a recorded age of 1 and the oldest 78 (mean age is 30). 85% of slaves had been born on the estate and 15% had been purchased from Africa. Of those with a health status recorded, 42% were in good health. Of those with a work status recorded, 80% were in active employment.

In the inventory of 1 January 1832, the estate's population had risen to 329, 22 of whom were classified as runaways. Mean age was 31, virtually unchanged from 1762, and the percentage of male slaves had dropped to 46%. 64% had been born on the estate, only eleven Africans purchased from the slave ships remained, with the balance of 99 (32%) comprising the transfers from other estates within Jamaica. Half of the 306 slaves for whom health status was recorded were in good health. Of the 279 slaves for whom work status was recorded, only half were in active employment, a large drop from the 80% in 1762.

Figures 2(a) and (b) show how the stocks of children, working females and working males, changed over time. Two features stand out. The first is the growing prominence of women fieldworkers after JFB II took over the ownership of the estate in 1789, a point noted by Dunn (1987, p 812). The rise in the ratio of women to men working in the field - from a steady 1:1 during JFB I's ownership, to a peak of 4.1:1 in 1810 - reflects both a fall in the number of actively employed males (from 108 in 1792 to just 59 in 1814) and an increase in females employed in fieldwork. The second notable feature is the fall in the number of children between 1802 and 1814, which contrasts with large increases after 1792/3, 1814, and 1819, the years of the transfers from Wedderburn, Cairncurran, and Springfield, respectively.

Table 7 compares the age and health profiles of the transferred slaves with those of the stock on the estate recorded in the inventory immediately prior to the time of transfer (since African imports were transferred at various points between 1762 and 1807, the comparator group is all slaves, other than African imports, at the first time that they appeared on the estate). Also presented are the median times spent on the estate for each group. For slaves born on the estate, the figures are restricted to show only those followed from birth. For this group only, the median figures represent median lifetimes.

African imports were, on average, older than the estate average at first inventory listing, had roughly the same proportion of unhealthy slaves and fewer healthy slaves, but missing values for both African imports and those born on the estate make the comparison of health status difficult. For transfers from estates other than Springfield, the average age of the transferred slaves was less than that of the average on the estate at the time. Transfers from Three Mile River, Wedderburn and Cairncurran were, on average, in better health than those on the estate at the time of the transfer. Those from Southfield Pen were in a slightly lower state of health and those from Springfield were in a similar state of health. For those born on the estate and followed from birth, median lifetime was slightly higher for females (36 years) than for men (34 years).

5.2 Tests of independence of truncation and failure times and noninformative censoring

Results of our nonparametric tests for the independence of left-truncation and failure times are reported in Table 8. None of the tests rejected the null hypothesis of independence between failure and right-censoring times at a 5% significance level.

The results of logit models using as the independent variable an indicator

	Year	Females						Males					
		Number of subjects	Mean age upon arrival	Proportion*			Median time on estate	Number of subjects	Mean age upon arrival	Proportion*			Median time on estate
				Healthy	Unhealthy	Other*				Healthy	Unhealthy	Other	
African imports	various	54	22	0.420	0.260	0.320	30	126	22	0.466	0.195	0.339	22
All other slaves (at first listing)	-	441	16	0.511	0.240	0.249		464	15	0.559	0.191	0.250	
Jamaican transfers													
Three Mile River	1786	15	25	0.667	0.333	0.000	34	24	23	0.833	0.167	0.000	25
Estate stock in 1786	-	105	31	0.490	0.462	0.280		151	28	0.497	0.450	0.053	
Southfield Pen	1791	28	25	0.464	0.536	0.000	22	29	24	0.444	0.518	0.037	18
Estate stock in 1791	-	128	30	0.535	0.457	0.079		160	30	0.506	0.462	0.031	
Wedderburn	1792/3	19	11	1.000	0.000	0.000	22	11	11	0.818	0.182	0.000	30
Estate stock in 1792	-	159	30	0.532	0.456	0.013		190	29	0.500	0.463	0.037	
Cairncurran	1814	25	27	0.680	0.320	0.000	-**	28	23	0.857	0.107	0.036	-**
Estate stock in 1814	-	155	31	0.619	0.368	0.013		135	28	0.674	0.311	0.015	
Springfield	1819	49	33	0.604	0.354	0.004	-**	56	30	0.717	0.283	0.000	13
Estate stock in 1819	-	164	30	0.656	0.325	0.018		146	28	0.648	0.324	0.028	
Born on the estate and followed from birth	various	199	0				36	190	0				34

NOTES
∗ Proportions based on slightly fewer subjects due to missing values.
∗∗ Where median not given it is because fewer than 50% of the slaves had died by 1832.

Table 7: Various age, health and survival descriptive statistics by source of slave.

Sample/subsample	n	Failures	K^*	p
Time on estate as analysis time				
Full sample	1111	698	-0.53	0.60
Females	507	298	-0.32	0.75
Males	602	398	-0.90	0.37
Age as analysis time				
Full sample	1111	698	-0.62	0.54
Females	507	298	0.42	0.67
Males	602	398	-1.65	0.10

Table 8: Conditional Kendall's Tau test results for independence of failure and truncation time.

variable equal to one if the survival time on a subject was right-censored for reasons unknown, and zero otherwise, are reported in Table 17 in the Appendix. For females, there is no evidence to suggest that being censored for a reason unknown is significantly associated with any of the explanatory variables. For males, only one parameter estimate - Good health - is significant at the 5% level. We concluded from this that there is little evidence that informative censoring is a major issue. We did, nevertheless, test the sensitivity of the Cox regression results to alternative models which treated these right-censored survival times as failures.

5.3 Non-parametric survival analysis

Figures 3(a) and (b) show, respectively, the smoothed estimates of the hazard functions according to gender and the source of slave, using calendar time as the analysis time. The estimate for males lies above that for females for the majority of the period. That for slaves born on the estate is relatively steady, at between 2% and 4%, in contrast to the rising estimate for slaves imported from Africa: few were purchased after 1793 and none at all following the closure of the trans-Atlantic slave trade in 1807, leaving an ageing cohort.

Figures 3(c) and (d) show the Kaplan-Meier estimates of the survival functions, split by gender and estate ownership, using, respectively, time on the estate and age as the analysis times. The figures show the contrasting fortunes of females and males according to the owner of the estate: females first observed under JFB II have similar survival prospects to men first observed

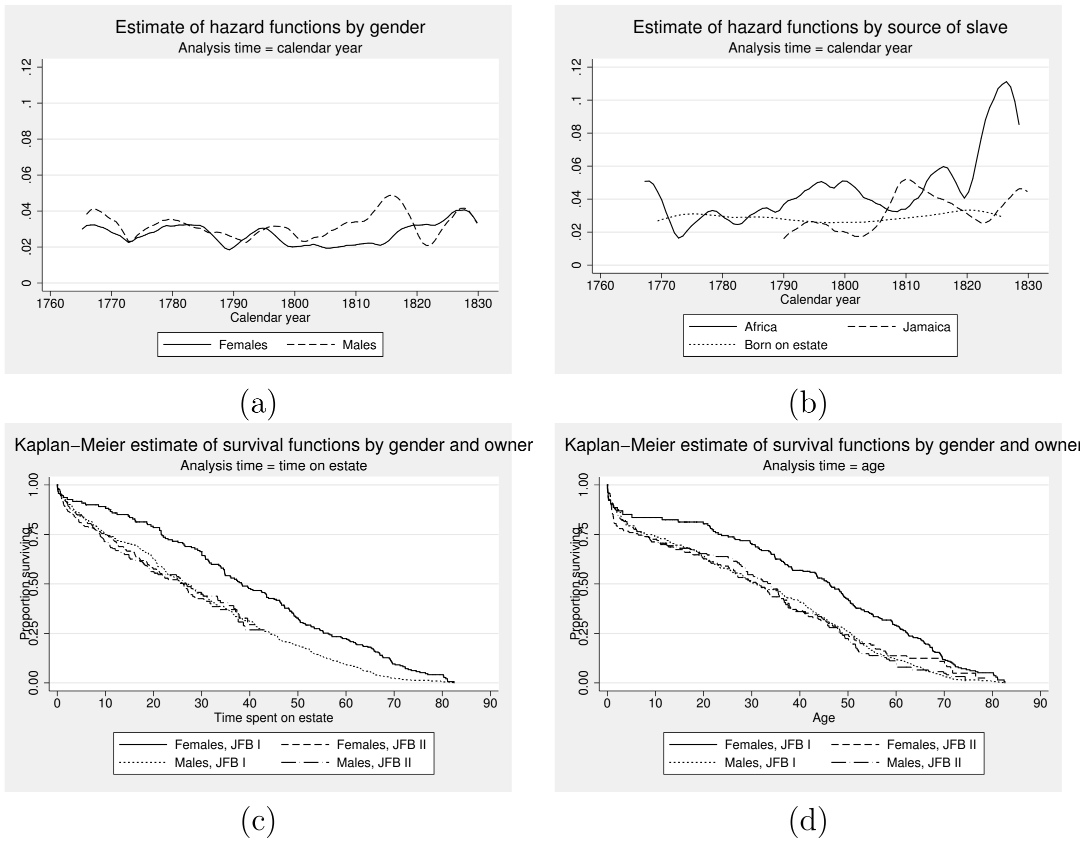


Figure 3: Estimates of hazard and survival functions: (a) hazard functions, calendar year as analysis time, by gender; (b) hazard functions, calendar year as analysis time, by source of slave; (c) survival functions, time on estate as analysis time, by gender and owner; (d) survival functions, age as analysis time, by gender and owner.

under JFB I and JFB II, but females first observed under JFB I have better survival prospects than any of these other groups. This result holds whether time spent on the estate or age is used as the analysis time. Figures 4(a) and (c) show the higher mortality risk of females under JFB II compared with females under JFB I by comparing the smoothed estimates of the hazard functions (Figures 4(b) and (d) show the result is not apparent for males). The different mortality risks for females according to the owner of the estate were statistically significant in Cox proportional hazards models which used as a regressor only whether the slave was first observed during JFB II's period of ownership (see section A.4.1).

Figures 4(e) and (f) show the smoothed estimates of the hazard functions for the three sources of slave (Africa, Jamaica and born on the estate). Only

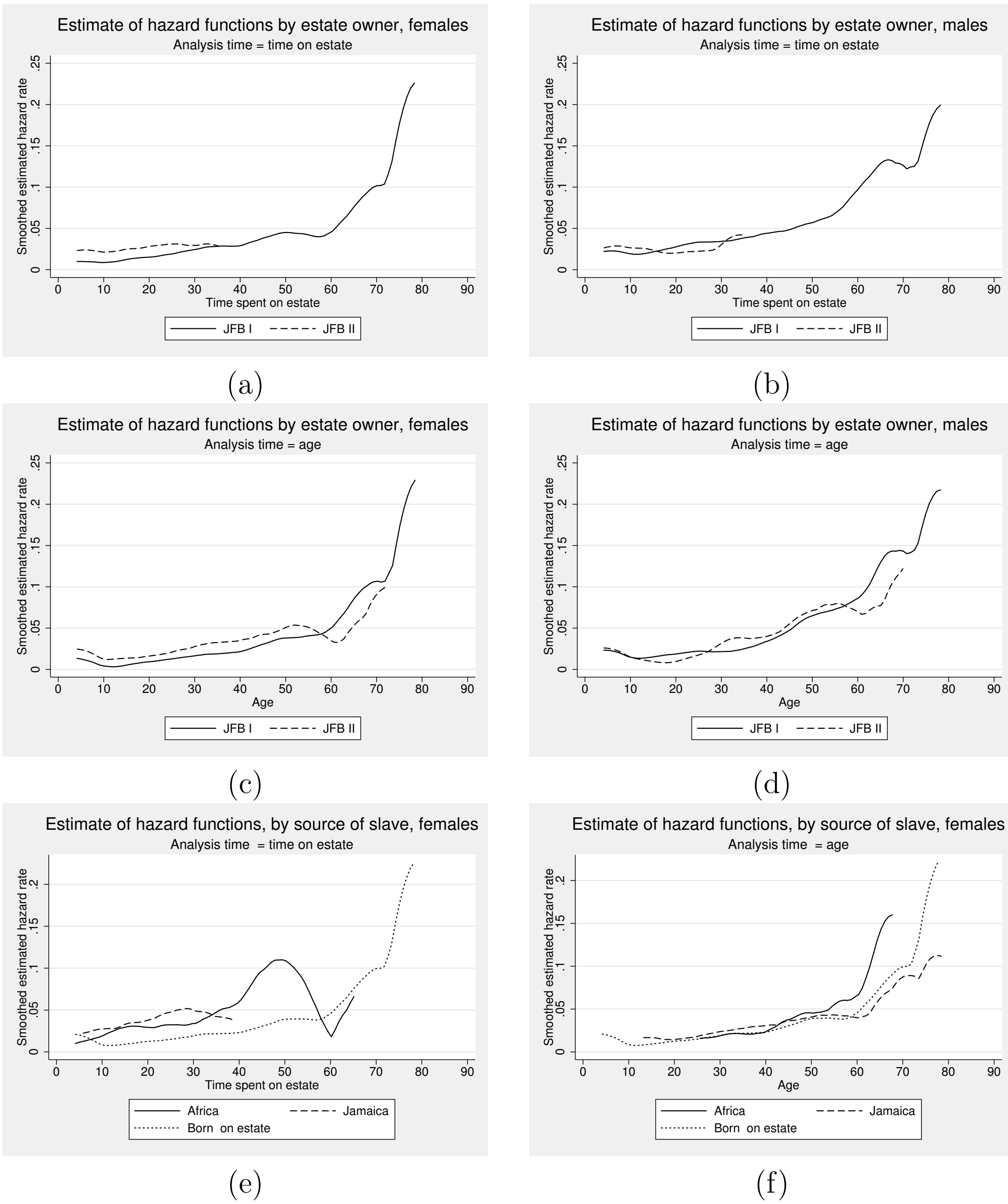


Figure 4: Estimates of hazard functions: (a) by owner, time on estate as analysis time, females; (b) by owner, time on estate as analysis time, males; (c) by owner, age as analysis time, females; (d) by owner, age as analysis time, males; (e) by source of slave, time on estate as analysis time, females; (f) by source of slave, age as analysis time, females.

the figures for females are presented; those for males show similar relationships. The estimates for those born on the estate are identical whether time on the estate or age is used as the analysis time. When time on the estate is the analysis time, the estimates for those imported from Africa and transferred within Jamaica both lie above that for those born on the estate, results confirmed by Cox proportional hazards models using as regressors only whether the slave was imported from Africa or transferred from within Jamaica (see section A.4.2). These models reported no significant difference between the parameter estimates for African imports and Jamaican transfers. When age is used as analysis time, the estimates of the functions show less separation and the simple Cox regressions suggested no significant differences between them (see section A.4.2). We attribute these results to the fact that the hazard function for those born on the estate is tracking subjects by age and, for any given elapsed time spent on the estate, African and Jamaican transfers are older and therefore at a greater risk of death. Contrary to Dunn's descriptive findings, the results provide little evidence that Jamaican transfers fared any better or worse than African imports.

5.4 Cox regression models

Table 9 presents the descriptive statistics for the Cox regression models and results are presented in Tables 10 (models 1 to 4, using time on the estate as the analysis time) and 11 (models 5 to 8, using age as the analysis time). Parameter estimates are presented as log hazard ratios for all explanatory variables. Each table presents the results of non-stratified and stratified models for female slaves and then male slaves, with stratification based on the source of the slave (Africa, Jamaica and born on the estate). The full set of diagnostic tests for the models is presented in Table 12 and plots of the cumulative Cox-Snell residuals are presented in Figures 5(a) to (h).

Choice of covariates was based on the main study questions outlined on page 6, the need to control for possible confounders, including measures of the cumulative number of years spent in good health and in fieldwork and the time elapsed since the first inventory (we used a cubic term to model this and do not report the parameter estimates in the tables). For the models using time on the estate as the analysis time, a main effect for age is not included because, for the baseline group (those born on the estate), time on the estate equals age. For the models using age as the analysis time, a main effect for time spent on the estate is not included for a similar reason. Where likelihood ratio tests suggested that a squared interaction term between the source of the slave and age or time spent on the estate was necessary, we included this variable. Where diagnostic tests rejected the null hypothesis of a proportional

	Females		Males	
	Mean	St. Dev.	Mean	St. Dev.
Source of slave				
African	0.141	0.348	0.236	0.425
Jamaican transfer	0.232	0.422	0.209	0.406
Born on estate (omitted)	0.627	0.484	0.555	0.497
Source of slave interacted with slave's age				
(models using time on estate as analysis time)				
Age (in years) × African	5.421	14.363	8.711	16.985
Age (in years) × Jamaican transfer	8.320	17.088	6.922	15.193
Age (in years) × Born on estate (omitted)	18.032	21.017	15.008	19.236
Source of slave interacted with time on estate				
(models using age as analysis time)				
Time on estate (in years) × African	2.855	8.716	4.803	10.772
Time on estate (in years) × Jamaican transfer	2.950	7.224	2.500	6.591
Time on estate (in years) × Born on estate (omitted)	18.033	21.017	15.008	19.236
Estate ownership				
First observed under JFB II	0.431	0.495	0.402	0.490
Health				
Good health baseline	0.773	0.419	0.798	0.401
Years in good health$_{t-1}$	9.342	8.915	8.500	8.724
Good health	0.532	0.499	0.545	0.498
Work				
Field work at baseline	0.388	0.487	0.320	0.466
Years in fieldwork$_{t-1}$	9.615	9.715	5.836	6.632
Field work	0.539	0.499	0.354	0.478
Years since 9 July 1762				
Calendar time / 10	4.105	1.839	3.855	1.853
(Calendar time / 10)^2	20.229	14.527	18.300	14.374
(Calendar time / 10)^3	109.07	100.89	96.484	98.397
Number of observations	9333		10111	
Person-years at risk	9251		9968	
Number of subjects	466		564	
Number of failures	263		366	

Table 9: Descriptive statistics and variable definitions for the non-stratified Cox regressions.

Model	Female slaves Not Stratified 1	Female slaves Stratified 2	Male slaves Not Stratified 3	Male slaves Stratified 4
African	-0.190		-0.580	
	(-0.28)		(-1.28)	
Age × African	0.019		0.018*	
	(1.42)		(2.14)	
Jamaican transfer	0.206		-1.098*	
	(0.53)		(-2.57)	
Age × Jamaican transfer	0.003		0.025**	
	(0.43)		(2.79)	
First observed under JFB II	0.556*	0.482*	-0.080	-0.133
	(2.42)	(2.02)	(-0.37)	(-0.63)
Good health baseline	-0.045	-0.106	-0.110	-0.142
	(-0.26)	(-0.58)	(-0.77)	(-1.02)
Years in good health$_{t-1}$	0.007	0.008	0.009	0.011
	(0.59)	(0.67)	(1.09)	(1.45)
Good health	-0.956***	-1.072***	-0.839***	-0.915***
	(-4.42)	(-4.77)	(-3.92)	(-4.00)
Good health $\times t \geq 15$			-0.582*	-0.457
			(-1.97)	(-1.44)
Fieldwork baseline	-0.227	-0.207	0.367	0.334
	(-1.18)	(-1.06)	(1.46)	(1.19)
Fieldwork baseline $\times t \geq 15$			-0.225	-0.202
			(-0.83)	(-0.64)
Years in fieldwork$_{t-1}$	0.030	0.020	-0.052*	-0.055*
	(1.15)	(0.77)	(-2.09)	(-2.19)
Years in fieldwork$^2_{t-1}$	-0.001	-0.001	0.002	0.002
	(-1.72)	(-1.55)	(1.93)	(1.94)
Fieldwork	-0.749***	-0.635***	-0.183	-0.055
	(-4.41)	(-3.47)	(-1.20)	(-0.34)
Age × transfer		-0.001		0.025**
		(-0.10)		(3.14)
Person years at risk	9251		9968	
Number of subjects	466		564	
Number of failures	263		366	
χ^2(df)	125.046 (15)	69.401 (12)	144.156 (17)	103.851 (14)
p	0.000	0.000	0.000	0.000

NOTES
1. Parameter estimates are log hazard ratios. t statistics in parentheses.
2. * $p < .05$, ** $p < .01$ and *** $p < .001$.
3. Parameter estimates for cubic expression measuring elapsed time since first inventory are not reported.
4. Huber/White/sandwich estimator of variance used.

Table 10: Results of Cox regressions using time on the estate as analysis time.

Model	Female slaves Not Stratified 5	Female slaves Stratified 6	Male slaves Not Stratified 7	Male slaves Stratified 8
African	0.211		0.796	
	(0.56)		(1.85)	
Time on estate × African	0.007		-0.051	
	(0.68)		(-1.89)	
Time on estate^2 × African			0.001	
			(1.63)	
Jamaican transfer	0.186		-0.776*	
	(0.54)		(-1.98)	
Time on estate × Jamaican transfer	-0.007		0.120**	
	(-0.55)		(2.85)	
Time on estate^2 × Jamaican transfer			-0.004**	
			(-3.18)	
First observed under JFB II	0.614*	0.611**	-0.158	-0.183
	(2.55)	(2.62)	(-0.76)	(-0.87)
Good health baseline	-0.014	-0.088	-0.104	-0.080
	(-0.08)	(-0.48)	(-0.75)	(-0.57)
Cumulative good health$_{t-1}$	0.011	0.016	0.009	0.007
	(0.90)	(1.22)	(1.16)	(0.94)
Good health	-1.264***	-1.293***	-1.084***	-1.100***
	(-5.47)	(-5.45)	(-5.80)	(-5.93)
Good health $\times t \geq 40$	1.252**	1.207**	-0.172	-0.092
	(2.74)	(2.64)	(-0.46)	(-0.25)
Fieldwork baseline	-0.197	-0.270	0.348	0.592*
	(-1.02)	(-1.36)	(1.33)	(2.00)
Fieldwork baseline $\times t \geq 40$			-0.243	-0.626*
			(-0.89)	(-1.99)
Years in fieldwork$_{t-1}$	0.044	0.044	-0.050*	-0.047
	(1.73)	(1.65)	(-1.96)	(-1.82)
Years in fieldwork$^2_{t-1}$	-0.001*	-0.002*	0.002	0.002
	(-2.08)	(-2.23)	(1.64)	(1.74)
Fieldwork	-0.696***	-0.683***	-0.024	-0.063
	(-3.81)	(-3.60)	(-0.14)	(-0.38)
Age × transfer		0.004		-0.018
		(0.33)		(-1.69)
Person years at risk	9251		9968	
Number of subjects	466		564	
Number of failures	263		366	
χ^2(df)	76.665 (16)	70.365 (13)	76.821 (19)	67.221 (14)
p	0.000	0.000	0.000	0.000

NOTES
1. Parameter estimates are log hazard ratios. t statistics in parentheses.
2. * $p < .05$, ** $p < .01$ and *** $p < .001$.
3. Parameter estimates for cubic expression measuring elapsed time since first inventory are not reported.
4. Huber/White/sandwich estimator of variance used.

Table 11: Results of Cox regressions using age as analysis time.

relationship between hazard functions for a dummy variable, we interacted it with analysis time, choosing the time for the 'split' by eyeballing a non-parametric plot of the hazard functions for the two categories of the variable of interest, and re-running the models to ensure that they passed the diagnostic test.

Table 12 and Figures 5(a) to (h) show that the fit of the models is reasonable; none of the numerical significance tests fail at the 5% significance level and the plots of the cumulative Cox-Snell residuals appear satisfactory. In view of the fact that (a) for variables common to the unstratified and stratified versions of each model, the parameter estimates are similar and (b) the unstratified models contain more information, since they include variables for the source of slave, our discussion concentrates on the unstratified versions of the models. In these, the baseline hazard function relates to a slave born on the estate, aged zero, first observed during JFB I's period of ownership, in poor health at baseline and t, not employed in the field at baseline or t, with zero years spent in good health and zero years of exposure to fieldwork, on 9 July 1762.

Table 13 shows the results of various Wald tests for the significance of the hazard functions for transferred slaves relative to those born on the estate and each other. Controlling for the other covariates in the models, and using time on the estate as the analysis time, there is some evidence that the hazard functions for those transferred from Africa and Jamaica differ from those born on the estate but not from each other (only the test of the hazard function for Jamaican females compared with those born on the estate is not statistically significant). Using age as analysis time, there is no evidence of any differences for females and no evidence that male Africans have different hazard functions compared with the baseline. There is, however, some evidence that the hazard function for Jamaican male transfers differs from those born on the estate and Africans.

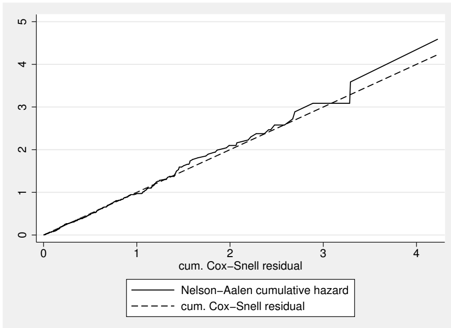
There is evidence to suggest that females first observed during JFB II's period of ownership experienced an increased hazard of death: using time on the estate as the analysis time, the estimated hazard ratio for these subjects is 1.744 (95% confidence interval $(1.112, 2.737), p = 0.015$). Using age as the analysis time it is 1.848 (95% confidence interval $(1.152, 2.966), p = 0.011$). However, no such result holds for males (parameter estimates of the hazard ratio are, respectively, 0.923 ($p = 0.713$) and 0.854 ($p = 0.449$)).

Controlling for the other variables, for both females and males, there is no evidence of an association between being in good health at baseline and working in the field at baseline and an increased or decreased hazard of death. For both males and females, there is strong evidence that being in current good health and being employed in fieldwork is associated with a reduced

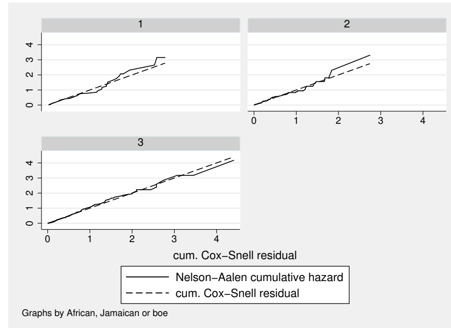
	Females		Males	
	Not stratified	Stratified	Not stratified	Stratified
Analysis time = time on estate				
Linktest z	0.66	0.87	-0.50	-1.70
	(0.508)	(0.384)	(0.620)	(0.089)
Reestimation χ^2, degrees of freedom	4.71, 5	5.79, 5	9.67, 7	10.54, 7
	(0.453)	(0.327)	(0.208)	(0.160)
Schoenfeld highest χ^2 (one degree of freedom)	1.53	0.85	1.82	2.27
	(0.216)	(0.355)	(0.178)	(0.132)
Schoenfeld global χ^2, degrees of freedom	4.27, 15	2.17, 12	8.53, 17	7.83, 14
	(0.997)	(0.999)	(0.954)	(0.898)
Analysis time = age				
Linktest z	0.49	0.34	-0.21	-0.61
	(0.624)	(0.735)	(0.837)	(0.540)
Reestimation χ^2	5.77, 6	3.42, 6	10.30, 7	9.27, 7
	(0.450)	(0.754)	(0.172)	(0.233)
Schoenfeld highest χ^2 (one degree of freedom)	1.03	0.52	2.99	2.15
	(0.309)	(0.472)	(0.084)	(0.143)
Schoenfeld global χ^2, degrees of freedom	9.46, 16	5.56, 13	11.53, 19	7.45, 14
	(0.893)	(0.961)	(0.905)	(0.916)

NOTES
p values in parentheses.

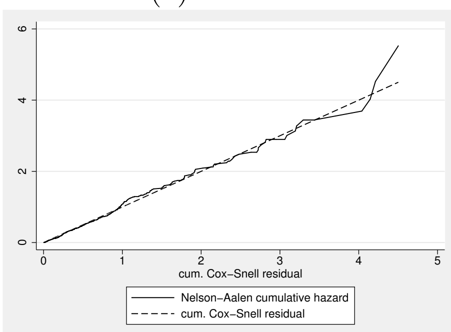
Table 12: Results of diagnostic tests for models presented in Tables 10 and 11.



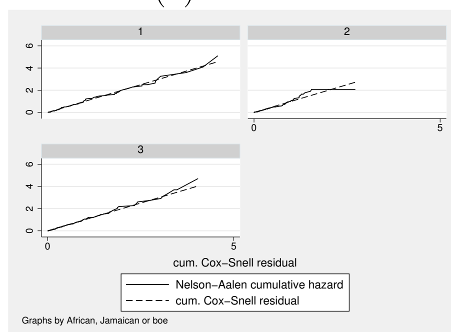
(a) Model 1



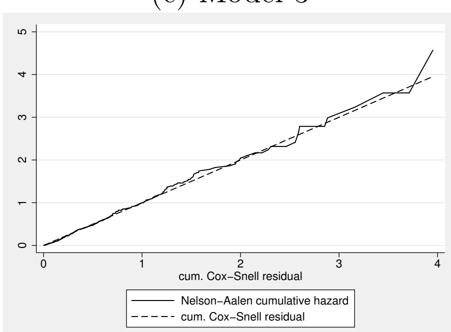
(b) Model 2



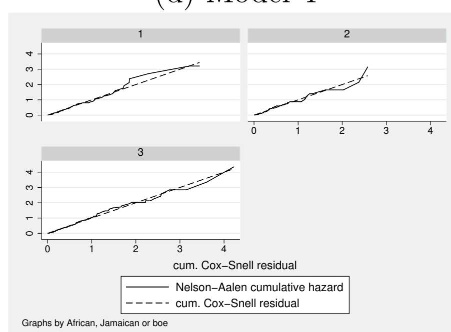
(c) Model 3



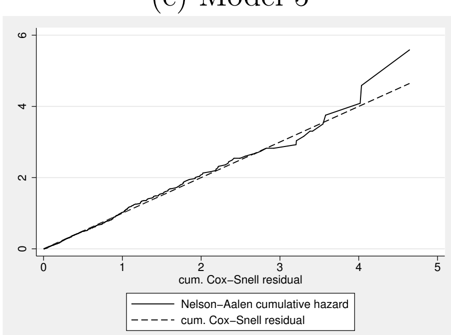
(d) Model 4



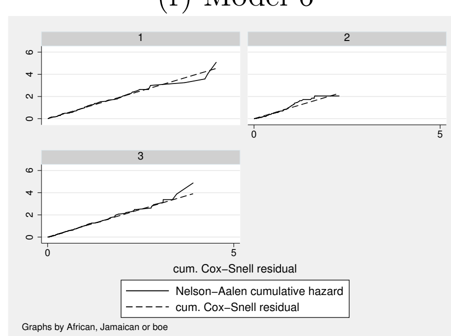
(e) Model 5



(f) Model 6



(g) Model 7



(h) Model 8

Figure 5: Cumulative Cox-Snell residual plots, Models 1 to 8.

	Time on estate				Age			
	Females		Males		Females		Males	
(a)	10.37	(0.006)	5.71	(0.058)	4.15	(0.126)	4.38	(0.223)
(b)	2.23	(0.329)	8.59	(0.014)	0.34	(0.844)	12.20	(0.007)
(c)	2.95	(0.229)	1.65	(0.439)	2.73	(0.256)	12.69	(0.005)

NOTES
$\chi^2(2)$ test statistics, p values in parentheses.

Table 13: Various Wald tests of significance for transfers: (a) African versus born on estate; (b) Jamaican transfers versus born on estate; (c) African versus Jamaican transfers.

hazard of death (for example, in Table 10, the estimate of the hazard ratio for good health is 0.384 (95% confidence interval $(0.251, 0.587), p = 0.000$) and for fieldwork it is 0.473 (95% confidence interval $(0.339, 0.660), p = 0.000$)). For both females and males, the parameter estimates for the number of years spent working in the field and in good health are not statistically significant. However, these results are likely to be biased because of the healthy worker survivor effect and are discussed in more detail in section 5.5.

5.4.1 Sensitivity analysis

Table 14 presents the results of our sensitivity analysis for the parameter estimate relating to slaves first observed under JFB II. Overall, the results showing, for females, an association between being first observed during JFB II's period of ownership and an increased hazard of death, but no such association for males, appears reasonably robust to different modelling assumptions. When the cubic expression for calendar time is replaced with a series of dummy variables marking ten year periods from the first inventory, the hazard ratio for females falls and loses significance at the 5% level, but only in the model using time on the estate as the analysis time. The parameter estimates for males change little in these alternative models. Treating right-censored failure times for reasons unknown as failures ('Informative censoring (a)' in Table 14) and at the right-censored failure time plus one year ('Informative censoring (b)' in Table 14) likewise makes little difference. Removing the subjects observed at the first inventory makes little difference. Classifying slaves according to whether or not they started their working lives during JFB II's period of ownership has little effect when the age of ten is used to denote the age of commencing working life. When the age of sixteen is used, parameter estimates for females and males both fall.[5] Those for females lose statistical significance although they remain above one; those for males show stronger evidence of an association between a reduced risk of death and working under JFB II, although they are not significant at the 5% level. When a dummy variable is used to denote whether the subject was under observation during JFB I or JFB II's period of ownership - a classification which ignores any 'cumulative exposure' to the regime of owners of the estate, and which we included for completeness - all parameter estimates lose statistical significance.

5.5 Estimating the impact of fieldwork on survival

Tables 10 and 11 have already shown that health status at t is associated with a reduced mortality risk at t. Further, a pooled logit model showed that lagged good heath status was significantly associated with an increased probability of working in the field. These results suggest health status could be a time-varying confounder for the relationship between fieldwork and mortality risk. A pooled logit model also showed that the lagged value of the number of years spent working in the field was significantly associated with poor health. Hence health status could also be an intermediate variable in the relationship between fieldwork and mortality risk. Health status therefore meets the conditions laid out in section 4.2 for being both a time-varying confounder and an 'intermediate variable'.

For G-estimation, owing to the missing data problems with the inventories of 1763 that were discussed on page 7, we chose to follow-up those recorded in the inventory of 31 December 1766. We used the inventory of 31 December 1765, to provide measurements of baseline and time-invariant confounders: the variables Field work, Good health and African, together with the subject's age and gender. Time-varying confounders were taken to be Field work and Good health and whether the subject was under observation during JFB I or II's period of ownership. Lagged confounders were the variables Years in good health and Years in fieldwork.

Deleted from our estimations were the two subjects whose gender was unknown (four observations), those aged 13 and under, many of whom had no information recorded for health and work status, those recorded at only one inventory and two subjects who ran away permanently from the estate. We treated those right-censored for reasons unknown (12 subjects) as deaths, given the results and discussion from section 5.4.1. This left us with 3626 observa-

[5]Dunn (1987, p 804) notes that children were put to work early, on average at age seven, and that by age 16 they were customarily assigned the jobs they would hold during their prime working lives (Dunn, 1987, p 800). Hence we chose two possible thresholds - age 10 and age 16 - to define the start of a slave's working life.

	Females	Males
Analysis time = time on estate		
Model 1 in Table 10	1.744*	0.923
	(2.42)	(-0.37)
Dummy variables for calendar time	1.512	0.917
	(1.82)	(-0.41)
Informative right-censoring (a)	1.826**	0.897
	(2.70)	(-0.52)
Informative right-censoring (b)	1.819**	0.899
	(2.69)	(-0.50)
Dropping subjects present at first inventory	2.028*	1.009
	(2.49)	(0.04)
Allocating under 10s on 1/1/1789 to JFB II	1.725*	0.833
	(2.24)	(-0.84)
Allocating under 16s on 1/1/1789 to JFB II	1.400	0.693
	(1.34)	(-1.69)
JFB II if date > 1/1/1789	1.088	1.330
	(0.26)	(1.09)
Analysis time = age		
Model 5 in Table 11	1.848*	0.854
	(2.55)	(-0.76)
Dummy variables for calendar time	1.595*	0.871
	(1.98)	(-0.67)
Informative right-censoring (a)	1.884**	0.817
	(2.71)	(-1.00)
Informative right-censoring (b)	1.904**	0.821
	(2.75)	(-0.97)
Dropping subjects present at first inventory	1.813*	0.848
	(2.23)	(-0.73)
Allocating under 10s on 1/1/1789 to JFB II	1.710*	0.873
	(2.09)	(-0.63)
Allocating under 16s on 1/1/1789 to JFB II	1.397	0.739
	(1.27)	(-1.34)
JFB II if date > 1/1/1789	1.113	1.075
	(0.33)	(0.27)

1. Coefficients are hazard ratios. t statistics in parentheses.
2. * $p < .05$, ** $p < .01$ and *** $p < .001$.

Table 14: Sensitivity of parameter estimates for first observed under JFB II to different versions of the unstratified models.

	$\hat{\psi}$	p value for $\hat{\psi} = 0$	Causal survival time ratio	95% confidence interval
Full sample ($n = 184$)	0.294	0.9995	0.745	(0.646, 0.873)
Females ($n = 81$)	0.160	0.9997	0.852	(0.726, 1.020)
Males ($n = 103$)	0.507	0.9999	0.603	(0.472, 0.809)

Table 15: G-estimates of $\hat{\psi}$ and causal survival time ratios for fieldwork, over-13s, cohort of 1766.

tions on 184 subjects, all of whom died prior to 1 January 1832. We replaced missing values for Field work and Good health with the most recent previous value and, if none was available, with the nearest available future value.

Results of the G-estimation are presented in Table 15. For the full sample the causal survival time ratio is estimated to be 0.745 (95% confidence interval (0.646,0.873)), for females it is 0.852 (95% confidence interval (0.726,1.020)) and for males it is 0.603 (95% confidence interval (0.472, 0.809)). These results suggest that, for this cohort, continuous exposure to fieldwork, relative to never being exposed, is estimated to reduce survival time by 15% (females, not statistically significant) and 40% (males, statistically significant).

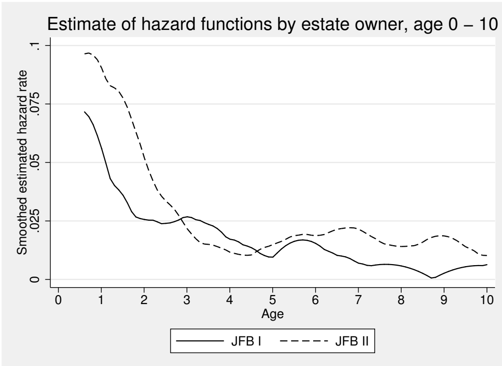
6 Discussion

The G-estimation results support Dunn's contention that the labour regime at Mesopotamia had a large and quantifiable impact on survival. However, there is weaker evidence to support Dunn's contention that JFB II erred when he voluntarily withdrew from the trans-Atlantic slave trade fifteen years early, because he was forced to rely on unhealthy, older, Jamaican slaves who were at greater risk of death. The nonparametric analysis (Figures 4(e) and (f), together with the Cox proportional hazards results in section A.4.2) shows little difference between the smoothed estimates of the hazard functions for slaves imported from Africa and transferred from within Jamaica. In general, the four full Cox regressions (Tables 10 and 11) confirm this, except for one model (that for males, using age as the analysis time), where there is evidence against the null hypothesis that the parameter estimates for these two groups are equal.

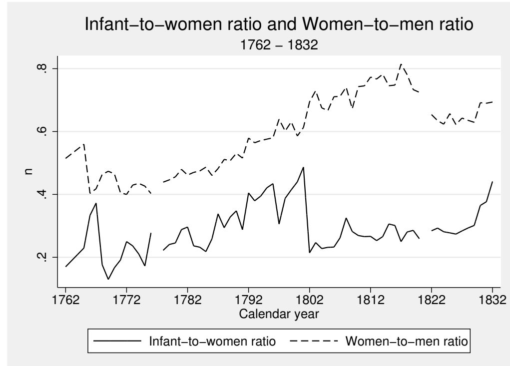
We believe that the difference between our results and Dunn's is due to the samples analysed. In making his observations, Dunn (1987) omits from his sample the 328 slaves who were still present on the estate at the time that the final inventory was taken in 1832. In his sample, Dunn reports the average age of Jamaican transfers at the time of transfer to be 34.0 (females) and 31.9 (males) (Dunn, 1987, Table 5, p 813). However, when the full sample is considered, the average ages of the Jamaican transfers arriving during JFB II's period of ownership fall to 26.4 years (females) and 24.9 years (males). As our Table 7 shows, these are closer to the average ages of the African purchases (22 years for both males and females). Table 7 also shows that the proportions of those transferred from within Jamaica who arrived at Mesopotamia in good health are either equal to, or greater, than the proportion in good health arriving from Africa.

By deleting from the data all subjects present on the estate in 1832, Dunn eliminates those who are (a) still working and (b) retired but yet to die. We would not expect these to be representative of the estate population observed between 1762 and 1832: the deleted subjects contain far more Jamaicans than Africans (112 Jamaicans, 13 of whom were runaways, versus eleven Africans), the deleted Jamaicans being younger and healthier than those remaining in Dunn's sample. Hence Dunn's reasoning is based on a comparison of almost all African slaves with a sub-sample of Jamaican transfers which is, on average, older and sicker than the full cohort of Jamaicans transferred to the estate.

Is there an alternative explanation for the continued failure of the slave population to achieve a natural increase under JFB II? One possibility is the contrasting fortunes of females under JFB I and JFB II. As the Kaplan-Meier plots of the survival functions in Figures 3(c) and (d) show, although males observed throughout the period had similar survival prospects to females first observed during JFB II's period of ownership, females first observed during JFB I's period of ownership fared better than these other groups. These results are, in general, confirmed by our main unstratified Cox regressions and sensitivity analysis, which estimate an increased hazard of death of between 40% (lowest estimate, not statistically significant) and 90% (highest estimate, $p < 0.01$) for females first observed or working for JFB II compared with JFB I, with no such difference existing for males. To what extent might there be a causal explanation for this association? As Figure 2(b) shows, JFB II's arrival heralded a major shift in the composition of the field gangs, from a male majority to a female one. G-estimation based on a cohort working originally for JFB I reports that, for those spending all of their time in fieldwork, the estimated percentage reduction in survival times for males exceeds that for females. Our results are not inconsistent with females working for JFB II carrying out more of the strenuous jobs that had previously been carried out by males working for JFB I, with a resulting adverse impact on females' expected survival times. It is possible that this also affected the survival chances of



(a)



(b)

Figure 6: (a) Estimates of hazard functions for infants and children, by estate owner; (b) Ratios for children aged 0 to 4-to-women of childbearing age and women of childbearing age-to-men.

babies, infants and children during JFB II's period of ownership: Figure 6(a) shows the smoothed estimate of the hazard rate for infants and children born during JFB II's period of ownership exceeding that for those born during JFB I's period of ownership.

Hence, while Dunn is right to point to a continued failure of the estate to achieve natural increase under JFB II, it is possible that this was due, in part, not to JFB II's switch from African imports to Jamaican transfers, but to his increasing reliance on women to carry out the strenuous jobs, such as fieldwork, that had previously been carried out by men. If true, JFB II's frustrations, which caused him to label his slaves 'dreadful idlers', were based, in part, upon the policies he himself had pursued since becoming owner.

Our results also raise some interesting directions for future research into the role played by fertility in explaining demographic sustainability on Mesopotamia. Since the lack of information regarding stillborn babies and infants dying shortly after birth make unbiased estimates of age-specific fertility rates for women difficult to obtain, the hypothesis of fertility failure is not easily testable. However, birth details for infants surviving at least as long as the inventory immediately following their birth are available, as is data for some babies who were born and died between inventories. It is therefore possible to track a broad, descriptive, measure of fertility over time by examining changes in the ratio of the annual average number of children aged 0 to 4 years present on the estate to the average, annual, number of women aged 15 to 44 years. Similarly, fecundity may be assessed by calculating the ratio of women aged 15 to 44 years to men aged 15 years and over.

As Figure 6(b) shows, after 1802, the ratio of children aged 0 to 4-to-women slumps, owing to a fall in the number of young children on the estate. In contrast, the ratio of women of child-bearing age-to-men continues to increase until 1819, when the Springfield slaves were transferred to the estate. These data are consistent with Dunn's (1977, p 60) finding of a high proportion of childless women despite a favourable sex ratio and age structure. However, conditions appear to worsen, at least as far as the children aged 0 to 4-to-women ratio is concerned, after 1802, during JFB II's period of ownership.

Caveats apply to our work. Our methods have used a simple dummy variable approach to delineate the regimes of JFB I and JFB II, where a more accurate method might be to use a measure such as 'person-years of exposure' to each owner. We have not, to date, dealt with the heaping problem in the reported ages in the first inventory, which might bias estimates in the Cox regressions and affect Tsai's test. G-estimation relies upon the inclusion of all confounders in the relationship between exposure and outcome and it is not clear that our data set provides this. Nevertheless, we feel that our results provide new insights into important questions which previously had been dealt with, in the main, by qualitative and descriptive methods. We hope that our work, and the data set which we shall make available upon the conclusion of our project, will encourage others to try to replicate our results and extend the inferential analysis in new directions.

A Appendix

A.1 The three concepts of analysis time

Let dates be recorded by the integers E, random variables which measure the number of elapsed days from a common 'base date'. The three different concepts of analysis time are calculated as follows:

1. *Calendar time - the number of days elapsed from 9 July 1762, the day prior to the day of the first inventory.* $Y = E - E_0$, where E is the last date at which each slave is observed (either the date of death or the date of the final inventory in which the slave is recorded) and $E_0 = 9$ July1762. $L = E_L - E_0$, where E_L is the date on which each slave is first observed, namely:

   - 10 July 1762, the date of the first inventory, if the slave appears in the first inventory or, if this is not the case,
   - the slave's date of birth, if there is information available on this and the slave was born on the estate after 10 July 1762 or, if this is not the case,
   - the slave's date of transfer to the estate or, if this is not the case,
   - the date of the first inventory in which the slave appears.

2. *Time spent on the estate.* Analysis time is $Y = E - E_0 + L$. E is as defined in 1. For slaves present on the estate at the first inventory, E_0 is 10 July 1762 and L is:

   - the slave's recorded age at the first inventory if the slave was born on the estate or, if the slave was not born on the estate,
   - an estimate of the time the slave had spent on the estate prior to the date of the first inventory, made by checking the surviving series of inventories running back as far as 1736.

   For slaves arriving on the estate after the first inventory:

   - if born on the estate and the date of birth is available, E_0 is their date of birth and $L = 0$;
   - if transferred to the estate and the date of transfer is available, E_0 is the date of transfer to the estate and $L = 0$;
   - if born on the estate and no date of birth is available, L is the age recorded at the first inventory in which the slave appears and E_0 is the date of that inventory;
   - if transferred to the estate and no date of transfer is available, $L = 0$ and E_0 is the date of the first inventory in which the slave appears.

3. *Age*. Analysis time is again $Y = E - E_0 + L$. For slaves born on the estate, age and time spent on the estate are equal. For slaves not born on the estate, L is the age of the slave when first observed and E_0 is either 10 July 1762, the slave's date of arrival on the estate (if available), or the date of the first inventory in which the slave is recorded (if not).

To visualise how the different concepts of analysis time affect the composition of risk sets, consider the three subjects in Table 16. Francisco was listed in the first inventory considered by us, that of 10 July 1762, aged ten years. No date of birth is recorded. Francisco died on 24 January 1798, aged 45.5 years, having spent all of his life on the estate. Hannah, a Jamaican transfer, arrived on the estate on 9 March 1791, aged 54.2 years. No date of birth is available. Hannah lives for 16.3 more years and died on 3 July 1807, aged 70.5 years. Jamantic is born on the estate on 10 December 1778. The subject is still alive and present on the estate in the final inventory of 1 January 1832, aged 53 years.

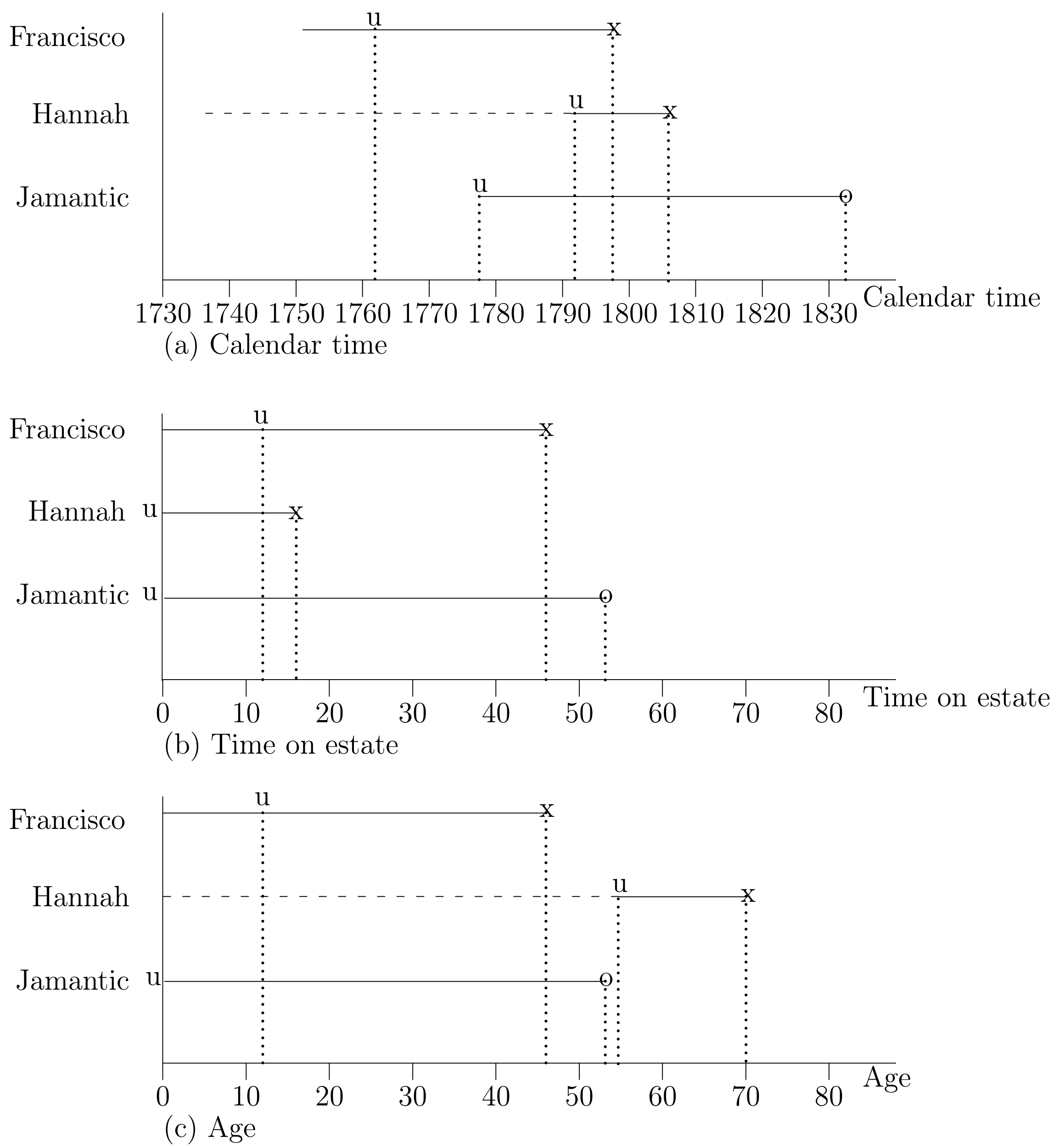
Figures 7(a) to (c) show how the ordering of subjects differs according to the analysis time. A continuous line denotes time spent on the estate, a dashed line time spent elsewhere. Figure 7(a) shows that, when calendar time is analysis time, Hannah appears first in this ordering, being born in 1737 (the date of birth being inferred from her age upon becoming 'under observation'), but only becomes under observation in 1791, when she moves to the estate, aged 54.2. Francisco comes 'under observation' in 1762 and Jamantic in 1778. The risk sets for the two subjects who die will only include those alive and 'under observation' at each time of death. For Francisco, who dies first, the risk set is therefore {Francisco, Hannah, Jamantic} and for Hannah, who dies next, it is {Hannah,Jamantic}.

Figure 7(b) shows the subjects arranged by the length of time spent on the estate. Francisco's failure time is 'left-truncated' at ten years; the other two subjects are observed from time zero. Hannah dies first, after 16.3 years on the estate, with risk set {Hannah, Francisco, Jamantic}. Francisco then dies, after 45.5 years, with risk set {Francisco, Jamantic}.

Finally, Figure 7(c) shows the subjects arranged by their age. Francisco's failure time is again 'left-truncated' at ten years, Hannah's at 54.2 years, when she moves to the estate. Jamantic is under observation from birth. The risk set for the first subject who dies, at 45.5 years - Francisco - is therefore {Francisco, Jamantic}. That for Hannah includes only Hannah, since Jamantic's failure time is right-censored at 53 years of age.

Subject name	Source	Date of birth	Date comes 'under observation'	Date last listed	Age first listed	Age at exit	Time on estate	δ_i
Francisco	Born on estate	missing	10/7/1762	24/1/98	10	45.5	45.5	1
Hannah	Jamaican transfer	missing	9/3/1791	3/7/07	54.2	70.5	16.3	1
Jamantic	Born on estate	10/12/78	10/12/78	1/1/32	0	53	53	0

Table 16: Different concepts of analysis time and implications for risk sets.



NOTES
u - comes 'under observation'.
x - death; o - right-censored.
—— - alive and present on the estate.
- - - - - alive and not present on the estate.

Figure 7: Ordering of subjects by analysis time.

A.2 Nonparametric test for quasi-independence of L and T

The standard approaches to dealing with left-truncation in survival analysis rely on the assumption of what is termed the 'quasi-independence' of the random variables L^0 and T^0 (the left-censoring and failure times, respectively, in the population, with joint distribution $H^0(l,t)$). Quasi-independence implies that, conditional upon observing only random variables L and T for which $T^0 > L^0$, L and T are independent (Tsai, 1990). If quasi-independence does not hold, nonparametric estimators of survival and hazard functions and semi-parametric regression analyses can be biased (Martin and Betensky, 2005).

Following the notation of section 4.1, order the data from the lowest failure time ($T_{(1)}$) to the highest ($T_{(m)}$), define $L_{(j)}$ as the left-truncation time for the subject failing at $T_{(j)}$ and define $\mathcal{R}_{(j)}$ and R_j as, respectively, the 'risk set' and the total number in the risk set at $T_{(j)}$. If L and T are quasi-independent and we assume that failure times and right-censoring times are also independent, then the probability mass function for $S_{(j)} = \sum_{k\in\mathcal{R}_{(j)}} \mathrm{sgn}(L_k - L_{(j)})$ should be discrete uniform (implying that there should be an equal chance of $L_{(j)}$ being ordered first, second, third and so on when the left-truncation times in $\mathcal{R}_{(j)}$ are ordered from lowest to highest).

Tsai's 'modified Kendall Tau statistic', K^*, to test the null hypothesis of quasi-independence, is defined as:

$$K^* = \sum_{j=1}^{m} \sum_{k\in\mathcal{R}_{(j)}} \mathrm{sgn}(L_k - L_{(j)}),$$

where $\sum_{k\in\mathcal{R}_{(j)}} \mathrm{sgn}(L_k - L_{(j)})$ has a discrete uniform distribution with conditional variance equal to $1/3(r_{(j)}^2 - 1)$, where $r_{(j)}$ is the number of elements of $\mathcal{R}_{(j)}$. Under a number of additional assumptions, the test statistic:

$$T^* = \frac{K^*}{\left(\frac{1}{3}\sum_{j=1}^{m}(r_{(j)}^2 - 1)\right)^{1/2}}$$

tends to the standard normal distribution (Tsai, 1990, Theorem 4, p 175).

A.3 Diagnostic tests and sensitivity analysis for the Cox regression models

For each model, diagnostic tests were carried out according the the methods recommended by Cleves et al. (2008) as follows:

1. a 'link test'. After estimation, the linear predictions and squared linear predictions of the dependent variable (the log of the relative hazard) are obtained and used as variables in a reestimated model. Under a null hypothesis that

$\boldsymbol{\beta}'\mathbf{x}(t)$ is correctly specified, it is to be expected that the coefficient on the squared linear predictor equals zero.

2. 'Re-estimation test': a test of the proportional hazards assumption for time-invariant categorical variables, based on multiplying each variable by analysis time, reestimating the model, and testing the null hypothesis that the joint effect of the newly-created variables is zero (Cleves et al., 2008, p 198 - 199). Variables failing this test were redefined as step functions of time and the tests re-run until the model passed them;

3. Schoenfeld residuals tests (Schoenfeld, 1982; Grambsch and Therneau, 1994). These test the null hypothesis that there is no time-dependent effect of covariates on the baseline hazard function. Rejecting this hypothesis would break the assumption of proportional hazards. Both individual tests and a global test were carried out.

4. Cumulative Cox-Snell residual plot. If the assumption of proportional hazards is valid, the Cox-Snell residuals, defined as $CS_i = \hat{H}_0(t_i)\exp(\hat{\boldsymbol{\beta}}'\mathbf{x}_i(t))$ should have a standard exponential distribution with hazard function equal to 1. Therefore a cumulative plot of these should be a 45° line (Klein and Moeschberger, 1997, 329-30; Cleves et al., p 214-215). For the stratified versions of the model we derived the plots for each separate strata, following the advice of Klein and Moeschberger (1997).

A.4 Supplementary results from section 5.3

A.4.1 Tests of equality of hazard functions by estate owner

Hazard ratios in Cox proportional hazards models using only a dummy variable for whether the subject was first observed during JFB II's period of ownership were: 1. using time on the estate as the analysis time, 1.802 for females ($z = 3.76, p = 0.000$, 95% confidence interval = (1.326,2.450)) and 1.058 for males ($z = 0.46, p = 0.649$, 95% confidence interval = (0.830, 1.349)); 2. using age as analysis time: 1.445 for females ($z = 2.78, p = 0.005$, 95% confidence interval = (1.115, 1.873)); males 1.000 ($z = 0.00, p = 1.000$, 95% confidence interval = (0.790, 1.266)).

A.4.2 Tests of equality of hazard functions by source of slave

For females, when time on the estate is the analysis time, the results of the tests of significance for the difference between the hazard functions according to the source of slave are (baseline category is slaves born on the estate): African imports hazard ratio = 1.619 ($z = 3.34, p = 0.001$, 95% confidence interval (1.221,2.148); Jamaican transfers hazard ratio = 1.594 ($z = 2.85, p = 0.004$, 95% confidence interval (1.157,2.197)). Test of equality of parameters for African imports and Jamaican slaves: $z = 0.09, p = 0.927$. For males: African imports hazard ratio = 1.823

($z = 5.11, p = 0.000$, 95% confidence interval (1.448,2.295)); Jamaican transfers hazard ratio = 1.595 ($z = 2.95, p = 0.003$, 95% confidence interval (1.170,2.174)). Test of equality of parameters on African imports and Jamaican slaves: $z = 0.89, p = 0.375$.

For females, when age is the analysis time, the results are: African imports hazard ratio = 1.210 ($z = 1.17, p = 0.242$, 95% confidence interval (0.879,1.664)); Jamaican transfers hazard ratio = 1.096 ($z = 0.58, p = 0.564$, 95% confidence interval (0.803,1.495)). Test of equality of parameters on African imports and Jamaican slaves: $z = 0.53, p = 0.594$. For males: African imports hazard ratio = 1.263 ($z = 1.85, p = 0.065$, 95% confidence interval (0.986,1.619)); Jamaican transfers hazard ratio = 1.077 ($z = 0.53, p = 0.598$, 95% confidence interval (0.817,1.421)). Test of equality of parameters on African imports and Jamaican slaves: $z = 1.03, p = 0.304$.

	Female	Male
African	-0.788	3.714
	(-0.34)	(0.64)
Age × African	0.002	-0.142
	(0.05)	(-0.84)
Jamaican transfer	0.012	1.892
	(0.01)	(1.10)
Age × Jamaican transfer	-0.021	-0.041
	(-0.49)	(-1.04)
First observed under JFB II	-1.246	-1.735
	(-1.16)	(-1.90)
Good health baseline	1.580	-1.049
	(1.55)	(-1.45)
Cumulative good health$_{t-1}$	-0.146	-0.020
	(-1.57)	(-0.33)
Good health	1.450	1.703*
	(1.51)	(2.06)
Fieldwork baseline	0.901	0.268
	(0.91)	(0.27)
Cumulative fieldwork$_{t-1}$	0.002	-0.200
	(0.01)	(-1.09)
Cumulative fieldwork$^2_{t-1}$	-0.007	0.004
	(-0.63)	(0.42)
Fieldwork	0.526	0.961
	(0.50)	(1.14)
_cons	-8.991	-37.453
	(-1.38)	(-1.93)
Number of subjects	458	562
χ^2 (df)	72.210 (15)	54.498 (15)
p	0.000	0.000

NOTES
t statistics in parentheses.
Parameter estimates for cubic expression measuring elapsed time since first inventory are not reported.

Table 17: Logit models with dependent variable 'censored for reasons unknown' and main explanatory variables used in Cox regressions.

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