

4.2. Econometric analysis of the decision to adopt grade cattle technology:

Column A: results of the logistic analysis, un-weighted and no control for the sample design with adjusted milk price at farm formation.

Column B: results of the logistic analysis, weighted and control for the sample design with milk price at the time of the survey (calculated at the cluster level).

Column C: results of the logistic analysis, un-weighted and no control for the sample design with milk price at the time of the survey (calculated at the cluster level).

The dependent variable is equal to 1 if the household is an adopter, 0 otherwise			
Variables	Odds Ratio- no control for sample design	Odds Ratio- with control for sample design	Odds Ratio- no control for sample design
<i>Access to credit</i>			
- Estimated probability of access to credit	1,027***	1,026**	1,023***
<i>Household &amp; household head characteristics</i>			
- age of the household head	0,993	0,997	0,998
- sex of the household head	1,380*	1,160	1,217
- education level (years) of the household head	1,060***	1,099***	1,080***
- 1 if kikuyu	3,041***	1,467	1,752**
- land acreage when established	1,048***	1,046***	1,048***
- number of adults	1,043	1,065*	1,067*
- proportion of female adults	1,696	1,448	1,590
<i>Prices and transaction costs</i>			
- adjusted milk price- farm formation	2,512	not included	not included
- milk price- time of the survey	not included	0,830***	0,866***
- dummy variable for liberalisation	0,444***	0,497**	0,437***
- distance on all-weather roads	0,980***	0,989	0,985**
- distance on dry-weather roads	1,006	0,984	0,992
- Wage rate	0,996	0,995	0,996
<i>Area characteristics</i>			
- dairy co-operative availability	1,434**	1,208	1,229
- extent of A.I. availability	1,784**	2,048**	1,800**
- 1 if it is a tick-infected area	0,670*	0,617	0,666*
- annual PPE	1,085***	1,053***	1,059***
- minimum temperature	1,318***	1,357***	1,332***
- 1 if other districts, 0 if Kiambu	1,147***	1,183***	1,139**
Number of observations	1254	1254	1254
Percent correct predictions: adopters	78.38	78.07	78.32
Percent correct predictions: non adopters	74.84	74.75	75.00
Percent overall correct predictions	77.51	77.27	77.51

\*\*\* indicates that the odd ratio is statistically significant at 1%, \*\* at 5% and \* at 10%.

4.3. Econometric analysis of the decision to adopt grade cattle technology when introducing a dummy variable for the credit constrained (Logit estimation)

<b>The dependent variable is equal to 1 if the household is an adopter, 0 otherwise</b>				
Variables	Coefficients	Z- values	P>	Z
<i>Access to credit</i>				
- 1 if the estimated probability of access to credit if above 50%, 0 otherwise	1,491	2,043	0,044	
<i>Household &amp; household head characteristics</i>				
- age of the household head	0,996	-0,468	0,641	
- sex of the household head	1,215	0,793	0,430	
- education level (years) of the household head	1,083	3,348	0,001	
- 1 if kikuyu	4,182	4,850	0,000	
- land acreage when established	1,054	4,134	0,000	
- number of adults	1,039	1,012	0,315	
- proportion of female adults	1,424	0,754	0,453	
<i>Prices and transaction costs</i>				
- adjusted milk price- farm formation	2,996	1,469	0,146	
- dummy variable for liberalisation	0,534	-2,075	0,041	
- distance on all-weather roads	0,987	-1,538	0,128	
- distance on dry-weather roads	1,005	0,112	0,911	
- Wage rate	0,996	-0,951	0,344	
<i>Area characteristics</i>				
- dairy co-operative availability	1,635	2,268	0,026	
- extent of A.I. availability	1,947	2,368	0,020	
- 1 if it is a tick-infected area	0,476	-2,249	0,027	
- annual PPE	1,079	5,335	0,000	
- minimum temperature	1,357	4,216	0,000	
- 1 if other districts, 0 if Kiambu	1,160	2,442	0,017	
Number of observations	1254			
Percent correct predictions: adopters	78.27			
Percent correct predictions: non adopters	72.19			
Percent overall correct predictions	76.71			

4.4. Calculating marginal effects for dummy variables

There are two ways to calculate marginal effect on adoption for dummies variables (Greene, p. 878). The first method is to use the same method than for the continuous variable, which is explained in equation (12). This method is however not exact, yet yields an approximation that is often accurate, as noted by Greene and confirmed in these cases.

The exact method to evaluate the effect of a binary variable  $b$  is as follows:

$$\text{effect} = \text{Prob}(D_{i,t} = 1 | \overline{X}_{i,t}, b = 1) - \text{Prob}(D_{i,t} = 1 | \overline{X}_{i,t}, b = 0)$$

where  $\overline{X}_{i,t}$  denotes the means of all the other variables in the model.

## Chapter 4

### Introducing time in the analysis of the adoption decision

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#### **1. Introduction**

The previous chapter analyses the adoption decision of smallholders' grade cattle technology at a specific point of time, i.e. at the time of the survey. Lack of access to credit is identified in this framework as a major constraint to adoption while the availability of services needed for dairying induces smallholders to enter into the activity. However, the model is fundamentally static and suffers from two major drawbacks. Firstly, the static framework does not link the adoption decision to the values of the determinants at the time of the decision; on the contrary, the model used in this paper introduces time-series data on the major determinants of adoption. Secondly, the static model does not treat the adoption decision as a transition, contrary to a duration model, which takes into account the dynamic of accumulation of savings and knowledge. Entering into dairy farming is a long-term decision that involves mobilising physical and human resources.

The household decision to adopt grade cattle technology at time  $t$ , given that it has not yet adopted, can be seen as the result of two time processes, an idiosyncratic time describing the own history of the household and a “historical” time describing external conditions (Carletto *et al.* 1999). The household decision to adopt after a certain length of time after establishment can then be analysed using a duration model that takes into account the two types of factors, at the household level and the external conditions. Using a duration analysis to study the adoption decision implies that all farmers will eventually adopt the grade cattle technology, if an infinite duration is allowed. Given the opportunities offered by dairying and the prevailing conditions (both agro- climatic and institutional), it is believed that this hypothesis is reasonable in the surveyed area.

The remainder of the chapter is organised as follows. Section 2 exposes the theoretical background and gives the hypotheses of the analysis. In section 3, the determinants of the adoption of grade cattle technology over time are presented. The econometric analysis is then developed in section 4. Section 5 concludes and proposes some policy recommendations.

## **2. The theoretical framework**

### 2.1. Background

The objective of this chapter is to identify the determinants of the time needed before adopting the grade cattle technology. The main constraint is assumed to be the entry cost, i.e. the cost of the dairy cow. The cost of a dairy cow is high compared, for example, to the monthly wage (a dairy cow costs on average 14 times the monthly wage of a rural male labourer), and farmers have to find different ways to meet the cost: revenues from crop activities (either food crop sales, especially maize, beans, bananas and potatoes or cash crop sales, coffee, tea, pyrethrum and horticulture), revenues from off-farm activities or a combination of the two. The farmers who established immediately after Independence in the White Highlands benefited from Settlement Schemes whereby land and dairy animals were sold at a subsidised price: for many smallholder families in these areas, these schemes represented a real opportunity for improving their standard of living. Finally, the obvious way to finance an agricultural investment like purchasing a dairy cow is to ask for a loan as described in chapter 3.

The dynamic model enables to take into account these different ways to meet the entry cost, contrary to the static model. In fact, revenues from past farm activities can be captured using an indicator reflecting the cumulative potential harvests in the area.

The other tested hypotheses deal with the availability of reliable marketing channels and livestock services and the incidence of tick-borne diseases. As explained in the previous chapters, the availability of reliable milk marketing channels is expected to foster adoption, while farmers in tick-infected areas face more difficult external conditions that could delay the adoption.

### 2.2. Modelling the adoption decision

A farmer decides to adopt the grade cattle technology at time  $t$  if the optimal number of grade animals kept on farm is positive, i.e.  $C^*_i > 0$ .

The model developed in chapter 3 resulted in the following equation that relates the optimal number of grade cattle on the farm at time  $t$  to the determinants of adoption at time  $t$ :

$$(1) C_{i,k,t} = F_{i,k,t} \cdot f + L_{k,t} \cdot l + \varepsilon_{i,t}$$

where the subscript  $i$  represents the  $i^{th}$  farmer and  $k$  the  $k^{th}$  cluster.

The variables  $F_{i,k,t}$  and  $L_{k,t}$  represent, respectively, the adoption determinants at the farmer level and at the cluster level. More specifically, the adoption determinants at the farmer level  $F_{i,k,t}$  are the farmer's access to credit ( $i$ ), land size ( $\overline{H}_t$ ), family labour availability (differentiating male  $L_t^m$

and female  $L_t^m$ ), farmer's other characteristics ( $Z_t^h$ ) and transaction costs ( $TC$ ) on the milk market. The adoption determinants at the cluster level  $L_{k,t}$  are introduced using milk price ( $p_t^m$ ), wage rate ( $w$ ), price of a grade cow ( $p_t^g$ ) and other prices ( $p_t^j$ ), climatic conditions ( $Z$ ), incidence of tick-borne diseases, and availability of reliable marketing channels and livestock services ( $Z_{c,t}$ ). Note that some determinants are time-invariant, thus are not indexed by  $t$ .

However, one way to meet the cost of a grade cow is not properly considered in the static modelling: using revenues from past agricultural activities. The examples of Jane in Nyandarua district and Wambui in Nakuru district illustrate how Kenyan farmers use revenues from crop activities to finance the entry cost into dairying.

**Box 1. Using revenues from agricultural activities to finance the entry cost into dairying: the example of Jane in Nyandarua district and Wambui in Nakuru district**

Jane is a widow living on her farm with her three sons. She bought her cow five years ago by using some savings from her farm products, namely the sale of maize and potatoes. Her farm lies far from the main tarmac road and transportation of agricultural products is costly: for the milk transportation, Jane has to hire somebody to deliver the milk to the tarmac road.

Wambui's family has currently two cows. They are the offspring of a female calf the farmer bought in 1984. The family is poor, but the maize harvest was very good that year and the farmer managed to save some money to buy the calf. This windfall made it possible for Wambui to become a dairy farmer.

Following the static model, the farmer derives a yearly total household income  $u_t$  that is accumulated over time. The farmer is able to finance the entry cost into dairying at  $T$  when the condition (2) is met:

$$(2) \sum_{t=t_0}^T u_t \geq p_{c,t}$$

where  $u_t$  is the total household income defined in chapter 3 and  $p_{c,t}$  is the price of a grade cow at time  $t$ . The determinants of the variable  $u$ , the total household income, can be identified by the static model presented in chapter 3. Using equation (1) of chapter 4,  $u_t$  is written as:

$$(1') u_t = u_t(i_t, p_{c,t}, \overline{H}_t, p_{m,t}, TC_m, w_t^m, w_t^w, s, L_t^m, L_t^w, p_{j,t}, p_{v,t}, Z_t^h, Z_{f,t}^r, Z_{c,t}^r, \sigma^2)$$

Equation (2) thus becomes:

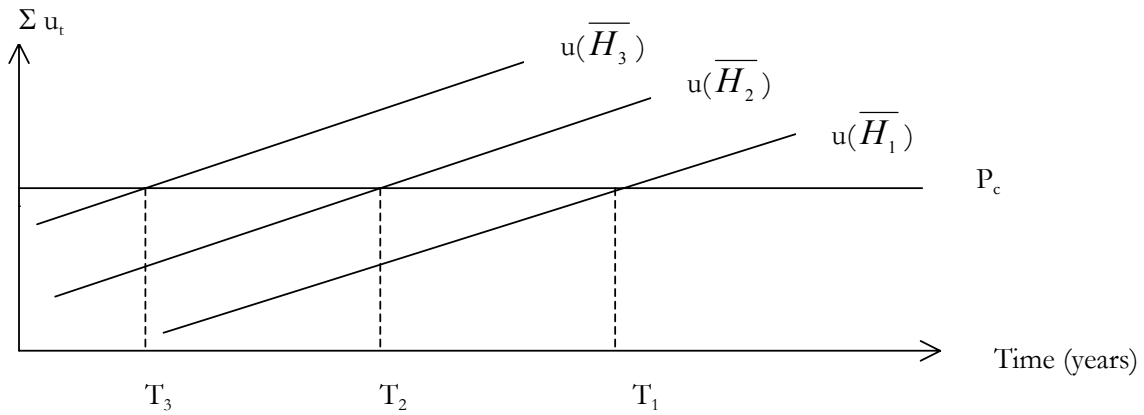
$$(3) \sum_{t=t_0}^T u_t(i_t, p_{c,t}, \overline{H}_t, p_{m,t}, TC_m, w_t^m, w_t^w, s, L_t^m, L_t^w, p_{j,t}, p_{v,t}, Z_t^h, Z_{f,t}^r, Z_{c,t}^r, \sigma^2) \geq p_{c,t}$$

Or put differently: (3')  $\sum_{t=t_0}^T u_t(x_t) \geq p_{c,t}$

Using equation (3'), it can be deduced that the duration  $T$  is a decreasing function of the determinants  $x_t$  that have a positive effect on the household income since the price of a grade cow is reached faster. On the contrary, the duration  $T$  is an increasing function of the price  $p_t$  and of the determinants  $x_t$  that have a negative effect on the household income.

The following graph presents the case of farmers with different land sizes with  $\overline{H}_1 < \overline{H}_2 < \overline{H}_3$ .

**Graph 1: Duration spells associated with different land sizes**



The farmer 1 ( $\overline{H}_1$ ) is characterised by the lowest land size. *Ceteris paribus*, it takes her more time ( $T_1$ ) compared to the other farmers for her total income to reach the threshold  $p_t$ .

Finally, the determinants of adoption over time are those defined in the static analysis augmented by the farmer's past revenues.

$$(4) \quad T^* = (i_t, p_{c,t}, \overline{H}_t, p_{m,t}, TC_m, w_t^m, w_t^w, s, L_t^m, L_t^w, p_{j,t}, p_{v,t}, Z_t^h, Z_{f,t}^r, Z_{c,t}^r, \text{past revenues}) \\ = T^*(x'_t)$$

$T^*$  can also be written as:

$$(5) \quad T_{i,t}^* = x'_{i,t} \cdot \beta + v_{i,t}$$

### 3. The determinants of adoption of grade cattle technology over time

The model developed in section 2.2. identified the determinants of adoption over time. This section presents the link between the theoretical model and the empirical analysis of the next section by describing the explanatory variables and deriving the expected effects on the duration before adoption. The variables identified in section 2.2. are classified by "constraints and opportunities" as presented in table 1 below. The last column presents the variable name of equation (4), thus linking section 2.2. and the empirical analysis that follows.

**Table 1: The determinants of the complete model**

Constraints & Opportunities	Determinants of Adoption	Variable name
<ul style="list-style-type: none"> <li>• How to finance to entry cost into dairying?</li> </ul>		
- Access to credit	Access to credit status	$i_t$
- Off-farm income	Family labour availability & wage rate	$L_t^m, L_t^w, w$
- Revenues from crop activities	Indicator of potential harvests since the farm establishment	<i>indicator of past revenues</i>
- Benefiting from the Resettlement Schemes	Dummy variable for the concerned farmers	$Z_t^b$
<ul style="list-style-type: none"> <li>• Milk marketing</li> </ul>		
- Milk price and transaction costs	Milk price and distances	$p_t^m, TC$
- Availability of reliable marketing channels	Existence of a dairy co-operative in the neighbourhood	$Z_{c,t}^r$
- Influence of the liberalisation	Dummy variable for liberalisation	$Z_{c,t}^r$
<ul style="list-style-type: none"> <li>• Animal disease risks</li> </ul>		
- Presence of ticks	Expert opinion on the distribution of ticks	$Z_{c,t}^r$
<ul style="list-style-type: none"> <li>• Household characteristics</li> </ul>		
- Household head characteristics	Sex, age and level of formal education	$Z_t^b$
- Other household characteristics	Family labour availability and land size	$L_t^m, L_t^w, \overline{H}_t$
<ul style="list-style-type: none"> <li>• External conditions</li> </ul>		
- Price of a grade cow	Price of a grade cow	$p_t^c$
- Price of cash crops	Farm-gate prices for tea and coffee	$p_t^j$
- Liberalisation of the dairy sector	Dummy variable for liberalisation	$Z_{c,t}^r$
- Learning from others	Indicator of extent of adoption in the area	$Z_{c,t}^r$
- Climatic conditions	Indicator of area suitability for crops and dairy activities	$Z_{j,t}^r$

The following sections detail the categories of variables presented in table 1.

### 3.1. How to finance the purchase of a grade cow?

Four means have been identified: getting a credit, using off-farm income, using revenues from crop activities and benefiting from the Resettlement schemes. They are detailed in the following points.

#### *3.1.1. the access to credit hypothesis*

The access to credit hypothesis was presented in chapter 3 and the econometric analysis has shown that the hypothesis that access to credit fosters adoption cannot be rejected in a static model. The definition for access to credit used in this analysis is the same as the definition used in the static analysis of chapter 3.

Moreover, for farmers with no access to credit, family size is assumed to influence negatively the resource accumulation since a large family has more needs. A combined variable, access to credit and dependency ratio, is then introduced in order to take into account this effect. The dependency ratio is computed as the ratio of the number of children (below 15 years) over total family size.

Following the theoretical model (equation (5)), the farmer's access to credit is to be introduced as a time-varying covariate  $i_{i,t}$ , linking the adoption decision at time  $t$  with the farmer's situation on the credit market at time  $t$ . However, there may be some unobserved variables that influence both the time before adoption (thus being captured in the residual term  $v_{i,t}$  in equation (5)) and the farmer's access to credit status ( $i_{i,t}$ ) as explained in chapter 3. Because of these unobserved variables,  $\text{Cov}(i_{i,t}, v_{i,t}) \neq 0$  and the access to credit status cannot be considered exogenous in the adoption equation. Therefore, the method of instrumental variables is used to predict the variable credit over time as presented in equation (6):

$$(6) \quad i_{i,t} = Z_{i,t} \cdot \xi + u_{i,t}$$

where  $Z_{i,t}$  represents the vector of explanatory variables that affect the farmer's access to credit.

Two sets of variables  $Z_{i,t}$  are assumed to influence the farmer's access to credit, as in the case in the static estimation. The first set includes some household characteristics: household head characteristics (female-headed households are likely to be more constrained, contrary to older and more educated heads). Another household characteristic that is expected to be relevant is ethnic group membership: a time-variant dummy variable is thus introduced for households from the same tribe as the ruling party. The variable is time-variant since the ruling party changed in 1978;

households are thus classified as 1 during the period when their ethnic group was leading the country. Finally, since collateral is required to obtain a loan (either from the co-operative or directly from the state-owned institution, the Agricultural Finance Corporation (AFC)), land size is expected to play an important role. In case of rationing, credit will be first allocated to the "richer" households, i.e. those with large land sizes. The variable introduced indicates whether household's land size is higher than the average land size in the corresponding agro-ecological zone.

The second set of variables describes the availability of credit supply; three variables are identified. Since some of the state-provided loans are channelled to farmers through co-operatives, availability of a dairy co-operative in the neighbourhood is expected to improve access to credit. The second variable is a time-variant dummy variable indicating loan availability because amounts of loans offered by AFC fell dramatically since the middle of the 1980s. The last variable captures the overall credit supply in the area: it is the percentage of farmers in the sublocation who got a credit (over the whole lifetime). The variable calculation is based on the survey data.

The estimation method is a "dynamic" logistic regression conducted on the available data, 847 farmers corresponding to 5100 observations. There is one observation per farmer per year, from the year of the farm establishment to the year of adoption for the "adopters" and to the year of the survey (1998) for the non-adopters. The estimation uses a "robust" procedure that controls for the non-independence between the observations of a same farmer. It was not possible to introduce fixed-effects per farmer because of the need to predict off-sample.

The results are shown in table 2 below. The goodness of fit indicators are satisfactory, with an overall percentage of correctly predicted observations at 65.3%. Results show that both farmer's characteristics and credit supply variables are significant. In fact, farmers with "larger" land holdings are more likely to have access to credit, as expected. Moreover, all the variables describing credit supply are significant and with the expected sign: whether the farmer is in the neighbourhood of a dairy co-operative (positive effect), whether AFC loans are "few" (negative effect) and the variable describing the overall credit supply in the area (positive effect).

The predicted probabilities of access to credit are then computed and introduced as explanatory variable in the duration models.

**Table 2: Logit regressions of access to credit**

The dependent variable is equal to 1 if the household has access to credit, 0 otherwise			
Explanatory variables	Coefficient	Std Errors	P>  z
<i>Household characteristics</i>			
- sex of the household head	0,230	0,301	0,444
- education level (years)	-0,024	0,035	0,495
- age of the household head ♦	0,009	0,010	0,396
- 1 if from the same ethnic group than the ruling party ♦	0,132	0,266	0,620
- 1 if “large” land acreage when established ♦	0,611	0,306	0,046
<i>Loan availability</i>			
- 1 if dairy co-operative in the neighbourhood ♦	0,850	0,350	0,015
- dummy for AFC loans ♦	-0,339	0,188	0,072
- % of farmers who received a loan in the area	1,462	0,290	0,000
<i>Constant</i>	-0,790	0,636	0,214
Number of observations	5100		
Number of farmers	847		
% correct predictions: access to credit	69.9		
% correct predictions: no access to credit	58.2		
% overall correct predictions	65.3		

♦ indicates that the variable is a time-variant covariate.

### 3.1.2. *Financing the purchase using off-farm income*

The variable availability of off-farm income raises the same issue as the access to credit variable, as explained in chapter 3. In fact the two decisions, the adoption decision and the decision to get an off-farm job cannot be considered separately since the household is likely to take these decisions simultaneously. The strategy is to introduce in the adoption equation variables characterising the environment in terms of off-farm employment opportunities and variables illustrating the household’s ability to take off-farm employment. However, these variables are introduced in the analysis as “direct” determinants of adoption; by consequence, their effect is a combination of the direct effect predicted by the model and the effect through the off-farm income.

### 3.1.3. *Financing the purchase using revenues from crop activities*

Revenues from the previous agricultural activities are introduced using rainfall data. The value of rainfall per year can be considered in the studied area as a proxy for the level of crop production since the majority of farmers have relatively homogenous techniques of production; harvests are thus mainly function of the quantity of rainfall. Using rainfall data as a proxy for revenues may raise biases because of the assumption of homogeneity of productivity between farmers and because the rainfall distribution within a specific year is not taken into account.

Rainfall data are computed by household by year using time-series data of rainfall per meteorological station. More precisely, rainfall surfaces are first created by year "around" the available meteorological stations; the corresponding rainfall data are then assigned to each household using its GIS position<sup>9</sup>.

Rainfall data are then summed to reflect the accumulation of revenues over time. A discounted factor (at 10%) is used to account for the fact that the stock of wealth diminishes over time. The variable that is introduced at time  $t$  is the discounted cumulative amount of rainfall since the farm establishment, with a one-year lag to account for the delay between revenues and investment.

It is further assumed that the larger the family size, the more difficult farmers find it to accumulate resources because of higher needs. A combined variable, rainfall and dependency ratio, is then introduced to account for this effect. Another combined variable, rainfall and land size, is also introduced since farmers with large land size are likely to benefit more from higher rainfall.

#### *3.1.4. Benefiting from the Resettlement schemes*

Farmers who established their farm in some areas (Nyandarua and Nakuru districts) after Independence are likely to have benefited from the Resettlement schemes and had purchased their first grade cow at a subsidised price, as explained in chapter 3. In the empirical analysis, a dummy variable indicating whether the household established his/her farm in the years following the Independence and in the areas concerned by the schemes is introduced.

### 3.2. Influence of milk marketing in the adoption decision

#### *3.2.1. Milk price and transaction costs*

Milk price is an indicator of the profitability of the dairy enterprise. Time-series of milk prices paid by KCC (as in chapter 3) were computed using data from the Statistical Abstracts published by the Government of Kenya and the FAO databases<sup>10</sup>, and then deflated by the prevailing consumer price index. Because the farmer takes the decision to adopt using observed milk price, the variable is introduced with a one-year lag.

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<sup>9</sup> The data computation was realised in the Arc View software by Tineke de Wolff whose help is gratefully acknowledged.

<sup>10</sup> Data on milk prices could not be obtained before 1966. However, the beginning of the adoption process was set at 1954. For the households established before 1966, it was thus not possible to get prices from 1954 to 1965. In order to maintain the households in the analysis, the 1966 price was used for the preceding years. While this solution may create a bias in the estimation, the concerned households are relatively few (approximately 7% of the observations).

Transaction costs are introduced through distances to Nairobi and to urban centres. Total distance is differentiated by road types, between all-weather roads (loose and bound surfaces) and dry-weather roads, as explained in chapter 1.

### *3.2.2. Availability of reliable marketing channels and influence of the liberalisation*

Farmers are induced to adopt if there is a reliable marketing institution ready to collect and market the milk produced on farm: at least until the beginning of the 1990s, dairy co-operatives were reliable agents and it is hypothesised that the existence of a dairy co-operative in the farmer's neighbourhood fosters the adoption. However, dairy co-operatives were not formed at the same time in all the surveyed area.

In order to compute an indicator of dairy co-operative availability per year per household, data on the starting (or registration) year and year when it collapsed (if applicable) were recorded for the co-operatives present in the studied area. Geographic surfaces of dairy co-operative availability using the GPS position of the institution were then created<sup>11</sup>. The final variable indicates the presence of a dairy co-operative within 5-km of the farm at each point of time (between the establishment of the farm and the adoption decision).

However, from the beginning of the 1990s and KCC financial difficulties, dairy co-operatives faced rising difficulties to pay their members: in some areas, farmers suffered from several month-delayed payments of the milk delivered to the dairy co-operatives. In the liberalised environment (1992 onwards), some co-operatives collapsed and farmers had not choice but to market their milk to unreliable "hawkers". In order to take into account the increasing difficulties of milk marketing, an epoch dummy variable for the beginning of the financial difficulties and the liberalisation of the dairy sub-sector is introduced. Note that the liberalisation of the dairy industry did not only concern the marketing of the milk: in some areas, the governmental system of livestock services was lifted as explained in chapters 1 and 3. The dummy variable thus captures a combined effect of the rising marketing difficulties and the removal of subsidised veterinary services.

### 3.3. Risks in dairy farming

Risks of animal disease are introduced through a dummy variable indicating the presence of ticks. The variable is based on expert opinion and is extracted from the ILRI GIS- database as

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<sup>11</sup> The data computation was realised in the Arc Info software by Tineke de Wolff and Russ Kruska whose help is gratefully acknowledged.

described in chapter 1. Risks are assumed not to have changed over time; by consequence, the variable that is introduced is a constant.

### 3.4. Household characteristics

The household characteristics include characteristics of the household head and other household characteristics. Household head characteristics that are introduced in the estimation are the age, gender and education level (years of formal education). The variable age is evaluated at the year of the farm establishment and not as a time-varying covariate in order not to introduce a time trend through this variable. The education level is supposed to be constant over time.

The other household characteristics that are introduced are the total land size, availability of family labour and whether the farmer reared local animals before entering into dairy farming. For the land size, some farmers experienced changes in their land holdings; complete time-series of the land holdings are thus introduced in the econometric analysis.

The availability of family labour is the total number of adults living on-farm. The number of adults on farm is susceptible to vary over time: the number of adults is thus introduced as a time-varying covariate. The variable number of adults takes into account the effect of off-farm income since this variable could not be introduced. There are thus two effects: the “pure” theoretical effect of labour availability (positive effect) and the indirect effect of off-farm income (positive effect since off-farm income encourages adoption by providing cash). By consequence, the overall expected effect of the number of household members on adoption is positive.

Finally, a dummy variable indicating whether the farmer reared local animals before entering into dairy farming is introduced. Farmers with some experience with local cows are expected to adopt faster; moreover, one strategy to finance the entry cost is to sell the local animals. The example of Shedrack in Machakos district illustrates this case.

Box 2. Using the revenues from the sale of local animals to finance the entry cost into dairying: the case of Shedrack in Machakos district

Shedrack is a young farmer who inherited his parents' farm some years ago. His parents used to have local breed animals. Since these animals were not producing much milk, Shedrack began to upgrade progressively the herd but realised that it was taking too long. He then sold the local animals to a butcher. With some savings from horticulture activity (especially French beans and tomatoes), Shedrack manages to save enough to purchase a grade cow. There are now three cows and their followers on his farm.

### 3.5. External conditions

The external conditions include the learning externalities, price of cash crops, the climatic conditions and the other external conditions. The effect of the liberalisation of the dairy sub-sector was explained in section 3.2.2.

#### *3.5.1. Learning externalities*

Learning externalities, or "learning- from- others" are expected to play a key role in the adoption of grade cattle technology because rearing grade animals involves some skills that are different from keeping local breed animals (chapter 1). Farmers whose neighbours have adopted the technology are expected to learn from them and to be induced to adopt<sup>12</sup>. The effect is captured by introducing a time- variant covariate of the percentage of farmers in the division who adopted grade cattle at each point of time. More specifically, the variable is computed as the ratio of the number of adopters at time  $t$  in the division  $d$  over the total number of farmers at the same time in the same division.

#### *3.5.2. Price of cash crops and other prices*

Two cash crop prices are computed, namely the producer-gate price for tea and coffee, using the FAO databases. They are then deflated by the prevailing consumer price index. Data are not available before 1966, as it was the case for the milk price. The same strategy is then used, i.e. using the 1966 price for all the preceding years. The expected effect of cash crop prices is undetermined: in fact, on the one hand, higher prices allow a farmer to finance the purchase of a grade cow. On the other hand, higher cash crop prices may discourage the adoption by rendering the entry into dairy farming relatively less attractive.

According to the theoretical model, another price should be included in the analysis: the wage rate. Since it was not possible to get time-series data of this variable, it is not introduced explicitly in the regression. However, the wage rate reflects mainly the labour opportunities in the area and other variables that characterise the labour markets are introduced in the analysis (distances to the urban centres). Another argument is that the wage rate variable was not significant in the econometric estimation of the static model. The bias is then expected to be relatively limited.

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<sup>12</sup> As noted by Bikhchandani *et al.* (1992), there are other explanations for an uniform social behaviour, besides positive externalities and "learning- from- others": risk of sanctions for these who do not adopt and preferences for conformity. The authors argue that another mechanism may explain the phenomenon: the existence of "informational cascades" whereby an individual's optimal behaviour is to mimic the behaviour of other individuals without using her own information. A similar view is exposed in Banerjee (1992).

Finally, the price of a grade cow, identified by the dynamic model as a main factor explaining the length of time before adoption is not explicitly introduced in the analysis. In fact, time-series data for this variable could not be obtained<sup>13</sup>. However, it is assumed that the effect of a change in the entry cost is captured both by the variable "year of establishment" (see section 3.5.4.) and the epoch dummy variable for the liberalisation of the dairy sub-sector. In fact, the liberalisation recorded a marked increase in the price of grade cattle.

### *3.5.3. The climatic conditions*

The climatic characteristics are introduced through an (continuous) indicator of the area suitability for crop production and dairy activities: the annual precipitation over overall potential evapo-transpiration ratio (PPE). This variable is extracted from the database "ACT" of Texas A&M University (see chapter 1). Note that this variable differs from the rainfall variable introduced as a proxy for past agricultural revenues. In fact; the proxy for past agricultural revenues measures the cumulative amount of rainfall since the farm establishment while the PPE is an indicator of the area general suitability for crop and dairy activities that takes into account other factors than the level of rainfall.

### *3.5.4. The other external conditions*

Another external condition is the implementation of the National Dairy Development Project in some districts of the surveyed area. This project aimed at promoting the adoption of grade cattle technology and the "zero-grazing system" as described in section 2.3 of chapter 3. The variable introduced in the analysis is a dummy time-varying variable equal to 1 if the project was implemented in the district  $j$  the year  $t$ , 0 otherwise. However, the introduction of a dummy variable to indicate the implementation of the project in some districts may create a bias if the areas where the project is implemented are as well the most "suitable" areas for dairy farming; the resulting bias is similar to the "program placement" bias. This was actually the case: results must thus be assessed with care.

The other external conditions that could not be taken into account by the included variables are assumed to be captured by the year of the farm establishment. It captures the specific conditions faced by the household at the beginning of the spell.

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<sup>13</sup> Reports by the livestock department of the Ministry of Agricultural and Livestock Production compute market prices of grade cattle by districts. However, the reported data are not consistent over time and gaps in the series of the reports prevented the computation of this variable.

#### **4. A duration model specification of the adoption of grade cattle technology**

Equation (5) in section 2.2 and section 3 identified the explanatory variables to be introduced in the empirical analysis. The adoption decision is taken at  $t=T^*$ , defined as the minimum time spell required to accumulate revenues to meet the entry cost into dairying. At each point of time, the adoption decision depends on the value of the covariate at that time, as described in equation (5) that presents the adoption decision at  $t=T^*$ :

$$(5) \quad T^* = T^*(i_T, \overline{H}_T, L_T^m, L_T^w, TC, Z_T^b, u_T, p_T^m, p_T^j, Z^R, Z_T^C) \\ = T^*(x_T)$$

The equation (5') differs from equation (5) by the exclusion of the variables  $w_T$  and  $p_T^C$ , exclusion that is explained in section 3.5.2.

The first section (4.1) presents the concept of the hazard rate and uses non-parametric methods to get some insights of the adoption process in play. In a second section (4.2), a semi-parametric analysis is conducted, that relates the covariates evaluated at time  $t$  with the adoption decision at the same point of time. Finally, parametric estimations of the adoption process are presented in section 4.3 and general conclusions are drawn on the determinants of the time spell before adoption.

##### 4.1. Analysis of the survival rate

###### 4.1.1. Some concepts of the duration analysis

The analysis of adoption behaviours has mainly used discrete choice models, resulting in static analyses (Feder *et al.* 1985). In those models, the dependent variable does not allow for farmers' different waiting times. On the contrary, duration analysis models the adoption as a choice process of when to adopt after the farm establishment, thus taking into account the accumulation of resources and possibly experience. Moreover, all variables are evaluated at the time of the decision, whether to adopt or not.

The probability distribution of duration is specified by the distribution function  $F(t)$  that specifies the probability that the random variable  $T$  is less than some value  $t$  (Kiefer 1988):

$$(7) \quad F(t) = \Pr(T^* < t) = \int_0^t f(s).ds$$

An alternative way of specifying the duration is through the survival function, specifying the probability that the farmer takes at least  $t$  years before adopting:

$$(8) \quad S(t) = 1 - F(t) = \Pr(T^* \geq t)$$

The central concept is the conditional probability that an event takes place (e.g. the probability that a farmer adopts after two years of farming given that she has not yet adopted) (Lancaster 1990; Kiefer 1988). The conditional probability is analysed with the concept of hazard function, defined as the probability of a spell being completed at time  $t$ , given that it has lasted until  $t$ . More formally, the hazard rate is defined by (Lancaster):

$$(9) \quad h(t) = \lim_{dt \rightarrow 0} \frac{\Pr(t \leq T^* < t + dt | T^* \geq t)}{dt} = \lim_{dt \rightarrow 0} \frac{\Pr(t \leq T^* < t + dt, T^* \geq t) / \Pr(T^* \geq t)}{dt}$$

$$= \lim_{dt \rightarrow 0} \frac{\Pr(t \leq T^* < t + dt) / \Pr(T^* \geq t)}{dt}$$

assuming  $\Pr(T^* \geq t) > 0$  and the intersection of the sets  $(t \leq T^* < t + dt)$  and  $(T^* \geq t)$  is equal to  $(t \leq T^* < t + dt)$ .

Using the formulation of  $F(t)$  and  $S(t)$ , the hazard function is equal to:

$$(10) \quad h(t) = \lim_{dt \rightarrow 0} \frac{\Pr(t \leq T^* < t + dt) / \Pr(T^* \geq t)}{dt} = \lim_{dt \rightarrow 0} \frac{[F(t + dt) - F(t)] / [1 - F(t)]}{dt}$$

$$= \lim_{dt \rightarrow 0} \frac{F(t + dt) - F(t)}{dt} \cdot \frac{1}{1 - F(t)}$$

Letting  $dt$  go to zero,  $h(t)$  can be written as:

$$(11) \quad h(t) = F'(t) \cdot \frac{1}{1 - F(t)} = \frac{f(t)}{S(t)}$$

The hazard rate is thus the rate at which spells will be completed at duration  $t$ , given that they last until  $t$ . The cumulative distribution, survival and hazard functions are equivalent ways to express the distribution of  $T$ . For example, it is worth noticing that:

$$(12) \quad S(t) = \exp\left(-\int_0^t h(s) \cdot ds\right)$$

Using time-variant covariates in the econometric analyses of duration models raises identification problems if the time paths of the covariates do not vary substantially across farmers (Kiefer). This is not the case in the present analysis, except for the price variables. Moreover, a distinction has to be made between exogenous covariate process and endogenous covariate process (Lancaster). A covariate process is said to be exogenous if "the information that a farmer has not adopted at  $t + dt$  does not aid prediction of the path of the covariate process from  $t$  to  $t + dt$  given its history to  $t$ " (Lancaster, p. 28). It can be shown that only exogenous covariates have to be introduced in the analysis. The wage paid by an employer in a model for job tenure is an example of endogenous covariate since it is only defined until the job is left: it is thus not

possible to condition the decision on this variable path from the origin to infinity (Lancaster, p. 25). In the analysis conducted here, all the time-variant covariates are either defined externally to the farmer (e.g. prices) or are determined independently of whether the farmer has adopted or not (e.g. number of adults in the household). It is thus possible to introduce time-variant covariates in the present analysis.

#### 4.1.2. The dynamic of adoption: a statistical and graphical analyses

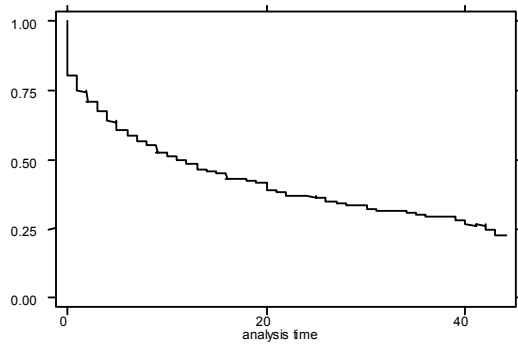
In the analysis of duration data for an innovation, the date for the start of the duration for each individual is either the date at which the farmer established the farm, or the date at which the innovation is first made available (Burton *et al.* 1997 and 1999). In the studied case, the technology was not available before 1954, date of the Swynnerton Plan that allowed African farmers to keep dairy cattle. Eighteen households established their farm before that date; the beginning of their adoption spell is then set at 1954. Adopters are farmers with at least one grade animal at the time of the survey (486 farmers or 58.2%); those without cattle or with only local animals are non-adopters (349 or 41.8%): their observations are censored.

The adoption dynamic is illustrated in graph 2 which shows the survival function for the adoption spell measured in human time (length between establishment and adoption). The Kaplan-Meier survival function gives the probability that the spell of years since household establishment is at least of length  $t$  (years on the horizontal axis). To obtain the Kaplan-Meier estimator, the estimated conditional probability of adopting at  $t_j$  is approximated by the observed relative frequency of adoption at  $t_j$  (Kiefer).

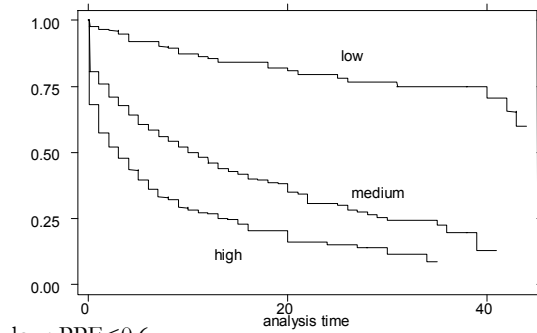
The graph shows that the probability of non-adoption declines over time at a decreasing rate: after two years of farming, twenty-five percent of the households have adopted, while the median duration before adoption is 7 years. The same graph is computed for different farmer categories: by climatic zone; by access to credit status and by land size.

**Graph 2: Kaplan- Meier survival estimates**

Kaplan- Meier estimator: all farmers



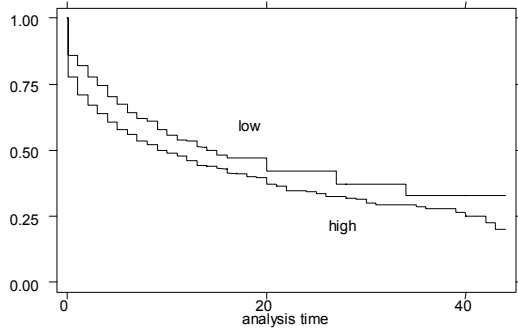
Kaplan- Meier estimator by ago-climatic zones



low: PPE < 0.6  
 medium: PPE between 0.6- 0.8  
 high: PPE > 0.8

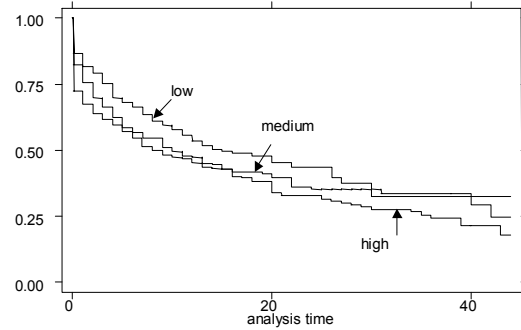
PPE: precipitation over evapo-transpiration ratio

Kaplan- Meier estimator by access to credit status



low access: estimated probability of access to credit < 0.5  
 high access: estimated probability of access to credit > 0.5

Kaplan- Meier estimator by land size



low: land size < 1.5 acre at the beginning of the spell  
 medium: land size between 1.5 – 4 acres  
 high: land size > 4 acres

Farmers in well-suited zones and those with higher access to credit adopt faster (the survival as non-adopter is lower).

For the adopters, the mean duration before adoption (from the year of the farm establishment to the adoption) is 5.7 years; however, there are important differences between categories of farmers as shown in table 3. Table 3 presents two sets of summary statistics: the first set is the average duration of spells for the adopters; the second set is the median duration for all the farmers, adopters and non- adopters. Since the duration is censored for the non- adopters, median values may be more applicable than mean values.

**Table 3: Average duration before adoption for Adopters and Median duration of spells for All Farmers, by categories of farmers (in years)**

	Average duration before adoption for Adopters	Median duration of spells for All Farmers
Number of observations	491	847
All farmers	5.7	7
By climatic zone		
- low suitability (PPE < 0.6)	12.0	16
- medium suitability (0.6- 0.8)	6.0	6
- high suitability (> 0.8)	4.1	3
<i>Test of difference of the three categories</i>	<i>significant at 5%</i>	<i>na</i>
By access to credit		
- low (< 50%)	5.2	7
- high (> 50%)	5.9	7
<i>Test of difference, low versus high</i>	<i>not significant</i>	<i>na</i>
By land size		
- small (0- 1.5 acre)	5.5	7
- medium (1.5- 4 acres)	5.1	6.5
- high (> 4 acres)	6.3	7
<i>Test of difference of the three categories</i>	<i>not significant</i>	<i>na</i>
By distance		
- close to the urban centres (< 20 km)	4.2	5
- less close (20- 30 km)	6.9	9
- far (> 30 km)	5.7	8
<i>Test of difference: close versus less close and far</i>	<i>significant at 5%</i>	<i>na</i>
<i>Test of difference: less close versus far</i>	<i>not significant</i>	<i>na</i>

*na*: not applicable

Table 3 shows that farmers situated in areas less suitable for agriculture and dairying need on average almost three times more time to adopt than farmers situated in the most suitable zones (12.0 years *versus* 4.1 years). On the other hand, adoption spells do not differ significantly when farmers are categorised by land size and access to credit status. The result on land size is explained by the fact that farmers in less suitable areas have, on average, larger land size: the statistical relationship between adoption length and land size thus does not permit to conclude. In order to take into account the interactions between variables, semi- parametric and parametric estimations are conducted and presented in the following sections.

## 4.2. Semi-parametric or Cox proportional hazards model

### 4.2.1. Presentation of the Cox proportional hazards model

The Cox proportional hazard model does not postulate any specific form for the baseline hazard function but relies on the assumption of proportional hazard over time. The hazard rate is equal to  $h(t, x, \beta, h_0) = h_0(t) \cdot \varphi(x_t, \beta)$  where  $h_0(t)$  is the "baseline" hazard corresponding to  $\varphi(\cdot)=1$ . The specification of  $\varphi$  which is used is  $\varphi(x_t, \beta) = \exp(x_t \cdot \beta)$ .

The hazard rate can thus be written as:

$$(13) \quad h(t, x, \beta, h_0) = h_0(t) \cdot \exp(x_t \cdot \beta)$$

where the vector  $x_t$  represents the adoption determinants (or covariates) as shown in equation (5). Two types of covariates can be distinguished: time invariant (e.g. gender of the household head) and time-variant covariates (e.g. land holdings).

The method uses the order of the durations to get an estimate of the vector of unknown coefficients  $\beta$ . The completed durations are ordered,  $t_1 < t_2 < \dots < t_n$ . The conditional probability that farmer  $i$  adopts at duration  $t$ , given that any of the  $j$  farmers has adopted at  $t$ , is given by:

$$(14) \quad \frac{h_0(t) \cdot \exp(x_{i,t} \cdot \beta)}{\sum_{j \in R(t)} h_0(t) \cdot \exp(x_{j,t} \cdot \beta)} = \frac{\exp(x_{i,t} \cdot \beta)}{\sum_{j \in R(t)} \exp(x_{j,t} \cdot \beta)}$$

where  $R(t)$  is the set of observations at risk at time  $t$  (the farmers who have not previously adopted) and there are no censoring and no tied in the durations. The log-likelihood is then obtained as the product of the individual contributions and is written as (Kiefer):

$$(15) \quad L(\beta) = \sum_{i=1}^n \left( x_{i,t} \cdot \beta - \ln \sum_{l \in R(t)} \exp(x_{l,t} \cdot \beta) \right)$$

An observation that is censored between duration  $t_j$  and  $t_{j+1}$  appears in the summation in the denominator of equation (14) from observation 1 through  $t_j$  and not in any others. Ties (when two or more observations have the same duration) can be handled by different ways; the one used in the analysis is the Breslow method whereby two farmers  $e_1$  and  $e_2$  that adopt at the same duration are assumed to be drawn from the complete pool, including both  $e_1$  and  $e_2$ . The Breslow method is an approximation of the exact marginal likelihood (Statacorp).

As written above, the Cox model does not impose a specific form of the hazard common to all farmers, contrary to parametric specifications. Some authors have argued that this method may be more adequate than imposing a parametric form (Meyer 1990; Fortin and Lacroix 1997). Several reasons are given: first, there is no strong theoretical support to choose a specific baseline

hazard (e.g. Weibull, log- normal); secondly, the shape of the baseline hazard may be irregular and "unlikely to be well approximated by a simple parametric form"; thirdly, "misspecification of the baseline hazard yields inconsistent estimate of the estimated coefficients" (Fortin and Lacroix, p. 9).

The strategy chosen here is to estimate the model using the different estimation methods and to compare the obtained results from the different specifications.

#### 4.2.2. Estimation of the Cox proportional hazard model

When estimating the model, the adjusted coffee price is not introduced in the regression since this variable is highly correlated with the adjusted tea price (the coefficient of correlation is 0.76, significant at 1%). The results of the maximisation of the log- likelihood of equation (15) are presented in table 4 below that reports the estimated coefficients. The estimations are conducted using a correction for the possible heteroscedasticity.

Two specifications are estimated. The first one includes the combined variables (access to credit and dependency ratio; rainfall and dependency ratio; and rainfall and land size), as described in section 3; the second specification does not include them. A likelihood ratio test is then conducted to test whether the constraints imposed on the second specification are supported by the data. The test is rejected at 1%: the complete model is then preferred in the following analysis.

Specification checking is assessed using a graphical representation of the Cox- Snell residuals. The annex 1 explains the method and presents the results: based on this method, the estimated model fits relatively well the data; however, the residuals deviate and caution is thus needed when interpreting the results. Moreover, the Cox model relies on the assumption of proportional hazard over time. More precisely, it means that the ratio of the adoption hazard between two farmers is constant over time since it does not depend on the baseline hazard (equation (14)). It is worth noticing that models including time- variant covariates are not strictly speaking proportional hazard models, unless the time- variant covariates are the same functions for every farmer (Lancaster, p. 42): the term is however used to describe models involving a multiplicative baseline hazard which is left parametrically unspecified.

The hypothesis of proportional hazard can be tested using the generalisation by Grambsch and Therneau (Statacorp 1999). The method implies deriving the residuals (or more precisely the

scaled Schoenfeld residuals) and regressing them on functions of time: the authors showed that "the test of zero slope is equivalent to testing that the log hazard ratio function is constant over time" (Statacorp).

In this analysis, time-variant covariates are included among the explanatory variables. Since they do not vary in the same way for every farmer, the ratio of the hazard between two farmers is not necessarily constant over time. When applying the Grambsch and Therneau's test, the assumption of constant hazard ratio is rejected: this result is explained by the inclusion of time-variant covariates. Table 4 presents the results of the estimations:

**Table 4: Results of the Cox proportional hazard model**

Variables	Hazard ratio	Hazard ratio
<i>Household human capital assets</i>		
age of the household head at establishment	1,006	1,005
sex of the household head	1,059	1,068
years of formal education of the household head	1,027**	1,027**
number of adults in the household ♦	1,031	1,027
dependency ratio ♦	0,077***	0,739
<i>Household physical assets</i>		
1 if there was a local cow before adoption	1,552***	1,552***
total acreage owned ♦	1,020***	1,021***
predicted probability for access to credit ♦	0,748	1,232
predicted probability for credit * dependency ratio ♦	28,711***	
total rainfall since farm establishment ♦	1,070***	1,071***
rainfall* dependency ratio ♦	1,016***	
rainfall* land size ♦	1,000	
<i>Role of time in adoption</i>		
idiosyncratic human time: year of farm establishment	1,059***	1,060***
idiosyncratic human time: dummy variable for "settlers"	2,521***	2,517***
pure historical time: dummy variable for liberalisation ♦	0,392***	0,385***
<i>External factors</i>		
adjusted milk price ♦	0,346*	0,330*
adjusted tea price ♦	1,000	1,000
distance to Nairobi on all weather roads, bound surface	1,012	1,013
distance to Nairobi on all weather roads, loose surface	1,092	1,089
distance to Nairobi on dry weather roads	0,598***	0,580***
distance to two other urban centres on all weather roads	0,946	0,942
% of "adopters" in the division ♦	1,011***	1,011***
availability dairy co-operative in the neighbourhood ♦	1,118	1,099
presence of the NDDP in the district ♦	1,071	1,110
annual precipitation / potential evapotranspiration ratio	1,013**	1,014**
presence of ticks in the area	0,763**	0,766**
Log-likelihood	-2577.340	-2585.480

♦ indicates that the variable is a time-variant covariate.

\*\*\* indicates that the hazard ratio is statistically significant at 1%, \*\* at 5% and \* at 10%.

Variables with a hazard ratio lower than 1 have a negative influence on the duration spell (they "delay" adoption), while those with a hazard ratio higher than 1 "accelerates" the adoption. The results are satisfactory in terms of variables with significant coefficients. The assumption that credit accelerates the adoption decision is supported by the data: controlling for the dependency ratio (which delays the adoption), results show that the estimated probability of access to credit has a significant and positive effect on the decision to adopt dairy cattle technology. Other hypotheses are supported as well by the data: the proxy for revenues from past crop activities (total rainfall since establishment) plays a positive role in the adoption. And farmers with large land size adopt faster, reflecting greater potential for growing fodder and fodder from crop residues. Education level plays a positive role in the adoption.

Time plays a key role in the adoption of grade cattle technology: households who established later adopt more quickly, reflecting the development of marketing facilities and better availability of services offered to dairy farmers. Farmers who benefited from the resettlement schemes adopt faster, as expected. Finally, the adoption rate slowed down after the 1990s liberalisation, as captured by the dummy variable for liberalisation. The unexpected negative effect of milk price (a higher milk price delays adoption) may be explained by the problems encountered when computing the data since no price data were available before 1966.

The agro-climatic conditions (annual precipitation/potential evapotranspiration ratio) have a strong influence on the decision, reflecting higher possibilities of growing fodder as well as potentially lower risks of animal diseases. This result is consistent with the incidence of ticks variable: farmers living in tick- infected areas record lower adoption rates.

Another interesting result deals with the learning externalities variable: a farmer whose neighbours adopted in the previous periods is more likely to adopt. The same conclusion is drawn for a farmer who kept local animals before adoption: results show that she adopts faster. Two explanations are possible: her experience with livestock activities and the possible sale of local animals to enable her to finance the entry cost.

Finally, GIS-derived distances give interesting insights on the adoption process: the further the farm from Nairobi on dry weather roads, the lower the speed of adoption. Distance on dry-weather roads is a good indicator of market accessibility at the farmer level, since they connect the farms to the main road infrastructure. Distances on all- weather roads seem not to play any

role in the adoption process: this result is consistent with the literature on transaction costs that identifies poor road infrastructures as the main constraints to the development of agriculture.

### 4.3. Parametric models

Contrary to the Cox model, the form of the hazard baseline function is specified when estimating parametric models. The different distributions of the hazard rates are first described, before estimating the adoption equation using parametric methods.

#### 4.3.1. Presentation of the parametric methods

Different distributions for the hazard rate have been used in the literature and differ from those used in other applications. In fact, the "usual" distributions (e.g. the normal distribution) have complex hazard functions that do not allow the constant hazard as a special case (Kiefer). The main hazard functions used are described in table 5:

**Table 5: Parametric hazard and survival distributions and the parameterisation**

Distribution	Hazard function, $h(t)$	Survival function, $S(t)$	Parameterisation
Exponential	$\gamma_{i,t}$	$\exp(-\gamma_{i,t} \cdot t)$	$\gamma_{i,t} = \exp(-x_{i,t} \cdot \beta)$
Weibull	$\gamma_{i,t} \cdot p \cdot t^{p-1}$	$\exp(-(\gamma_{i,t} \cdot t)^p)$	$\gamma_{i,t} = \exp(-x_{i,t} \cdot \beta / p)$
Log- normal	$\frac{1}{t \cdot \sigma \cdot \sqrt{2 \cdot \pi}} \cdot \exp\left(\frac{-1}{2 \cdot \sigma^2} \cdot (\ln t - \gamma_{i,t})^2\right)$ $1 - \Phi\left(\frac{\ln t - \gamma_{i,t}}{\sigma}\right)$	$1 - \Phi\left(\frac{\ln t - \gamma_{i,t}}{\sigma}\right)$	$\gamma_{i,t} = x_{i,t} \cdot \beta$
Log- logistic	$\frac{(\gamma_{i,t})^{1/\alpha} \cdot t^{1-\alpha}}{\alpha \cdot (1 + (\gamma_{i,t} \cdot t)^{1/\alpha})}$	$\frac{1}{1 + (\gamma_{i,t} \cdot t)^{1/\alpha}}$	$\gamma_{i,t} = \exp(-x_{i,t} \cdot \beta)$

where  $\Phi(z)$  is the standard normal cumulative distribution.

The exponential distribution is characterised by a constant hazard rate. It is termed *memoryless* since the conditional probability of adoption does not depend on duration. The Weibull distribution is a generalisation of the exponential distribution, obtained by setting  $p = 1$ . The hazard function is increasing (positive duration dependence) if  $p > 1$  and decreasing if  $p < 1$  (negative duration dependence). The ancillary parameter  $p$  is to be estimated with the coefficient vector  $\beta$ .

Unlike the exponential and the weibull distribution whose distributions are monotonic, the log-normal distribution and the log- logistic distribution have non-monotonic hazard rate (increasing and then decreasing rates), enabling to capture non linearity in the dynamic process. The ancillary parameter of the log-normal distribution is  $\sigma$ ; for the log- logistic distribution, the ancillary parameter is  $\alpha$ .

When the parametric distribution of  $T$  is chosen, the data distribution is known up to a vector of parameters  $\theta$ , which is composed by the unknown vector  $\beta$  and the ancillary parameter specific to the distribution. After the estimations, specification analyses are conducted to check whether the family of distributions that is specified fits adequately the data.

The estimation of the parameters is then performed using maximum likelihood procedures. Since the density of a duration of length  $t$  is  $f(t)$ , and assuming that each farmer's spell is independent of the others, the log-likelihood function is:

$$(16) L(\theta) = \sum_{i=1}^n \ln f(t_i, \theta)$$

When the spell is censored, i.e. the farmer has not yet adopted at the time of the survey, the only information available is that the duration was at least  $t_j$  (Kiefer). As a consequence, the contribution to the likelihood function is the survival function. More specifically:

$$(17) L(\theta) = \underbrace{\sum_{i=1}^n d_i \cdot \ln f(t_i, \theta)}_{\text{completed spells}} + \underbrace{\sum_{i=1}^n (1 - d_i) \cdot \ln S(t_i, \theta)}_{\text{censored spells}}$$

with  $d_k = 1$  if the  $k$ th spell is completed, 0 if censored.

The parameters are then estimated by maximum likelihood procedures using a "robust" estimator of the variance (or White estimator) to relax the assumption of independence of the observations of a same farmer.

Distributions of durations are modified by the introduction of explanatory variables, or covariates in the same way as in the Cox proportional hazard model. The hazard function is then reformulated by introducing explanatory variables (time- variant and time- invariant covariates). Two frequently used models are the proportional hazard rate model (PH) and the accelerated failure-time model (AFT). In the proportional hazard rate model, the effect of the covariates  $x_t$  is to multiply the hazard function by a scale factor  $\varphi(x_t, \beta)$ . The hazard rate is then equal to:

$$h(t, x_t, \beta, h_0) = h_0(t) \cdot \varphi(x_t, \beta)$$

where  $h_0(t)$  is the "baseline" hazard corresponding to  $\varphi(\cdot)=1$ .

A specification of  $\varphi$  which is commonly used is  $\varphi(x_t, \beta) = \exp(x_t \cdot \beta)$ . The details of the exact specifications that are used are presented in table 5.

In the accelerated failure-time model, the effect of the covariates is to re-scale the time axis. More specifically:  $h(t, x_t, \beta) = h_0[t, \varphi(x_t, \beta)] \cdot \varphi(x_t, \beta)$ . The same specification for  $\varphi(x_t, \beta) = \exp(x_t \cdot \beta)$  is used. Note that with the specification  $\varphi(x_t, \beta) = \exp(x_t \cdot \beta)$ , the exponential and the weibull distributions are simultaneously proportional hazard and accelerated failure-time models (Kiefer).

An interesting feature of the accelerated failure-time models is that the logarithm of the survival time  $t$  can be expressed as a linear function of the covariates (Kiefer):

$$(18) \ln t_i = x_{i,t} \cdot \beta + z_{i,t}$$

where  $x_{i,t}$  is the vector of covariates (equation (5')),  $\beta$  is the vector of regression coefficients and  $z_{i,t}$  is the error term with density  $f()$ . The distribution of the error term determines the regression model. When  $f()$  follows the extreme-value density, the exponential and Weibull models are obtained. By setting  $f()$  equal the normal density, the log-normal model is obtained; finally by setting  $f()$  equal to the logistic density, the resulting model is the log-logistic.

#### 4.3.2. Estimation of the parametric models

Estimation by parametric methods requires using a specific distribution of the hazard rate. However, the theoretical model does not postulate any specific form for the hazard function. In order not to restrict the results to a particular specification, different specifications are used and the results compared.

Four models are estimated: exponential, weibull, log normal and log logistic and the complete results are presented in annex 2. Two specifications are used, with and without the combined variables (access to credit\* dependency ratio; rainfall\* dependency ratio and rainfall\* land size). Likelihood ratio tests are conducted to test whether the exclusion of the combined variables is supported by the data. The constrained specification (without the combined variables) is preferred for the exponential, log-normal and log-logistic models. For the weibull model, the non-constrained (with the combined variables) is preferred.

The four models are compared using both the graphical method of specification checking (Cox-Snell residuals, see annex 3) and using the Akaike information criterion (see annex 4). The weibull

specification provides the best estimates; the results of this specification are presented in table 6 and commented below.

**Table 6: maximum likelihood duration model, weibull specification**

Variables	Weibull	Weibull
<i>Household human capital assets</i>		
age of the household head at establishment	-0,007	-0,005
sex of the household head	0,053	0,050
years of formal education of the household head	-0,088**	-0,088**
number of adults in the household ♦	-0,024	-0,016
dependency ratio ♦	6,424***	1,663**
<i>Household physical assets</i>		
1 if there was a local cow before adoption	-0,939***	-0,925***
total acreage owned ♦	-0,062***	-0,065***
predicted probability for access to credit ♦	-0,375	-1,563*
predicted probability for credit * dependency ratio ♦	-8,321***	
total rainfall since farm establishment ♦	-0,126***	-0,127***
rainfall* dependency ratio ♦	-0,010	
rainfall* land size ♦	0,000	
<i>Role of time in adoption</i>		
idiosyncratic human time: year of farm establishment	-0,221***	-0,218***
idiosyncratic human time: dummy variable for "settlers"	-2,486***	-2,421***
pure historical time: dummy variable for liberalisation ♦	3,273***	3,230***
<i>External factors</i>		
adjusted milk price ♦	0,184	0,294
adjusted tea price ♦	0,000	0,000
distance to Nairobi on all weather roads, bound surface	0,006	0,002
distance to Nairobi on all weather roads, loose surface	-0,201	-0,211
distance to Nairobi on dry weather roads	1,040***	1,078***
distance to two other urban centres on all weather roads	0,268*	0,259*
% of "adopters" in the division ♦	-0,037***	-0,036***
availability dairy co-operative in the neighbourhood ♦	-0,127	-0,089
presence of the NDDP in the district ♦	-0,521	-0,543*
annual precipitation / potential evapotranspiration ratio	-0,044***	-0,044***
presence of ticks in the area	1,067***	1,023***
<i>Constant</i>	27,452***	27,716***
Ancillary parameters	0,34	0,35
Log-likelihood	-1127.941	1132.001

\*\*\* indicates that the coefficient is statistically significant at 1%, \*\* at 5% and \* at 10%.

♦ indicates that the variable is a time-variant covariate.

The results are reported using coefficients: a positive coefficient indicates that the covariate has a positive impact on the duration, i.e. the covariate "delays" the adoption. On the contrary, a covariate with an estimated negative coefficient "accelerates" the adoption.

In annex 2, the two first models (exponential and weibull) are estimated in the accelerated failure time form in order to compare the results with those of the two last specifications. Results are relatively consistent between the different specifications. The graphical analyses of the residuals of the exponential and log- logistic specifications show major departures from the 45° line and cannot be considered accurate. On the contrary, the results of the other two specifications (weibull and log- normal) are relatively similar and can thus be considered reliable.

The ancillary parameter is estimated at 0.34, thus below 1: controlling for the included covariates, the hazard function exhibits a negative duration dependence. This result shows that the probability of adoption decreases with time after the farm establishment, thus indicating that there is no significant learning by doing.

In the four parametric specifications, the variables capturing the role of time in the adoption process are highly significant. Farmers who established their farms later take relatively less time to adopt than the "pioneers". Conelly (1998) in a review of the colonial era livestock development policy shows how the conditions of adoption were difficult at the beginning of the process: strict conditions were to be met by farmers interested in dairying (land consolidation, livestock management regulations and minimum farm size restrictions). Moreover, livestock services, especially artificial insemination services were not widely available. On the other hand, results show that settlers adopt faster than the other farmers, reflecting the preferential conditions they benefited. Finally, the dummy variable representing the liberalisation is significant: dairy adoption seems to be more difficult after 1990, when difficulties in marketing increased with the collapse of some dairy co-operatives and veterinary services were privatised in some areas, as exposed in chapter 1.

Price variables are not significant in any of the regressions, except tea price in the exponential regressions (and only at 10%): this can be explained by the problems encountered when computing the data since no price data were available before 1966. Results on tea price suggest that tea enterprise and dairying are competing activities since higher tea prices delay the adoption of grade cattle technology.

The time- variant covariate for dairy co-operative availability is not significant in any of the regressions. This result may be linked to the difficulty of constructing the variable: it may not capture the whole network of co-operatives in the area. In fact, it was demanding to survey all the

dairy co-operatives and to obtain the information on dates of registration and end (if relevant); some co-operatives may not be recorded and this can explain the lack of significance. This result is surprising since the variable was significant in the estimation of the static model presented in chapter 3 (when milk price at farm establishment is introduced).

The equation (18) can be used to quantify the effect of the explanatory variables on the estimated time length before adoption. The effect is calculated in two ways: at the mean duration for the sub- sample of the adopters and at the median duration for the all sample. Results are summarised in table 7 below.

Relaxing the probability of credit constraint by ten percent decreases the time length before adoption by slightly less than one year (from 5.7 years to 4.8 years) when the effect is evaluated at the mean value of the sub-sample of adopters and by one year for the all sample. The effect is thus relatively limited. It can be compared with an increase in rainfall: while access to credit ranges from 0 to 100, rainfall data range from 0 to 13,900 mm<sup>14</sup>. By consequence, ten percent increase in credit can be compared to 1390 millimetres increase in rainfall (each being ten percent of the maximum value). The results show that a adopter with 1390 millimetres more rainfall needs, *ceteris paribus*, almost five years less to adopt (precisely 4.7); calculated at the median duration for the all sample, the farmer adopts almost six years before (precisely 5.8). The effect of higher rainfall and, by consequence, higher savings from crop activities has a dramatic effect on the farmer's waiting time before adoption, especially in comparison with the effect of credit access.

The model includes the dependency ratio since it is hypothesised that farmers with a higher dependency ratio are disadvantaged in accumulating savings because of higher cash needs. The results do not reject this hypothesis: farmers with a dependency ratio higher by 0.1 (recalling that the dependency ratio is defined as the ratio of the number of children below 14 over the total family size) adopt, on average, five years later than the "mean" adopter and six years later for the "median" farmer. The effect is thus large. It is worth noticing that the combined effect between credit access and dependency ratio "accelerates" the adoption; results thus suggest that access to credit offsets the effect of a higher dependency ratio.

The effect of the distance on dry-weather roads is quite large: an adopter situated ten kilometres further is estimated to need more than ten more years (exactly 10.4 years) to adopt, *ceteris paribus*. The effect of the distance on all weather roads is lower, as expected: ten kilometres "delays" the

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<sup>14</sup> Values are relatively large since the variable records rainfall since the farm establishment.