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Predicting technology adoption to improve research priority—setting

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Abstract

This paper presents an improved approach for predicting the speed and ceiling of technology adoption, which is a crucial information for research priority setting. In the models it is assumed that both the speed and ceiling of adoption depend on the perceived characteristics of technologies. Knowing the characteristics that have determined adoption in the past provides relevant information about the characteristics which will enable new technologies to be quickly and widely adopted in the future. Using a case study from Meru District in Kenya, it is shown that relative investment, relative risk and relative complexity significantly influenced the speed and ceiling of adoption of dairy technologies in the past. These empirical results are used to predict the speed and ceiling of adoption of potential new dairy technologies to be developed by the Dairy Cattle Research Programme (DCRP) of the Kenya Agricultural Research Institute (KARI). The approach is theoretically sound and based on empirical evidence. It clearly distinguishes promising technologies from less promising technologies and is transparent to participants in priority setting exercises. Allowing for the participation of all interest groups within the research system, the approach improves the quality of the assessment and hence the credibility of results.

JEL classification: O32, Q16

Keywords: Research priority setting; Performance assessment; Innovation adoption; Technology characteristics; Decision-making

1. Introduction

In the face of stagnating and even declining funding, decision makers in research systems are under increasing pressure to allocate their available budgets efficiently. This means that only those research activities can be carried out that promise the most efficient use of research resources. Priorities have to be set in order to allocate funds to the most promising research.

The likely extent of future adoption of research results has a strong influence on the efficiency of research and on the results of priority setting exercises: research activities are only beneficial if their results are transferred to clients, i.e. farmers. Hence, prediction of technology adoption is crucial to guide the priority setting process. However, ex ante estimates of technology adoption are difficult to make. Adoption is a dynamic process that is determined by various factors, including farmers' perceptions of the relative

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advantages and disadvantages of technologies, and the efforts made by extension services to disseminate these technologies.

In practical priority setting exercises, adoption information is provided by experts. Given the complex set of factors influencing adoption decisions, expert-based ex ante estimates of technology adoption may lead to biased research assessments and hence to distorted results in priority setting exercises. A method based on empirical estimates of technology adoption would be of great value. By introducing such estimates in adoption models, the overall outcome of priority setting could be improved.

This paper describes a method to improve ex ante estimates of technology adoption for priority setting. The method is based on the assumption that an understanding of past adoption behaviour by a target group can help to predict future adoption behaviour. The National Dairy Development Programme (NDDP) of Kenya provided us with an opportunity to collect empirical information on technology adoption by Kenyan dairy farmers. The Kenya Agricultural Research Institute (KARI) allowed us to apply the results in a priority setting exercise for its Dairy Cattle Research Programme (DCRP).

This paper concentrates on a method for the estimation of adoption parameters within a programme. The overall results of the priority setting exercise will not receive further attention.

2. The role of adoption information in priority setting

The contribution of technology adoption to research performance can be measured using net present value (NPV) as an indicator. Eq. (1) defines the NPV arising from the development of a new technology as the difference between the expected benefit and the costs of the research (Alston et al., 1995):

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{B_{ikt} - C_{ikt}}{(1+r)_t} \tag{1}$$

where B_{ikt} is the expected economic benefit from the new technology i on commodity k in year t; C_{ikt} the expected research costs associated with developing technology i, on commodity k in year t; and r is the social discount rate.

The principal elements of the economic benefit are presented in Eq. (2). Economic benefit depends linearly on the adoption of the innovation developed, as the benefit of research will be zero if the adoption of resulting innovations is zero. Benefits are assumed to increase linearly with the number of adopters:

$$B_{ikt} = [Y_{ik}(V_k - C_{Aik})]A_i \, \mathrm{Ar}_i \, P_i \tag{2}$$

where Y_{ik} is the average expected yield increase per potential adopter as a result of adoption of technology i on commodity k; V_k the value per unit of commodity k; C_{Aik} the expected incremental per unit costs associated with the adoption of technology i on commodity k; A_i the number of potential adopters of technology i; Ar_i the percentage of farmers who have adopted technology i; and P_i is the probability that research will lead to technology i.

Costs associated with the development of innovations (C_{ikt}) are also influenced by their adoption. As shown in Eq. (3), innovation development incurs not only costs for research (e.g. salaries, capital, administration), but also costs for the dissemination of an innovation after its release. These costs include salaries for extension workers as well as costs for overheads and fixed capital, which are described as special capital costs:

$$C_{ikt} = (R_{\mathrm{n}} C_{\mathrm{Rs}} + C_{\mathrm{Rz}}) + (D_{\mathrm{n}} C_{\mathrm{Ds}} + C_{\mathrm{Dz}}) \tag{3}$$

where R_{n} is the total number of researcher-years; C_{Rs} the average cost of a researcher per year; C_{Rz} the special capital costs for research; D_{n} the total number of extension worker-years; C_{Ds} the average cost of an extension worker per year; and C_{Dz} is the special capital costs for extension.

The longer an innovation takes to be adopted by farmers, the higher these costs in relation to the benefits and the lower the NPV of the research. Moreover, because the NPV is adjusted by a social discount rate, net benefits in the long-term count less than net benefits in the short-term. This means that slow adoption of innovations leads to diminishing net present values. The adoption information needed for priority setting is depicted in Fig. 1 as a typical s-shaped adoption curve. The faster adoption proceeds, and the larger the number of individuals who eventually adopt, the greater the benefits. Costs are incurred through research and extension. The benefit–cost ratio is smaller,

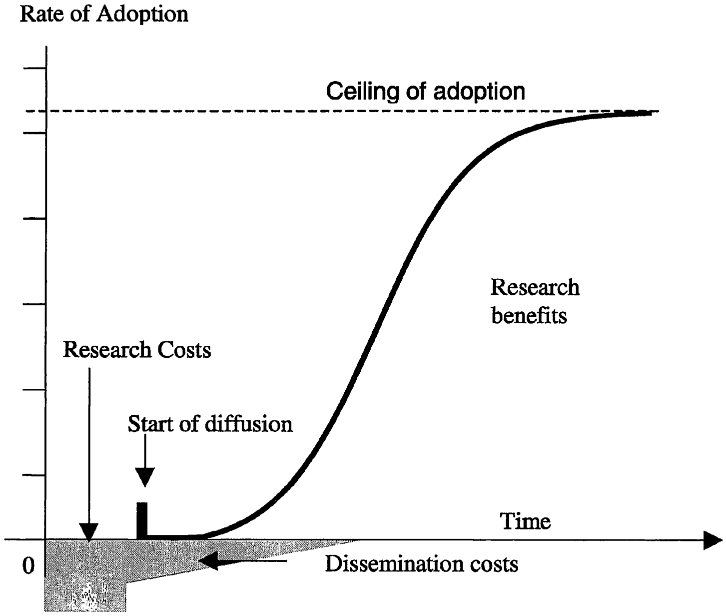

Fig. 1. Adoption information for research priority setting.

the longer the duration of research and extension and the smaller the benefits from the technology.

Considering these relationships one can conclude that innovations that show a higher speed of adoption are more profitable than those with low rates of adoption because the benefits occur faster and the ceiling of adoption is achieved earlier, all other thing being equal. Moreover, the higher the level of adoption achieved at a given time, the higher the benefits obtained through the use of the technology. Consequently, priority setting analysts should know, for each technology considered in the priority setting process, the speed and the ceiling of adoption.

3. An approach to predicting technology adoption

In the past, different approaches have been used to generate data for adoption parameters and to integrate them into priority setting exercises. All of the approaches are based on the utilisation of expert knowledge. Experts are provided with a list of factors that are assumed to influence the adoption of innovation. They are then asked to provide, on the basis of these factors, a quantitative estimate of the speed and ceiling of adoption for all of the innovations under development.

The use of such approaches implicitly assumes that experts are aware of the factors that determine adoption processes. Moreover, they must have access to information on the impact of these factors on the speed and ceiling of adoption. Only if such knowledge is available can one assume that experts will be able to provide solid ex ante assessments of innovation adoption. However, analysis of the literature shows that experts can hardly have access to such information. In particular, empirical studies that analyse the determinants of the speed and ceiling of adoption are rare (Batz, 2000). Moreover, studies investigating the adoption behaviour of farmers show that there are no a priori relationships between the factors that are assumed to influence innovation adoption and adoption decisions by farmers.

This lack of information causes problems for sound priority setting: the adoption of technologies must be taken into account for rational decision-making, but the benefit of taking available estimates into account is uncertain. Unrealistic assessment of adoption by experts produces unrealistic results with regard to performance assessment and thus adversely affects the quality of priority setting. Credibility also suffers. Experts who do not feel that they are in a position to give the required information will probably not accept the outcome of the priority setting exercise, which will in turn affect institutional ownership.

One way around this information problem is to carry out adoption studies to support priority setting. The main assumption underlying the approach is that data on past adoption behaviour provides information about likely future adoption behaviour. Information on the factors that have determined the rate, speed and ceiling of adoption in the past will help to estimate adoption of new technologies in the future.

There are two phases to the approach. The first phase comprises ex post adoption analysis: an empirical model is estimated to explain the speed and ceiling of adoption as a function of measurable farmer, farming system and technology characteristics. The second phase comprises ex ante adoption analysis: the empirical results are used to predict the adoption of potential new technologies. The technologies that may be generated in a research program are characterised with regard to the factors that proved to be significant in the ex post analysis. The speed and ceiling of adoption of the potential new technologies are then predicted by applying their characteristics to the ex post model. The following sections describe the two phases of this approach.

4. Ex post study: analysing past adoption behaviour

4.1. Modelling technology adoption

For the purpose of this study, it is assumed that farmers make adoption decisions based upon utility considerations.[1] After comparing the new technology with the traditional technology, they adopt the former if its utility exceeds that of the latter. The probability that a farmer adopts a new technology is a function of its relative utility (4). The expected utility of a technology is determined by its characteristics as perceived by the farmers and the characteristics of the farmers themselves, the farming system and the farming environment (5):

$$P(A_{\mathrm{TN}}=1)=f\left(\frac{\mathrm{EU}_{\mathrm{TN}}}{\mathrm{EU}_{\mathrm{TO}}}\right) \tag{4}$$

$$\mathrm{EU}=f(Q_{\mathrm{T}}, Q_{\mathrm{H}}, Q_{\mathrm{F}}, Q_{\mathrm{X}}) \tag{5}$$

where P is the probability of adoption; A_{TN} (=1) the adoption of new technology; $\mathrm{EU}_{\mathrm{TN}}$ the expected utility of new technology; $\mathrm{EU}_{\mathrm{TO}}$ the expected utility of traditional technology; Q_{T} the technology characteristics; Q_{H} the farmers' characteristics; Q_{F} the farming system characteristics; and Q_{X} is the farming circumstances.

Consequently, the probability that a farmer adopts a new technology is a function of technology characteristics, farmers' characteristics, farming system characteristics, and farming circumstances (6). Assuming that the term $f(Q_{\mathrm{TN}})/f(Q_{\mathrm{TO}})$ in (6) equals $f(Q_{\mathrm{TN}}/Q_{\mathrm{TO}})$ in (7) and that the effects of the different variables are additive, the probability of adoption can be considered a function of relative technology characteristics, farmers' characteristics, farming system characteristics, and farming circumstances (7):

$$P(A_{\mathrm{TN}}=1)=f\left[\frac{f(Q_{\mathrm{TN}})}{f(Q_{\mathrm{TO}})}, Q_{\mathrm{H}}, Q_{\mathrm{F}}, Q_{\mathrm{X}}\right] \tag{6}$$

$$P(A_{\mathrm{TN}}=1)=f\left[\frac{Q_{\mathrm{TN}}}{Q_{\mathrm{TO}}}, Q_{\mathrm{H}}, Q_{\mathrm{F}}, Q_{\mathrm{X}}\right] \tag{7}$$

$$\mathrm{Speed}=f\left(\frac{Q_{\mathrm{TN}}}{Q_{\mathrm{TO}}}\right) \tag{8}$$

$$L=f\left(\frac{Q_{\mathrm{TN}}}{Q_{\mathrm{TO}}}\right) \tag{9}$$

where Q_{TN} is the characteristics of new technology; Q_{TO} the characteristics of traditional technology; 'Speed' the speed to complete adoption; and L is the ceiling of adoption.

Applying this model to a homogenous group of farmers, utility is a function of technology characteristics. Speed of adoption is a function of the relationship between the characteristics of the new and traditional technologies (8). The ceiling of adoption depends on the same variables (9).

4.2. The case study

A case study provided information on both dependent and independent variables. The case study was done in the Meru district of Kenya. Meru farms have an

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[1] See also Batz et al. (1999).

Table 1
New and traditional dairy technologies

New dairy technologies	Traditional dairy technologies
Cowshed Fence/corral[a] Calf pen Manure pit Milking place	Free grazing/herding including combinations with: Tethering of calf Compost making Traditional milking
Napier grass By-products Concentrates Minerals	Grazing with use of farm residuals and by-products
Dipping of cows Spraying of cows[a]	Picking and burning ticks (cows)
Deworming of cows	Using herbs and roots
Dipping of calves Spraying of calves[a]	Picking and burning ticks (calves)
Deworming of calves	Using herbs and roots
Bucket feeding of calves Concentrate feeding of calves	Suckling

[a] Not promoted by the NDDP.

average size of about 4 acres. The main cash crops are tea and coffee, while the main food crops are maize, yam and potato. Every farm household keeps at least one cow. The main animal feed is Napier grass, which is grown on an average of 0.4 acres per farm (Batz, 2000).

The case study was undertaken in collaboration with the Dairy Research Programme of KARI, aiming to improve future resource allocation. It focused on the technologies that the National Dairy Development Programme of Kenya has been promoting to smallholder dairy farmers since the early 1980s in the areas of housing, feeding, animal health, and calf rearing. Metz et al. (1995) finds that these technologies were adopted independently from each other even though together they might have a larger impact on farm productivity. In order to assess the relative characteristics of the innovations, traditional technologies were identified that were being replaced by new technologies. Table 1 presents the new technologies and their traditional alternatives.

4.3. Estimating the speed and ceiling of adoption of case technologies

The adoption parameters of the new technologies were measured by interviewing a total of 112 randomly-sampled farmers, who were asked about the technologies currently in use, and the year in which they had adopted them. Based on this information different adoption parameters were estimated.

Speed$_{94}$ indicates the average speed per year at which the technology was adopted by farmers until 1994, the year in which the survey was carried out. It was calculated by dividing the percentage of farmers who had adopted in 1994 (Ar$_{94}$) by the number of years between the year when the first farmer adopted and the survey year 1994:

$$\mathrm{Speed}_{94} = \frac{\mathrm{Ar}_{94}}{t_{(t,\dots,94)}} \tag{10}$$

$$\mathrm{Ar}_{94} = \frac{A_{94}}{A} \tag{11}$$

where Ar$_{94}$ is the percentage of farmers who have adopted in 1994; A_{94} the number of adopters in 1994; A the number of potential adopters; and $t_{(t,\dots,94)}$ is the time (years) from start of adoption to 1994.

To analyse the full process of adoption, the expected speed to ceiling of adoption (Speed) and the expected ceiling of adoption (L) were estimated.

There are various ways to calculate the speed to ceiling of adoption. One way is to use the rate at which adoption occurs according to a logistic growth function (12) (CIMMYT, 1993):

$$\mathrm{Ar}_t = \frac{L}{1 + \mathrm{e}^{-a-bt}} \tag{12}$$

where Ar$_t$ is the percentage of adopters in year t; L the ceiling of adoption; a the constant term; b the rate at which adoption occurs; and e is the base of the natural logarithm.

The limitation of this approach is that it depends on the ceiling of adoption. Since technologies rarely reach the same ceiling, the parameter b is not suited to serve as a dependent variable. Another way to calculate the speed of adoption is to adjust for the ceiling attained by transforming the parameter b in (12) to $b' = bL$ (Griliches, 1957). The limitation of both approaches is that the figures obtained are not illustrative and are difficult to use for descriptive purposes in a priority setting exercise. We therefore decided to use the linear slope of the diffusion curve as an indicator of the average speed of adoption.

For this purpose, the ceiling of adoption (L) was divided by the number of years before L is reached.

Table 2
Adoption parameters for case technologies

Technologies	Speed_{94} (percentage per annum)	L (%)	Speed (percentage per annum)
Fence/corral	1.8	100	2.1
Cowshed	1.5	100	2.5
Calf pen	1.1	100	1.8
Manure pit	0.7	11	0.6
Milking place	2.2	100	2.2
Dipping of cows	2.2	91.1	2.2
Spraying of cows	1.5	100	1.9
Deworming of cows	2.2	100	2.3
Dipping of calves	1.8	73.5	1.8
Spraying of calves	1.7	100	2.0
Deworming of calves	2.2	100	2.2
Napier grass and by-products	2.4	100	2.5
Napier grass, by-products and concentrates	1.4	100	1.6
Napier grass, by-products, concentrates and minerals	1.4	100	1.6
Bucket feeding of calves	0.6	100	1.1
Bucket feeding of calves with concentrates	0.3	21.8	0.5

Source: Own calculations.

Theoretically, it is not possible to calculate the years to ceiling of adoption since the logistic function only approaches L asymptotically. Instead, we calculated the time by which $L - 10\%$ had adopted the technologies using the formula below (13).[2] The speed to $L - 10\%$ adoption (Speed) was then calculated as the ratio of $L - 10\%$ to $t_{L-10\%}$, which is the slope of the linearised adoption curve and which represents the average speed to 90% of ceiling of adoption (14), indicating the percentage of farmers who adopt the technology per year:

$$t_{(L-10\%)} = \frac{-\ln[(10/(L - 10\%)) + a]}{b} \tag{13}$$

$$\text{Speed} = \frac{L - 10\%}{t_{(L-10\%)}} \tag{14}$$

where $L - 10\%$ is the ceiling of adoption minus 10%; and $t_{(L-10\%)}$ is the number of years to $L - 10\%$.

The coefficients of correlation between Speed and b (for technologies that are estimated to reach a ceiling of 100%) and between Speed and b' were 0.85 and 0.93, respectively. Consequently, we assume that the linearisation of the speed of adoption is a suitable simplification. The parameter 'Speed' is easy to understand, and it shows the speed of the adoption process in a more comprehensible way.

The results of the adoption calculations are presented in Table 2. Considering Speed_{94}, the results reveal that the technologies disseminated very slowly. All rates of adoption were below 3% per year. However, there were considerable differences between the technologies. Whereas Napier grass and by-products, dipping of cows and deworming technologies showed a relatively high speed of adoption, manure pits, and all of the calf-rearing technologies diffused extremely slowly.

Estimates of L show that most technologies will reach a ceiling of adoption of 100%. According to the estimated logistic curves, only manure pits and bucket feeding of calves with concentrates can be expected to remain poorly adopted.

Estimates of Speed ranged from 2.5 to 0.5% per year. Technologies with the highest Speed were cowshed, Napier grass and by-products, and deworming technologies. Manure pits and bucket feeding including concentrates had the lowest Speed.

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[2] In order to generate starting values to run the non-linear regression procedure, the logistic function in (12) was transformed to $\ln[Y_t/(L - Y_t)] = a + bt$ following the method proposed by Griliches (1957) and CIMMYT (1993). Using the non-linear regression procedure of the SAS software package, values for a, b and L were estimated.

4.4. Measuring technology characteristics and adoption parameters

Utility of technologies was assumed to be determined by four major types of technology characteristics: profitability, initial costs, risk and complexity. The selection of these characteristics was based on a detailed analysis of literature on technology adoption (Batz, 2000). The first three variables reflect standard project investment parameters (profitability, investments, risk). The final variable (complexity) defines the likelihood that farmers are able to apply the technology correctly. The variables are not case specific and the model can be applied in other studies. An empirical study on technology adoption in the Meru district was carried out to test a series of research hypothesis to support the selection of these variables (Batz, 2000).

Profitability of technologies is expected to be an overriding factor in farmers' decision-making (Byerlee and Hesse de Polanco, 1982). Farmers will adopt technologies that give high returns to investment (Adesina and Zinnah, 1993; Shrestha and Gopalakrishnan, 1993). High profitability will accelerate speed of adoption and lead to a high ceiling of adoption. The profitability of the technologies was defined by taking into account that they may affect not only the dairy enterprise but also other farm enterprises.

Costs determine adoption decisions especially in the case of the resource poor smallholders (Adesina and Zinnah, 1993; Shrestha and Gopalakrishnan, 1993; Runge-Metzger, 1991). Initial costs can become a limiting factor for adoption as farmers cannot adopt a highly profitable technology if they cannot acquire it due to scarcity of capital. The low rate of adoption of capital intensive technologies such as cowshed and manure pits by the Meru farmers supports this hypothesis (Batz, 2000). This means when capital is scarce, the relationship between initial costs and profitability may explain adoption behaviour better than the single variables would. An index, called relative investment, was calculated as the ratio of initial costs to profitability. A high relative investment index means that initial costs are high compared to additional profit. Technologies with high relative investment indices will be adopted less rapidly than technologies with a low relative investment indices.

Risk characteristics of technologies also influence adoption. In a risky environment, farmers can be assumed to adopt risk-reducing technologies. In the Meru district, crossbred cows face a high risk of infection by tick born diseases such as Anaplasmosis and East Coast fever, and worms (Batz, 2000). The adoption study clearly showed that risk-reducing technologies such as dipping, spraying and deworming are adopted at a high rate in Meru (Batz, 2000). Some of the technologies analysed can be assumed to have a risk-reducing effect in this environment whereas other technologies may not effect risk or may even increase the risk. It was hypothesised that technologies with a high risk-reducing effect will be adopted faster and to a greater extent than technologies with a low impact on risk reduction.

Following concepts in systems theory, complexity was defined as a function of the number and difficulty of activities that have to be performed to adopt and use a technology (Willke, 1991). Complexity is high when a farmer has to carry out many activities to establish and to run a technology. Complexity is higher, the more difficult these activities are and the more difficult it is to make the decisions that lead to the activity. Meru farmers with poor education (Batz, 2000) would only slowly adopt such technologies. The relative complexity of an innovation is higher the higher its complexity in relation to its traditional counterpart. Technologies with high relative complexity diffuse more slowly than others and will finally be adopted by a smaller number of farmers.

Technology characteristics were measured using a scoring approach involving extension workers. A scoring approach was necessary because making quantitative assessments of the profitability and risk characteristics of each technology would have involved considerable costs of data collection and modelling. Most extension workers are farmers themselves, and are able to assess the relative advantages and disadvantages of technologies from a farmer's point of view.

With respect to profitability and initial cost assessment, the extension workers were asked to give scores from 1 to 9 for each technology considered. Low scores corresponded to low profitability or costs. The risk associated with the use of a technology was assessed using *plus* and *minus* scores. Extension workers assigned a minus (−) if a technology reduced the risk of losing a cow and a plus (+) if it

Table 3
Results of extension workers' estimates of technology characteristics

Technologies analysed	Relative investment	Relative risk	Relative complexity
Fence/corral	3.16	0.50	3.46
Cowshed	4.21	0.56	3.69
Calf pen	3.92	0.79	3.37
Manure pit	2.74	1.00	4.83
Milking place	3.55	0.60	5.00
Dipping of cows	1.67	0.33	0.53
Spraying of cows	3.74	0.50	1.37
Deworming of cows	2.25	0.50	2.50
Dipping of calves	1.02	0.85	0.79
Spraying of calves	1.76	0.85	1.17
Deworming of calves	1.04	0.92	2.50
Napier grass and by-products	2.56	0.47	1.44
Napier grass, by-products and concentrates	3.44	0.47	2.11
Napier grass, by-products, concentrates and minerals	3.33	0.40	2.75
Bucket feeding of calves	2.60	0.92	4.67
Bucket feeding of calves with concentrates	2.40	0.92	8.67

Source: Values obtained from workshop participants. Relative investment: the higher the value, the greater the investment in relation to profitability. Relative risk: (>1) when the new technology is riskier than the old technology, (=1) when the new technology is risk-neutral, (<1) when the new technology is less risky than the old technology. Relative complexity: the higher the value, the greater the relative complexity.

increased the risk. If a technology was expected to strongly increase or decrease the risk, the extension workers could assign one additional plus and minus, respectively. These scores were converted into values from 1 to 5 such that low values indicated a high risk-reducing effect. Finally, complexity was measured by counting the activities that a farmer had to undertake to acquire and use a technology. These activities were listed; a score between 1 and 3 was assigned for the relative difficulty of each activity and for the difficulty of the decision-making leading to these activities. The scores for the different activities were summed into the final assessment.[3]

Table 3 shows the results of the assessment of the new technologies' characteristics. The first column shows the values for relative investment. Technologies with a comparatively high relative investment included housing technologies and Napier grass with by-products, minerals and concentrates. Relative investment was lowest for animal health technologies such as spraying, dipping and deworming. The second column shows the values for the relative risk effect of the new technologies. The risk-reducing effect was greatest for dipping of cows and the three feeding regimes based on Napier grass. Deworming and spraying of cows were also assumed to have a high impact on risk, followed by housing technologies such as fencing, cowshed and milking place. Manure pits were found not to have any effect on the risk of losing a cow. The last column shows the results of the complexity assessment. Compared with traditional technologies, bucket feeding of calves with concentrates increases management complexity most. Most of the technologies increase the complexity of farm management. Only the dipping technologies were assumed to be less complex than their traditional alternatives. Very high increases in complexity relative to the traditional alternatives are caused by the use of bucket feeding of calves, concentrates, milking place, and manure pits.

4.5. Statistical analysis

The influence of technology characteristics on the adoption parameters was analysed using linear regression analysis. The ceiling of adoption (L) was not analysed because its values did not show significant variance (see Table 2). The regression models were specified using combinations of relative complexity,

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[3] For more details on the characterisation of technologies see Batz (2000).

Table 4
Influence of technology characteristics on speed of adoption

Model	Constant	Relative investment	Relative risk	Relative complexity	Adjusted R^2
Speed$_{94}$					
I	2.22*** (10.51)			−0.21*** (−3.70)	0.45
II	3.90*** (6.62)	−0.35** (−2.79)	−2.09*** (−3.80)		0.50
III	3.49*** (5.80)	−0.23 (−1.69)	−1.44** (−2.21)	−0.11 (−1.68)	0.56
Speed					
IV	2.41*** (11.18)			−0.19*** (−3.33)	0.40
V	2.90*** (8.13)		−0.97 (−1.68)	−0.15** (−2.41)	0.47
VI	2.83 (4.26)	0.02 (0.12)	−0.92 (−1.28)	−0.154* (−2.05)	0.43

Source: Own calculations. The figures in parentheses denote the *t*-values.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

relative risk and relative investment as explanatory variables for the adoption parameters. The basic model is presented below (15):

$$\begin{aligned}\text{Speed} = {} & \beta_0 + \beta_1(\text{relative investment}) \\ & + \beta_2(\text{relative risk}) \\ & + \beta_3(\text{relative complexity}) + \epsilon \qquad (15)\end{aligned}$$

where ϵ is the random disturbance term.

The estimation results are presented in Table 4. All of the models for Speed$_{94}$ yield significant results. Considering relative complexity as the sole explanatory variable, the model explains about 45% of the variance in Speed$_{94}$. Consideration of relative risk and relative investment yields significant coefficients, with an adjusted R^2 of 0.49. The model that includes all three technology characteristics yields a significant coefficient for relative risk. Relative complexity and relative investment are not significant, but the coefficients show the expected signs.

Finally, the estimation results for Speed show that the relative complexity of the technologies is the only significant variable. The model that uses relative complexity as the sole explanatory variable yields an adjusted R^2 of 0.40. The model that includes both relative complexity and relative risk gives an adjusted R^2 value of 0.47. However, although both coefficients show the expected signs, only relative complexity is significant at the 5% level. In the model that considers all three variables, only the coefficient for relative complexity is significant.

5. Ex ante study: predicting adoption of new technologies

In 1995/1996 KARI's dairy programme research was developing its new plan for the coming 5–10 years. For this purpose workshops were held in which new technologies to be developed by research were proposed and priorities were set. The results on adoption obtained in Section 4 of this paper were used to strengthen this priority setting process in KARI.

5.1. Identification of potential new technologies to be developed by research

The identification of the new potential technologies was done by applying participatory tools, visualisation techniques and moderation in a workshop. Participants were researchers, extension workers and dairy farmers.[4] First, the subsector was reviewed to identify dairy research objectives. Second, a constraint-tree analysis was done, as described by Schubert et al. (1991) and Collion and Kissi (1995). In a third step, existing results from the research thrusts for animal health, animal breeding and animal feeding were analysed. The evaluation took into account not only the experience of KARI, but also that of the International Agricultural Research Centres (IARCs) and of

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[4] The workshop was run by Hitzel and Waithaka (1996). For a detailed description of this exercise see Hitzel and Mukisiera (1998).

Table 5
Expected characteristics of new technologies based on expert assessments

Technologies	R&D gap	Relative investment	Relative risk	Relative complexity
Calf diets based on commercial feed	5.0	4.0	1.0	3.5
Calf diets based on local feed	4.0	2.0	1.0	3.0
Appropriate diets for heifers and cows using locally available feed	5.0	0.3	1.0	3.0
Appropriate forage/food intercropping system	5.0	0.5	1.0	3.0
Forages for frost-prone areas	7.0	1.7	1.0	4.3
Feed processing and forage legume utilisation	4.0	3.0	1.0	5.4
Feed conservation techniques	4.0	7.0	0.5	0.7
Calf house and helminth control	4.0	2.0	1.0	3.6
Improved fertility-management package	4.0	1.5	1.3	3.1
Tested East Coast fever on farm immunisation	4.0	2.3	0.3	4.8
Practical mastitis-control method	4.0	0.6	1.0	3.3
Ethnovet package	7.0	0.4	1.0	1.0
Animal health delivery system	9.0	1.3	0.7	5.3
Improved breeds for zero/semi-zero grazing	10.0	1.3	1.5	2.3

Source: Values obtained from workshop participants. Relative investment: the higher the value, the greater the investment in relation to profitability. Relative risk: (>1) when the new technology is riskier than the old technology, (=1) when the new technology is risk-neutral, (<1) when the new technology is less risky than the old technology. Relative complexity: the higher the value, the greater the relative complexity.

the private sector.[5] In step four, the results of the first three steps were used to develop possible research projects. These are listed in Table 5.

5.2. Characterisation of potential new technologies

The characterisation of the new potential technologies was done in a workshop by experts from the Kenyan research and extension system. Proposed new technologies were assessed with respect to the characteristics that had been identified in the ex post analysis as having influenced the rate and speed of adoption of earlier innovations, as well as with respect to the required research and development time. The results of these assessments are also presented in Table 5.

The assessments led to research and development gaps (R&D gaps) of 4–10 years. The technologies with the smallest R&D gaps were the feeding technologies, including feed conservation and processing and calf diets based on local feed. Most of the animal health technologies were expected to have R&D gaps of 4 years. Some technologies were expected to require between seven and 10 years before dissemination can begin.

The scores for relative investment range from 0.3 to 7, and those for relative risk from 0.33 (indicating a high risk-reducing effect) to 1.5 (indicating an increase in risk). The scores for relative complexity range from 0.70 to 5.40. The variability in the scores suggests that adoption patterns will be quite variable.

5.3. Predicting the adoption of new technologies

The adoption of the new technologies was estimated using a linearised adoption model that considered the speed of adoption and the expected R&D gaps. Speed of adoption was estimated using models II, III and V in Table 4. Model II defines Speed_{94} as a function of relative investment of the technologies and their relative risks. Model III defines Speed_{94} using all three technology characteristics as explanatory variables. Model V defines Speed to 90% of ceiling of adoption as a function of relative risk and relative complexity.

The results of the calculations were used to calculate rates of adoption for subsequent use in the priority setting exercise. For this purpose, the adoption rates that the technologies were expected to have reached after 15 years were calculated using Eq. (16). This particular period was used for demonstration purposes, but can, of course, be changed to suit any chosen planning

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[5] For further details see Mwendia (1996).

Table 6
Rates of adoption after 15 years, calculated using models II, III and V (in %)

Technologies	Using model II	Using model III	Using model V
Calf diets based on commercial feed	4.1	7.3	14.1
Calf diets based on local feed	12.2	13.8	16.3
Appropriate diets for heifers and cows using locally available feed	17.0	16.4	14.8
Appropriate forage/food intercropping system	16.3	16.0	14.8
Forages for frost-prone areas	9.7	9.4	10.3
Feed processing and forage legume utilisation	8.3	8.2	12.4
Feed conservation techniques	4.5	11.9	25.4
Calf house and helminth control	12.2	13.0	15.3
Improved fertility management package	7.2	10.2	13.0
Tested East Coast fever on farm immunisation	27.2	21.8	20.8
Practical mastitis control method	17.5	16.9	15.8
Ethnovet package	13.3	14.8	14.3
Animal health delivery system	11.9	9.5	8.6
Improved breeds for zero/semi zero grazing	1.5	3.9	5.5

Spearman's rank correlations (r_{SP}): 0.927 (models II and III); 0.742 (models III and V); 0.538 (models II and V).

horizon. Using this approach, an adoption figure was estimated for each technology that predicts how many farmers can be expected to adopt a technology in each year and how many are expected to have adopted it after a period of 15 years (Eq. (16)):

$$\mathrm{Ar}_{1,\dots,15} = (15 - \mathrm{RD})\mathrm{Speed}_{\mathrm{est}} \quad (16)$$

where $\mathrm{Ar}_{1,\dots,15}$ is the percentage of farmers who have adopted 15 years after the start of research; $\mathrm{Speed}_{\mathrm{est}}$ the estimated speed of adoption; and RD is the research and development gap.

The results of the assessments are presented in Table 6. The calculations based on models II and III in columns two and three, respectively, are highly correlated as shown by the Spearman's rank correlation coefficient. Both of these calculations result in the same seven technologies being most likely to achieve the highest rates of adoption. Similarly, both of these calculations identify the same set of technologies as being most likely to achieve the lowest rates of adoption.

The results obtained by applying model V are comparable with those from the first two models, but they make very different predictions with respect to improved feed conservation technology. This technology requires high relative investment, a factor that inhibits adoption but is not considered in the model. The Spearman's rank correlation coefficient increases considerably when this technology is not considered.

The predicted adoption rates were used in a priority setting exercise in KARI. An interdisciplinary team of experts from research, extension and international organisations assessed the new technologies with respect to the data required for estimating the costs and benefits of research. The adoption figures were integrated, benefits and costs of each technology estimated and benefit–costs ratios calculated.[6]

Our modelling results were discussed with the entire group. Any deviations from experts' common sense expectation were discussed in detail. Discussions about adoption rates could be focused on the findings of the ex post field study, the model used, assessments of technology characteristics and the resulting ex ante estimates of adoption. The outcomes of the priority setting exercises first surprised and then convinced most participants: research on feed production and utilisation had higher average expected benefits than traditional areas such as breeding and animal health research (especially as the adoption of breeding innovations is very slow).

The priority setting exercise benefited much from the approach chosen. The empirical evidence on technology adoption received in the field added to the credibility of the assessments. The participatory nature of our approach increased the quality of the

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[6] The results can be obtained from ISNAR and KARI (1996). Gierend (1999) provides a detailed description of the modelling approach.

data as farmers' and extension workers' perceptions were considered. The theoretically sound approach was well understood and accepted. The transparent application of the approach had a positive impact on the ownership of the entire priority setting exercise and on the acceptance of the results.

6. Conclusions for research priority setting

This paper uses an adoption study to improve the information available for research priority setting. The approach developed in this study is theoretically sound and provides the information required to predict research performance. This improves the quality of priority setting, and helps to avoid the objections that may arise if priority setting leads to a change in the allocation of research funds. The approach allows us to distinguish promising technologies from less promising technologies, and to make corresponding choices. The approach is easy to understand for non-economists and is transparent to decision makers. This improves the acceptance of the outcome. Finally, the approach is participatory in nature since all the main interest groups within the research system are involved. This improves institutional ownership. Further development of the approach may benefit from the following observations.

6.1. Development of the adoption model

The adoption model in this study is based on both economic and non-economic variables. The economic variables are in line with mainstream economic theory. The non-economic variables are selected on the basis of plausibility and could benefit from more attention. They should be investigated in advance of the field survey to identify non-economic technology characteristics that are likely to be relevant to farmers' decision-making.

6.2. Identification of case technologies

The research approach is based on analysing the adoption of case technologies in the target area. For this purpose, case technologies must be identified. The number of technologies should be large enough to allow statistical analysis. If the number of technologies is small, regression analysis of the rate, speed and ceiling of adoption may not be possible. The technologies should be used by the farmers who are targeted by the research program, since farmers' objectives may differ from one system to the next. Characteristics identified as influencing farmers' decision-making are not necessarily transferable.

6.3. Estimation of the speed and ceiling of adoption

Estimation of the ceiling of adoption based on past adoption can be risky. If changes occur in relative factor prices, farmers' choices of technology may vary. Other new technologies may be introduced that have a higher expected utility than the ones being assessed. This also affects the expected speed of adoption.

6.4. Assessment of technology characteristics

The quality of the technology assessments relies on the informed judgement of the resource persons. This is certainly a weakness of the approach. However, the application of objective methods based on a quantitative framework such as farm modelling would increase the time involved in the assessment of adoption and, hence, the costs. Further improvements to the measurement of technology characteristics should be based on a careful trade-off between costs and the quality of the data. Finally, the experts who carry out the ex ante assessment of new technologies (during the priority setting) must have similar qualifications and perspectives as the experts responsible for the ex post assessment of traditional technologies (in the adoption study). The scoring of new and conventional technologies must be done on the same scale.

6.5. Definition of potential new technologies

To apply this approach, new technologies must be clearly specified. The clear specification of potential new technologies requires a solid analysis of constraints. If this is poorly done, the value of the outcome of the subsequent steps is compromised, because poor constraint analysis leads to the definition of irrelevant technologies. Even the best modelling cannot compensate for such a weakness. The participation of farmers is desirable to ensure that research concentrates on their particular innovation needs;

researchers and extension workers participate by designing the innovations that need to be developed; and partner-organisations should participate in order to avoid overlapping and duplication of research.

6.6. The influence of technology characteristics on adoption parameters

Our results indicate that technology characteristics such as relative investment, relative complexity and relative risk have determined technology adoption and diffusion in the past. Nevertheless, the models explain only 40–56% of the variability in adoption and diffusion, indicating that other characteristics may also influence farmers' decision-making. A possible way to identify relevant characteristics would be to combine the quantitative approach with a qualitative approach. Using Participatory Rural Appraisal methods, key informants could be asked what is relevant to farmers, farming systems and farming circumstances. Such key informants could be farmers, extension agents, or researchers who are familiar with the area, the farmers and the technologies.

6.7. Institutional ownership and costs

Decision makers in research institutions will accept the priority setting outcomes only if they understand how they have been generated. Experience shows that a lot of effort is required to convince participants, particularly if they are not economists. A procedure to ensure institutional ownership would be to compare the empirical results of adoption studies with expert judgements.

Finally, the quantitative approach proposed in this study generates extensive costs for the preparation, design and execution of adoption surveys. In order to save time and resources, extensive quantitative field work could be replaced by qualitative approaches using selected key informants instead of sampling farmers. Further research should focus on methods to reduce the costs of sound priority setting.

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