The results concerning the determinants of the intensification level are on overall disappointing: goodness of fit indicators are low and few conclusions can be drawn. Using the "secondary" indicators exposed in section 2 and recalling that feed shortage is described in the literature as the main constraint to milk production on smallholders farms, analysis of the inputs levels may provide more insights for the understanding of the process at play. However, attempts to analyse levels of planted fodder and quantities of purchased feed (both expressed per tropical livestock unit) proved to be disappointed; this result may be explained by the inadequacy of the collected data (yearly data) to the estimation of inputs decision (frequent decisions). More research is thus needed to get a better understanding of the determinants of intensification level on smallholders' dairy farms.

# Annexes

Annex 1: Econometric methods used:

Because of possible outliers, econometric methods robust to their influence are conducted. Three different methods are used. The first method is a weighted least squared estimation; the second is a robust estimation which takes into account outliers; the third is a median regression, a method that is less sensitive to outliers and that controls for heteroscedasticity.

*The first method* is a "classical" weighted least squared estimation, using the White (or Huber) estimator of the variance. For the estimation of the milk production function, there is more than one observation per cow in some cases; therefore the regression is conducted controlling for the fact that observations from the same cow are not independent.

*The second method* is a robust regression that is less sensitive to outliers. The method begins by using the ordinary least squares method; in a second step, Cook's distance is calculated to detect outliers. Cook's distance $D_i$ is defined by:

$$D_i = \frac{1}{k} \cdot \frac{s_i^2}{s^2} \cdot r_i^2 \cdot \frac{h_i}{1-h_i}$$

where $k$ is the number of variables, $s$ is the root mean square error of the regression, $s_i$ is the root mean square error when the $i$th observation is omitted, $r_i$ are the studentized residuals and $h_i$ is the leverage.

The Cook's distance is "a scaled measure of the distance between the coefficient vectors when the $i^{th}$ observation is omitted" (Statacorp Reference manual P- St, p. 199). The procedure then excludes any gross outliers, defined as observations for which $D_i$ is higher than 1.

The following steps are iterative: a regression is performed and case weights are calculated based on absolute residuals. Another regression is then performed using those weights. "Iterations stop when the maximum change in weights drop below 0.01" (Statacorp Reference manual P- St, p. 256).

*The third method* is a median regression that estimates the median of the dependent variable, conditional on the values of the independent variables. This method is more robust to outliers since it aims at minimising the sum of the absolute residuals rather than the sum of the squares of the residuals as in ordinary least squares estimations. However, the median regression method understates the standard errors for heteroscedastic errors: the method thus uses bootstrapping resampling to estimate consistent standard errors.

Annex 2: Estimations of the milk production function

The first table presents the results of the first specification, i.e. quantities of feed planted on-farm are introduced by types of fodder (maize, Napier grass and pasture). The second table presents the results when the fodder acreages are combined into a single variable (using the expected dry matter yields as weights). Each specification is estimated with the three econometric methods, as described in annex 1.

**The dependent variable is the milk production per day at specific dates: First specification**

| | WLS | Robust regression | Median regression & bootstrap |
|---|---|---|---|
| | | Coefficients | |
| *Cow characteristics* | | | |
| Ln(month of lactation) | -1.962*** | -1.748*** | -1.750*** |
| 1 if the cow is local breed | -2.061*** | -2.331*** | -2.408*** |
| 1 if the cow is a high-grade | 0.540** | 0.400** | 0.174 |
| Number of previous calvings | 0.520*** | 0.387*** | 0.381*** |
| Squared value of number of calvings | -0.040*** | -0.033*** | -0.028** |
| *Farm characteristics* | | | |
| 1 if the cow is stall-fed | 0.810*** | 0.197 | 0.362** |
| 1 if the cow is vaccinated | 0.357 | 0.548*** | 0.556*** |
| Acreage in maize per TLU | 0.019 | 0.215** | 0.110 |
| Acreage in Napier per TLU | 0.048 | -0.100 | -0.106 |
| Acreage in pasture per TLU | 0.139 | 0.076 | 0.157 |
| Feed expenditures per TLU | $6.10^{5}$ | $1.10^{4}$*** | $9.10^{5}$*** |
| *Environment characteristics* | | | |
| Annual PPE (*100) | 0.069*** | 0.055*** | 0.058*** |
| *Constant* | 1.172 | 1.870*** | 1.601*** |
| *Number of observations* | 2629 | 2629 | 2629 |
| *R-squared* | 0.360 | - | 0.278 |
| *Prob > F* | 0.000 | 0.000 | - |

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

| **The dependent variable is the milk production per day at specific dates: Second specification** | | | |
|---|---|---|---|
| | WLS | Robust regression | Median regression & bootstrap |
| | | Coefficients | |
| *Cow characteristics* | | | |
| Ln(month of lactation) | -1.962*** | -1.755*** | -1.761*** |
| 1 if the cow is local breed | -2.068*** | -2.341*** | -2.423*** |
| 1 if the cow is a high-grade | 0.538** | 0.418** | 0.097 |
| Number of previous calvings | 0.526*** | 0.390*** | 0.407*** |
| Squared value of number of calvings | -0.041*** | -0.033*** | -0.030** |
| *Farm characteristics* | | | |
| 1 if the cow is stall-fed | 0.736*** | 0.135 | 0.294* |
| 1 if the cow is vaccinated | 0.350 | 0.555*** | 0.600*** |
| Acreage in fodder per TLU | 0.025 | 0.020 | 0.019 |
| Feed expenditures per TLU | $6.10^5$ | $1.10^4$*** | $5.10^5$** |
| *Environment characteristics* | | | |
| Annual PPE (*100) | 0.070*** | 0.055*** | 0.060*** |
| *Constant* | 1.118 | 1.917*** | 1.530** |
| *Number of observations* | 2629 | 2629 | 2629 |
| *R-squared* | 0.359 | - | 0.278 |
| *Prob > F* | 0.000 | 0.000 | - |

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

Annex 3: the Heckman procedure and other ways to control for the selectivity bias

The variable of intensification level ($IL_i$) is a truncated variable since it is only observed for the adopters. It was showed in chapter 3 that a household adopts dairy cattle if its maximisation problem results in a positive optimal number of animals: $C^* > 0$

Let's define $D_i$ equals to 1 if the household is an adopter. By consequence:

$D_i = 1$ if $C_i^* > 0$

$D_i = 0$ if $C_i^* \leq 0$

Moreover, the intensification level is only observed for adopters: $E(IL_i \mid D_i = 1)$ where $E(\bullet)$ is the expectation operator. A functional form for the intensification level is assumed:

$IL_i = \gamma. Y_i + u_i$

And for the optimal number of cows on farm: $C_i^* = \varphi'. X_i + \varepsilon_i$

with $(u_i, \varepsilon_i)$ following a bivariate distribution $N(0, 0, \sigma_u, \sigma_\varepsilon = 1, \rho)$.

Because of unobservable variables, it cannot be assumed *a priori* that the correlation coefficient between the residuals of the two equations $\rho$ is equal to 0. By definition (Greene, p.975), the conditional distribution of $u_i$, knowing $\varepsilon_i$ is $N(\rho.\sigma_u. \varepsilon, \sigma_u^2.(1-\rho^2))$.

The expected value of $IL_i$ can thus be written as:

$$
\begin{aligned}
E(IL_i \mid D_i = 1) &= \gamma. Y_i + \rho.\sigma_u. E(\varepsilon_i \mid \varepsilon_i > -\varphi'. X_i) \\
&= \gamma. Y_i + \rho.\sigma_u. f(\varphi'. X_i) / F(\varphi'. X_i) \\
&= \gamma. Y_i + \rho.\sigma_u. \lambda_i
\end{aligned}
$$

where $f(\bullet)$ is the normal density distribution function and $F(\bullet)$ is the normal cumulative distribution function. $\lambda_i$ are called the Inverse Mills ratios (IMR).

An unbiased estimation is thus obtained using linear estimation methods, in which the IMR are added as explanatory variable in the equation of the intensification level.
Note that the regression method that is used in chapter 3 to estimate the decision to adopt dairy cattle technology is a logit formulation (and not a probit). To derive the IMR, the model is re-estimated using a probit formulation. Results do not change significantly between the two formulations, as it was expected (Greene).

However, the Heckman procedure requires assuming the normality of the residuals. Because this assumption may not hold, alternative methods to control for the possible selectivity bias are needed. Deaton (1997, p. 105) proposes a "mixture of parametric and nonparametric techniques". The first step is the same as in the Heckman procedure, i.e. estimate a probit to investigate the determinants of the adoption decision (chapter 3) and to use the results to generate variables that "summarise" the probability of adoption for each farmer. Besides computing the IMR, two other variables are computed: the index and the probability of adoption. More specifically, the index of adoption is equal to $\varphi'. X$ and the probability of adoption is equal to $F(\varphi'. X)$. These two variables are then introduced in the equation of the intensification level, instead of the IMR.

Annex 4: Econometric results on intensification level

The following tables present the results of the econometric estimation of the intensification level (annex 4.1.), of the simultaneous estimation of the two routes (annex 4.2.), of the indicator "number of cows per acreage " (annex 4.3.) and of the indicator "milk yields" (annex 4.4.).
The first three columns of table 4.1, 4.3 and 4.4 present the results using the first estimation method (i.e. WLS), the following three using the second estimation method (robust regression) and the last three using the third estimation method (median regression with bootstrapping). Annex 1 gives the details of the estimation methods.
As explained in the body of the chapter, three methods to control for a possible selectivity bias are used: the first column for each estimation method presents the result when introducing the IMR; the second column when introducing a polynomial term for the probability of adoption (i.e. probability of adoption, probability squared and probability cube); the third column when introducing a polynomial term for the index of adoption (i.e. index of adoption, index squared and index cube).

Annex 4.1. Results of the econometric analysis of the intensification level (159 observations)

| Variables | Weighted Least Squares | | | Robust Regression | | | Median Regression | | |
|---|---|---|---|---|---|---|---|---|---|
| *Household & household head characteristics* | | | | | | | | | |
| age of the household head | -14,45*** | -11,50** | -11,81** | -7,63 | -5,46 | -6,25 | -10,00** | -6,44 | -7,58 |
| sex of the household head | -102,999 | -81,856 | -79,935 | -100,579 | -96,686 | -81,862 | -38,629 | -157,999 | -139,545 |
| education level (years) | 24,911* | 34,717** | 33,387** | 25,267 | 35,505** | 33,967** | 27,504 | 27,597 | 28,686 |
| 1 if kikuyu | 169,545 | 174,631 | 160,244 | 372,196 | 400,367* | 371,680 | 292,238 | 398,598 | 411,165 |
| land acreage | -16,38*** | -11,24** | -13,12** | -12,83** | -7,63 | -9,54 | -13,94* | -8,55 | -7,21 |
| number of adults | -11,965 | -17,246 | -16,407 | -15,815 | -20,665 | -21,065 | -5,061 | -1,791 | 2,786 |
| proportion of female adults | 570,106 | 652,548 | 643,482 | 279,119 | 368,635 | 363,987 | 123,684 | 156,272 | 73,127 |
| *Prices and transaction costs* | | | | | | | | | |
| milk price in the sublocation | 23,293 | 42,600 | 36,492 | 42,920 | 54,375*** | 48,619 | 83,398 | 54,882 | 55,736 |
| distance on all-weather roads | -13,783* | -11,052 | -11,580* | -12,314* | -10,251 | -11,358* | -12,439 | -1,130 | -3,863 |
| distance on dry-weather roads | 2,141 | 1,342 | 1,745 | 8,437 | 6,175 | 5,369 | 4,780 | 6,070 | 4,584 |
| Wage rate | -2,809 | -3,290 | -3,428 | -2,469 | -2,975 | -3,151 | -1,927 | -2,252 | -3,109 |
| *Area characteristics* | | | | | | | | | |
| dairy cooperative availability | 327,595* | 338,962** | 338,473** | 224,069 | 236,238 | 245,561 | 236,248 | 102,309 | 170,571 |
| extent of A.I. availability | 151,417 | 179,728 | 175,461 | 262,984 | 278,551 | 266,549 | 350,218 | 395,479 | 360,516 |
| 1 if it is a tick-infected area | 162,140 | 140,687 | 148,101 | 9,418 | -15,399 | 1,114 | -102,546 | 13,695 | 11,946 |
| annual PPE | 28,577*** | 35,804*** | 34,945*** | 25,951*** | 32,975*** | 32,280*** | 30,514** | 36,427*** | 36,589*** |
| minimum temperature | 51,281 | 47,798 | 50,607 | 39,583 | 38,972 | 44,081 | 50,849 | 33,260 | 46,791 |
| *IMR for adoption of grade cows* | 695,342** | | | 669,742** | | | 831,476* | | |
| *Polynomial terms for the probability of adoption* | | | | | | | | | |
| *- level* | | 2541,387 | | | -222,984 | | | -2800,481 | |
| *- squared* | | -2809,165 | | | 1717,451 | | | 6075,529 | |
| *- power three* | | -381,366 | | | -2633,265 | | | -5064,214 | |
| *Polynomial terms for the index of adoption* | | | | | | | | | |
| *- level* | | | -389,39* | | | -415,012* | | | -416,508 |
| *- squared* | | | -373,82** | | | -278,350* | | | -302,511 |
| *- power three* | | | 155,26** | | | 120,813* | | | 108,594 |
| *Constant* | -1558,26 | -2443,26* | -1715,79 | -2018,85 | -2259,86* | -2027,48 | -2929,77 | -2067,79 | -2499,77 |
| R- squared | 0.35 | 0.38 | 0.38 | | | | 0.23 | 0.25 | 0.24 |
| Prob> F | | | | 0.00 | 0.00 | 0.00 | | | |

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

Annex 4.2. Results of the econometric analysis: simultaneous estimation of the two routes (159 observations)

| Variables | Number of cows per land size | | Milk yield per cow | |
|---|---|---|---|---|
| | Coefficient | P>\|t\| | Coefficient | P>\|t\| |
| *Household & household head characteristics* | | | | |
| age of the household head | -0,008** | 0,016 | -0,076 | 0,975 |
| sex of the household head | -0,055 | 0,572 | -17,651 | 0,806 |
| education level (years) | 0,017 | 0,119 | 6,265 | 0,436 |
| 1 if kikuyu | 0,148 | 0,380 | 104,108 | 0,403 |
| land acreage | -0,011** | 0,011 | -3,635 | 0,238 |
| number of adults | -0,011 | 0,546 | 0,068 | 0,996 |
| proportion of female adults | 0,388* | 0,078 | -190,891 | 0,239 |
| *Prices and transaction costs* | | | | |
| milk price in the sublocation | 0,019 | 0,399 | -9,886 | 0,556 |
| distance on all-weather roads | -0,007 | 0,112 | -3,494 | 0,302 |
| distance on dry-weather roads | -0,001 | 0,915 | 4,551 | 0,615 |
| Wage rate | -0,001 | 0,577 | 0,556 | 0,666 |
| *Area characteristics* | | | | |
| dairy cooperative availability | 0,132 | 0,243 | 106,179 | 0,203 |
| extent of A.I. availability | 0,053 | 0,690 | 116,173 | 0,238 |
| 1 if it is a tick-infected area | 0,030 | 0,821 | 154,261 | 0,117 |
| annual PPE | 0,008 | 0,230 | 26,771*** | 0,000 |
| minimum temperature | 0,027 | 0,353 | -3,634 | 0,863 |
| *IMR for adoption of grade cows* | 0,376 | 0,113 | 136,751 | 0,433 |
| *Constant* | -0,317 | 0,715 | -430,224 | 0,503 |
| "R- squared" | 0.33 | | 0.53 | |
| Correlation between the residuals | 0.08 not significant at 30% (Chi2(1)= 1.034) | | | |

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

Annex 4.3. Results of the econometric analysis on the number of cows per total land acreage (751 observations)

| Variables | Weighted Least Squares | | | Robust Regression | | | Median Regression | | |
|---|---|---|---|---|---|---|---|---|---|
| *Household & household head characteristics* | | | | | | | | | |
| age of the household head | -0,008*** | -0,007*** | -0,007*** | -0,003** | -0,002** | -0,002** | -0,004*** | -0,004*** | -0,005*** |
| sex of the household head | 0,043 | 0,075 | 0,053 | -0,017 | 0,012 | 0,008 | -0,005 | 0,031 | 0,024 |
| education level (years) | 0,011* | 0,013* | 0,014** | 0,004 | 0,010*** | 0,008** | 0,001 | 0,006 | 0,004 |
| 1 if kikuyu | 0,355*** | 0,349*** | 0,382*** | 0,145*** | 0,196*** | 0,184*** | 0,163*** | 0,229*** | 0,200*** |
| land acreage | -0,007*** | -0,006** | -0,005 | -0,007*** | -0,003** | -0,004*** | -0,007*** | -0,002 | -0,004** |
| number of adults | -0,017 | -0,013 | -0,016* | -0,004 | -0,002 | -0,002 | -0,003 | -0,002 | 0,000 |
| proportion of female adults | 0,169 | 0,196* | 0,197* | -0,012 | 0,026 | 0,016 | 0,023 | 0,074 | 0,087 |
| *Prices and transaction costs* | | | | | | | | | |
| milk price in the sublocation | -0,003 | 0,002 | -0,001 | -0,006 | -0,004 | -0,008* | -0,005 | -0,005 | -0,008** |
| distance on all-weather roads | -0,012*** | -0,009*** | -0,012*** | -0,008*** | -0,007*** | -0,008*** | -0,008*** | -0,008*** | -0,009*** |
| distance on dry-weather roads | 0,001 | 0,003 | 0,001 | -0,001 | 0,000 | -0,001 | 0,001 | 0,001 | 0,002 |
| Wage rate | -0,001 | 0,000 | -0,001 | -0,001** | -0,001* | -0,001* | -0,001* | -0,001* | -0,001*** |
| *Area characteristics* | | | | | | | | | |
| dairy cooperative availability | 0,145*** | 0,157*** | 0,160*** | 0,059** | 0,080*** | 0,073** | 0,073 | 0,093** | 0,087*** |
| extent of A.I. availability | 0,213*** | 0,201*** | 0,219*** | 0,197*** | 0,218*** | 0,212*** | 0,213*** | 0,249*** | 0,241*** |
| 1 if it is a tick-infected area | -0,068 | -0,081 | -0,097 | -0,046** | -0,096** | -0,085** | -0,034 | -0,102* | -0,090* |
| annual PPE | 0,010** | 0,009* | 0,012** | 0,006*** | 0,010*** | 0,009*** | 0,006** | 0,011*** | 0,009*** |
| minimum temperature | 0,027 | 0,016 | 0,032* | 0,011** | 0,016* | 0,017* | 0,001 | 0,009 | 0,012 |
| *IMR for adoption of grade cows* | 0,637*** | | | 0,309*** | | | 0,318*** | | |
| *Polynomial terms for the probability of adoption* | | | | | | | | | |
| *- level* | | -3,323** | | | -1,435** | | | -1,679*** | |
| *- squared* | | 5,629** | | | 2,192* | | | 2,557* | |
| *- power three* | | -3,863** | | | -1,766** | | | -2,012** | |
| *Polynomial terms for the index of adoption* | | | | | | | | | |
| *- level* | | | -0,432*** | | | -0,302*** | | | -0,327*** |
| *- squared* | | | 0,049** | | | -0,008 | | | 0,002 |
| *- power three* | | | 0,002 | | | 0,019*** | | | 0,020*** |
| *Constant* | -0,235 | 0,904** | -0,023 | 0,192 | 0,396* | 0,151 | 0,333 | 0,631** | 0,352 |
| R- squared | 0.21 | 0.21 | 0.21 | | | | 0.13 | 0.15 | 0.14 |
| Prob> F | | | | 0.00 | 0.00 | 0.00 | | | |

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

Annex 4.4. Results of the econometric analysis on milk yields (160 observations)

| Variables | Weighted Least Squares | | | Robust Regression | | | Median Regression | | |
|---|---|---|---|---|---|---|---|---|---|
| *Household & household head characteristics* | | | | | | | | | |
| age of the household head | -0,110 | -0,559 | -0,598 | 0,488 | -0,422 | -0,396 | -0,929 | -2,185 | -1,685 |
| sex of the household head | -18,986 | -21,789 | -23,941 | -13,250 | -23,735 | -25,769 | -20,887 | -13,913 | -16,348 |
| education level (years) | 6,316 | 4,760 | 4,853 | 2,567 | -0,371 | 0,103 | 7,497 | -0,575 | -1,180 |
| 1 if kikuyu | 105,235 | 100,975 | 108,691 | 27,707 | 17,506 | 25,943 | 58,128 | 64,625 | 73,117 |
| land acreage | -3,593 | -4,529 | -3,936 | -6,192** | -7,843*** | -6,708** | -5,424 | -7,859 | -8,537 |
| number of adults | 0,301 | 1,010 | 1,232 | 20,372 | 22,645* | 22,560* | 24,518** | 23,701 | 29,372 |
| proportion of female adults | -198,881 | -212,381 | -212,250 | -99,687 | -104,296 | -99,225 | -140,581 | -137,231 | -171,432 |
| *Prices and transaction costs* | | | | | | | | | |
| milk price in the sublocation | -10,131 | -13,258 | -12,487 | -14,360 | -18,025 | -16,528 | -33,665* | -27,065 | -27,226 |
| distance on all-weather roads | -3,506 | -3,835 | -3,891 | 0,443 | -0,262 | -0,366 | 1,211 | 1,853 | 2,622 |
| distance on dry-weather roads | 4,596 | 4,653 | 4,584 | 3,439 | 3,466 | 3,023 | 3,246 | 2,296 | 5,327 |
| Wage rate | 0,568 | 0,650 | 0,696 | 1,618 | 1,894 | 1,927* | 1,634 | 2,186 | 2,771 |
| *Area characteristics* | | | | | | | | | |
| dairy cooperative availability | 106,464 | 103,983 | 104,416 | 93,316 | 85,262 | 89,030 | 110,580 | 25,312 | 4,448 |
| extent of A.I. availability | 114,625 | 108,011 | 109,939 | 93,810 | 86,765 | 85,047 | -5,381 | 26,569 | 5,568 |
| 1 if it is a tick-infected area | 153,779* | 159,517* | 154,844* | 121,506 | 120,267 | 113,573 | 124,828 | 163,922 | 168,171 |
| annual PPE | 26,725*** | 25,438*** | 25,646*** | 23,668*** | 21,243*** | 21,622*** | 24,868*** | 21,240*** | 20,901*** |
| minimum temperature | -3,555 | -3,349 | -3,583 | -6,423 | -7,504 | -7,755 | 5,381 | 1,834 | -0,059 |
| *IMR for adoption of grade cows* | 138,407 | | | -22,660 | | | 216,454 | | |
| *Polynomial terms for the probability of adoption* | | | | | | | | | |
| *- level* | | -1010,519 | | | -2036,630 | | | -1737,363 | |
| *- squared* | | 717,251 | | | 2794,143 | | | 2094,039 | |
| *- power three* | | -43,825 | | | -992,104 | | | -639,802 | |
| *Polynomial terms for the index of adoption* | | | | | | | | | |
| *- level* | | | -89,826 | | | 33,828 | | | 0,580 |
| *- squared* | | | 105,613* | | | 154,795** | | | 117,164 |
| *- power three* | | | -32,285 | | | -63,853** | | | -36,980 |
| *Constant* | -420,820 | 183,997 | -194,087 | -246,062 | 433,679 | -76,593 | -221,762 | 508,104 | 4,758 |
| R- squared | 0.53 | 0.53 | 0.53 | | | | 0.36 | 0.37 | 0.37 |
| Prob> F | | | | 0.00 | 0.00 | 0.00 | | | |

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

# Conclusion

The analyses conducted in this dissertation aim at identifying the opportunities offered and constraints imposed by dairying in the specific case of the Kenyan smallholders' sector. More broadly, this work deals with the general literature on adoption of agricultural innovations in Developing Countries, focusing on a case that has not yet been extensively considered in the literature. As presented in the introduction, the reasons for analysing the adoption of grade cattle technology are related to the expected positive impacts of dairying: increase in smallholders' well-being through higher income (milk sale), higher milk consumption and increased employment opportunities for the family members and also for the whole rural community. Dairying can thus be considered as a way to decrease poverty, both in the rural areas and in peri- urban areas where dairying is a viable alternative to other employment opportunities. The analysis of poverty reduction is particularly relevant in Kenya, recalling that the percentage of the population below the (national) poverty line is estimated at 42% in 1992 (World Bank 1999); incidence of poverty is higher in rural areas, with 46.4% of the population living below the poverty line. Finally the role of dairying in the long- term sustainability of the crop- livestock systems should not been neglected.

Two points will be discussed in this conclusion The first point summarises the main thrusts of the dissertation and the methodology followed in the different chapters. An analysis of the results follows, together with a comparison of the findings of the different approaches and some policy recommendations.

## The main thrusts of the dissertation

In the economic literature concerning the adoption of agricultural innovations in Developing Countries, the specific topic of smallholders' adoption of grade cattle technology has not been examined and no formal model has yet been developed. Examination of the general economic literature on adoption along with extensive field work and meetings with scientists of different fields of research allowed identifying the main constraints and advantages of dairying. Building on these elements, an original theoretical framework that takes into account the most salient features of the dairy enterprises of the smallholders' sector in Kenya was developed and tested using a reduced- form approach. The data used in the empirical analyses are extracted from two surveys conducted in Kenya on randomly- selected households in several areas that represent a broad range of levels of dairy productivity potential and market access.

The main constraint considered in this analysis is the entry cost i.e. the price of a grade cow. Because of the high entry cost, one way to ease the adoption is to find ways not to bear it. The analysis of the means to start dairying without purchasing constitutes **the first thrust** of the dissertation. Two ways are identified: getting the animal at no cash cost and upgrading progressively local animals through crossbreeding. The first option is the "ideal" alternative; however, the "lucky" beneficiaries do not share particular observable characteristics and no policy recommendations can be derived. The second route seems more promising since it enables a farmer to dramatically reduce the lumpiness of the entry cost, as the costs of acquiring a grade cow are spread out over several years. However, the process is long and risky. The analysis of the choice to follow this route *versus* all the other routes identify three determinants: the availability of local animals in the area, the education level of the household head and distance to urban centres. Farmers in distant areas are more likely to choose the upgrading process to start dairying because the incentives to increase milk production for sale are lower, *ceteris paribus*.
Few farmers chose one of the two routes to start dairy farming: more than 90% of the surveyed farmers had to purchase their first grade cow. One difficulty of the analysis is related to the fact that the data do not provide the way farmers meet the cost of the purchase: the analysis thus has to take into account the different possibilities.

**The second thrust** focuses on access to credit as a way to finance the cost of the first grade cow. A theoretical model is build that incorporates the different factors that are likely to influence a smallholder's decision to purchase a grade cow. The model considers the adoption decision at a specific point of time, i.e. the time of the survey. "Adopters" are farmers with a least one crossbred or grade cow at the time of the survey. Note that this definition may underestimate the adoption trend since farmers who discontinued dairying are not classified as "adopters" by this definition. The hypothesis that access to credit facilitates the adoption of grade cattle technology is tested within this framework; borrowers are classified as non- constrained agents, thus setting the hypothesis that the amount asked equals the amount lent. The hypothesis that access to credit facilitates the entry into dairy farming is not rejected by the data. The other findings are consistent with the expectations: education, land holding, proximity with a dairy co-operative and availability of livestock services in the neighbourhood influence positively the adoption decision. On the other hand, farmers in distant areas are less likely to adopt. The result on the liberalisation of the dairy sector suggests also that farmers are less induced to adopt after 1992; while the result may reflect the fact that the non- adopters have not yet adopted, the result is consistent with the observations during field work that indicate that conditions for dairy farming deteriorated in some areas: worsening of the marketing conditions where dairy co-operatives collapsed and were replaced by unreliable traders and progressive withdrawal of government support in the delivery of livestock services.

While the second thrust deals with the analysis of the adoption process at a specific point of line, **the third thrust** considers the adoption process as a transition toward higher income levels that necessitates mobilising financial and human resources. The analysis is thus more "dynamic" as it aims at explaining the differentials in the length of time before adoption. A similar theoretical framework to the previous model is used, augmented by determinants that could not be introduced in the static analysis: the accumulation of past agricultural revenues and the learning process. Past agricultural revenues are approximated by the farm potential harvests, based on household- level rainfall data. The learning process is twofold, as emphasised by the literature: the "learning by doing", captured in the general shape of the adoption trend, after controlling for the other determinants (or more specifically the ancillary parameter of the parametric specifications in the duration models analysis) and the "learning-from-others", captured by the overall adoption rates in the area. The analysis supports the different hypotheses and the results are consistent with the previous findings. Past agricultural revenues, although crudely approximated, play a crucial role in the adoption process. A certain "learning from others" seems at play but there is no evidence of "learning by doing" since the adoption hazard rate is decreasing over the farmer's life span (negative duration dependence).

**The fourth and last thrust** deals with the level of intensification in dairy farming, after the acquisition of a grade cow took place. While grade cows have a higher milk potential than local breed cows, levels of milk production per unit of land vary widely within the adopters' population. The objective is thus to get a better understanding of this observed variability. The second objective is to understand the means used by dairy farmers to intensify the dairy enterprise: either by increasing the animal productivity (milk production per cow per year) or by increasing the number of animals kept on farm (per unit of land). The analysis of the intensification level necessitates in a first step the estimation of the yearly milk production using a production function approach. Using the results of the production function approach, an unique indicator for the level of intensification in dairy farming is then derived. The results are however relatively disappointing, despite the number of different regression methods used. As expected, land size (negatively) and availability of livestock services (positively) influence the level of intensification. Results suggest that no other factor introduced in the analysis is a major determinant. More research is thus needed to better identify the constraints faced by smallholders; other indicators, relative to the inputs levels (especially relative to feed) would have to be developed.

What has been learned? Discussion of the results

Four main points are discussed: the role of access to credit and the other ways to finance the entry cost; the role of education and the "learning from others"; the role of transaction costs in milk marketing; and the role of the delivery of livestock services and the liberalisation of the dairy sector.

The different analyses conducted in this dissertation support the hypothesis that **access to credit** facilitates the adoption of grade cattle technology. This result is consistent across the different regression methods. However, the quantitative effect is limited since increasing access to credit by 10% only increases the probability of adoption by 4.8% (chapter 3) and decreases the time length before adoption by less than one year (chapter 4). **The other ways to finance the entry cost** identified by the literature and field work are using off- farm income and using savings from past agricultural activities. Besides these three main ways to finance the entry cost, there are two options: benefiting from Resettlement schemes after Independence and selling local breed animals. Results in chapter 4 show that farmers living in Settlement areas and established soon after Independence adopt faster, *ceteris paribus*, reflecting the preferential conditions they are likely to have benefited A last option is related with the ownership of local breed cattle before adoption: farmers can finance the cost of a grade cow by selling the local breed cattle. The effect of keeping local animals on the probability of adopting grade cattle may however be explained by another factor: the experience gained with livestock activities that induces farmers to enter into this skill- specific activity. The analysis of chapter 4 shows that keeping local breed cattle diminishes the duration before adoption, thus supporting the hypotheses.

Off- farm income could not be introduced directly since its determination is simultaneous with the adoption decision. Indirect measures of off- farm income were thus introduced in the analysis through the family labour force. No significant effect is however established. This result is unexpected and diverges from some field work interviews. There are two possible explanations:

(1) the included variables do not capture accurately the existence and extent of off- farm income and (2) farmers with off- farm income are those with large land holdings and/or are close to markets: these households would have started dairying anyhow and the possible effect of off-farm income is then captured through other variables (land size and distances to urban centres).

Past agricultural revenues are another way farmers may use to finance the entry cost: while the computation of the variable is subject to critics, the following point emerge from the analysis of chapter 4. First, the empirical analysis takes into account the depleting effect due to consumption: a combined variable with the (time- variant) dependency ratio is introduced that accounts for the fact that a large family has larger needs. Secondly, it is unlikely that the variable capture a time trend that could explain the negative relationship between the variable and the duration before adoption: in fact, a discounted factor is used for the depreciating effect of time. Controlling for the other factors, a 10% increase (of the observed maximum of the variable) has a substantial effect on the adoption decision since it diminishes the time length before adoption by almost 6 years (compared to the "median" surveyed farmer).

The comparison of this result with the effect of credit access (results in chapter 4) reveals that own savings have a more important effect on the adoption decision than external funding. However, results show also that the negative effect of lack of access to credit is stronger for the female- headed households: if targeted toward this class of households, improved access to credit can thus have a significant effect on the adoption of grade cattle technology. While the main way to reduce poverty is by implementing sound macroeconomic policies that contribute to overall growth through an increase in the allocative efficiency of resource use, it may not be a sufficient condition (Bardhan and Udry 1999). In fact, the growth process may not benefit some poor who are unable to get out of the poverty trap. These situations arise because of the existence of market failures and especially imperfections of the credit and insurance markets: "rich" farmers have the needed collateral to have access to credit and are then are able "to climb out of poverty" (Bardhan and Udry, p. 136) by accessing to profitable enterprises like dairying. On the other hand, farmers with smaller land size and female- headed households find it more difficult to finance the entry cost.

Since imperfections on credit markets are one of the main factors that explain the persistence of income inequalities, policy interventions on these markets are justified. Outcomes of policy interventions on credit markets results are however mixed: outside agencies usually lack the needed information to screen the potential borrowers so that a collateral is imposed, driving the poor out the market as in the case of AFC (chapter 3). The example of the Brazilian rural credit programs studied by Anderson (1990) shows that regulations imposed on private banks to lend a specified volume to small farmers are unlikely to have the desired effect. Other solutions have thus to be found. The well- known example of the Grameen Bank in Bangladesh consists in lending money to women groups and organising credit monitoring through peer pressure and social sanctions. In Kenya, farmers group could be a viable alternative for channelling credit in the rural areas: self- help- groups whose members have a greater sense of ownership than co-operative members, women groups and "merry go round" groups (the Kenyan rotating savings and credit associations) could be used.

The second set of results is related to the role of **education and the learning externalities**. The economic literature on the adoption of agricultural innovations in Developing Countries identifies education as a main determinant since it enables the farmer to better understand the information relative to the innovation. Grade cattle require specific care and skills and it is thus assumed that more educated farmers are more likely to adopt. This hypothesis is not rejected by the data, both in the static framework (chapter 3) and in the duration analysis (chapter 4): from a primary school to a secondary school education level, the likelihood of adoption increases by 4.5% and the duration before adoption is decreased by approximately 2 years. Note that the effect of four more years education is similar to the effect of ten percent more access to credit in the static analysis. Finally, the analysis of chapter 4, by introducing time, allows to test for the existence of learning externalities, or "learning from others". The hypothesis of the existence of some learning externalities in the adoption process is not rejected by the data, although the obtained result may be explained by other phenomena, e.g. peer pressure.

Because of the join causality between income and human capital, improving access to education is crucial to facilitate the adoption of profitable agricultural innovations. Coupled with increasing returns to investments in education and imperfect credit markets, the joint determination of income and human capital can generate another mechanism through which a poverty trap may emerge (Bardhan and Udry): only wealthy farmers are able to invest in education, enabling them to remain well- off.

The third set of results are those related to **milk marketing and the existence of transactions costs**. Transaction costs are introduced through distances from the farm to Nairobi and to the two nearest urban centres. Distances are differentiated by road types, between all-weather roads (bound or tarmac, and loose or "murram" surfaces) and dry- weather roads. It is expected that distances on seasonal roads are a higher impediment to smallholders' marketing, compared to all- weather roads, since transport costs are higher. Transaction costs are particularly relevant in the case of milk marketing since milk is highly perishable, bulky and needs to be sold daily. According to the results of the static analysis (chapter 3), distances on all- weather roads have a negative effect on the adoption decision, yet limited since a farmer situated further from the urban centres by 10 km is less likely to adopt by "only" 2.4%. On the other hand, the analysis in chapter 4 shows that the effect of 10 more km on dry- weather roads has a huge effect since it increases the time length before adoption by almost 13 years (when comparing with the median farmer). The difference is explained by the way the distances in the analysis of chapter 3 are computed: since distances by road types were not available for the "Kiambu" farmers, adjustments were necessary as explained in the corresponding chapter. Caution must thus be exercised in the interpretation of the distance variable in the first analysis; results of chapter 4 should be preferred. Distances for all the surveyed farmers, including Kiambu, by road types are now available and econometric analyses will be rerun in order to introduce "direct" distances similar to those for the other observations.

In Kenya, the creation of smallholders' co-operatives has been encouraged by the government since co-operatives provide an effective way to organise milk collection and marketing. By providing a reliable outlet, at least until the beginning of the 1990s, dairy co-operatives play a major role in the profitability of the dairy enterprises. Moreover, some co-operatives provide other services to their members, besides collecting and marketing their milk: provision of animal feeds (some co-operatives on short- term loans) and livestock services (veterinary and artificial insemination). In the analysis of chapter 3, availability of a dairy co-operative fosters the adoption of grade cattle technology: farmers in the neighbourhood of a "reliable" marketing channel thus are more induced to adopt by 6.8%. A limitation of this analysis is related to another type of farmers' organisations that is not taken into account in the analyses: the self- help- groups. Self-help- groups are "spontaneous" farmers' group that are not registered with the Ministry of Co-operative Development (but with the Ministry of Culture and Social Services). They are primarily engaged in milk marketing (some offered artificial insemination services also). Since their membership is on average lower than co-operatives, their exclusion from the analysis is unlikely to bias significantly the results but further research will need to take into account these organisations.

In the analysis of chapter 4, the availability of a dairy co-operative in the neighbourhood is introduced as a time- variant determinant. The computation of the variable necessitated the recording of all the dairy co-operatives in the surveyed area, as well as their registration and termination (if relevant) dates. In the duration analysis, the hypothesis that the existence of a dairy co-operative in the farmer's neighbourhood accelerates the adoption is rejected by the data.

While this result may suggest that the variable is measured with error (linked to the difficulty to record all the dairy co-operatives), it may also indicate that dairy co-operatives have no significant effect on the adoption decision, *ceteris paribus*. In fact, measures of market access (through distances to urban centres) are introduced in the analysis and these may be the main constraint to smallholders' milk marketing. The impact of the existence of a dairy co-operative in the neighbourhood is ambiguous also in the determination of the intensification level in dairy farming (chapter 5) since the effect is significant only in few regressions.

The last set of results deals with **the delivery of livestock services and the effect of the liberalisation of the dairy sector**. Deliveries of livestock services are assumed to play a major role in the decision to enter into dairying since they are important inputs of the dairy enterprises. As shown by the analysis of chapter 3, the availability of livestock services in the neighbourhood encourages farmers to start dairying: farmers for which artificial insemination (veterinary) services are available are more likely to adopt grade cattle technology by 11% (16%), compared to farmers without those services. Note that the positive effect of veterinary services is higher, in absolute value, to the negative effect of being in a tick- infected area since farmers in these zones are less likely to adopt by almost 10%. If targeted, this analysis shows that the delivery of livestock services can more than offset the constraints of the environment. Moreover, livestock services seem to play a key role in the productivity of the dairy farms as shown in the intensification level analysis (chapter 5).

The liberalisation of the sector at the beginning of the 1990s comprised two main aspects: the progressive withdrawal of the government delivery of livestock services in some areas and the liberalisation of the milk market. Because time- series data on the availability of livestock services could not be obtained by area, the duration model analysis introduces this factor indirectly, through the dummy variable describing the liberalisation of the sector. The two approaches, the static modelling (chapter 3) and the duration model analysis (chapter 4) do not reject the hypothesis that the speed of adoption slowed down after the liberalisation. This result must however be interpreted with prudence since it may reflect the fact that the non- adopters have not yet adopted. Considering that it captures truly the effect of the liberalisation, it suggests that the conditions for the adoption of grade cattle technology worsened with the closing of some dairy co-operatives and privatisation of livestock services. Although the private sector was expected to progressively take over milk marketing and delivery of livestock services, the process is slow and hindered by administrative regulations. These results suggest that liberalisation policies may need to be accompanied by interim support for farm services and market mechanisms to maintain technology adoption trends.

For dairying to be a means to decrease poverty, livestock services should be made more available to smallholders. The public sector used to play a key role in their delivery but progressive withdrawal has left a "vacuum" in some areas. Both the private sector and co-operatives are expected to fill the gap. Smallholders' co-operatives are believed to have a comparative advantage: firstly, combination of services are source of economies of scale since milk collection are combined with the delivery of other services, and secondly credit for inputs are deducted from the farmer's milk payment thus providing short- term credit (Owango *et al.*). The role of the dairy co-operative is then worth promoting; the revision of the Co-operative Development Act in 1997 increases farmers' control over the management of their co-operatives, aiming at avoiding past mismanagement and increasing farmers' sense of ownership. However, its effect on the ground is not yet effective (Omore *et al.*).

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