Innovation Adoption in Agriculture : Innovators, Early Adopters and Laggards

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Diffusion de l'innovation en agriculture : précurseurs, suiveurs et retardataires

Mots-clés :
diffusion d'une innovation, modèle logit, agriculture, Pays-Bas

Résumé – Cet article analyse les choix possibles pour un exploitant agricole face à l'adoption des innovations disponibles sur le marché, il peut être : précurseur, suiveur oui retardataire. Dans cette perspective, un modèle logit emboîté est estimé en utilisant un échantillon important d'agriculteurs néerlandais. Les résultats empiriques montrent que les caractéristiques structurelles (taille de l'exploitation, âge et solvabilité de l'exploitant) expliquent les différences de comportement d'adoption entre, d'une part, les précurseurs et les suiveurs, et, d'autre part, les retardataires. Cette étude montre également que les précurseurs et suiveurs ont des réactions similaires au regard des variables structurelles. Ils se différencient cependant pour ce qui est des variables de comportement : les précurseurs utilisent davantage les sources externes d'information et ils sont bien plus impliqués dans le développement actuel des innovations.

Innovation adoption in agriculture : innovators, early adopters and laggards

Key-words :
innovation, adoption, nested logit model, agriculture, The Netherlands

Summary *– This paper analyses the choice of a farmer to be an innovator, an early adopter or a laggard (an adopter of mature technologies or a non-adopter) in the adoption of innovations that are available on the market. We estimate a nested logit model with data from a large sample of Dutch farmers. We find that structural characteristics (farm size, market position, solvency, age of the farmer) explain the difference in adoption behaviour between innovators and early adopters on the one hand and laggards on the other. We also find that early adopters and innovators do not differ from each other regarding these structural characteristics. However, they appear to differ in behavioural characteristics : innovators make more use of external sources of information and they are more involved in the actual development of innovations.*

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AGRICULTURE progresses technologically as farmers adopt innovations. The extent to which farmers adopt available innovations and the speed by which they do so determines the impact of innovations in terms of productivity growth. It is a common phenomenon that farmers, like any other kind of entrepreneurs, do not adopt innovations simultaneously as they appear on the market. Diffusion typically takes a number of years, seldom reaches a level of 100% of the potential adopters population, and mostly follows some sort of S-shaped curve in time. Apparently, some farmers choose to be innovators (first users) while others prefer to be early adopters, late adopters, or non-adopters.

Most studies of innovation adoption analyse the pattern of diffusion of one specific technology[1]. In this article we take a different route. Contrary to most studies on this subject we do not study one specific innovation, but rather look at a large range of innovations. We analyse the behaviour of a farmer who is confronted with all these different innovations and chooses to adopt or not. Some of these innovations are relatively new: they are in an early stage of their diffusion process. Other innovations are further down their diffusion curve. By adopting an innovation that has a specific degree of novelty, a farmer chooses to be an innovator, an early or a late adopter. In this paper we analyse the characteristics that influence this farmer's choice.

The advantage of our approach is that the results are more robust because they are not linked to a specific innovation. The disadvantage is that we put together completely different innovations, comparing for example small low cost innovations with large capital intensive ones. Such characteristics of innovations can interfere with the characteristics of the farmer when he chooses to adopt or not. For example credit constraints (a farmer characteristic) may only hamper the adoption of capital-intensive innovations. Further classification of innovations may overcome this problem, but has not been pursued due to data limitations.

In this paper we analyse the farmer's choice of being an innovator, an early adopter, a late adopter or a non-adopter. First of all, we differentiate between frontrunners (farmers that adopt as first or early users) and laggards (farmers that adopt late or not at all). We find that structural characteristics explain the difference between these two groups. Secondly, we differentiate within the group of frontrunners between innovators and early adopters. Here we find that the two sub-categories do not differ in their structural characteristics. However, behavioural characteristics partly explain the difference between innovators and early adopt-

[1] Studies range from hybrid corn (Griliches, 1957) to the adoption of genetically modified products in Hategekimana and Trant (2002) and Huang *et al.* (forthcoming).

ers. Due to the data limitations, we could not test whether behavioural characteristics contribute to the difference between frontrunners and laggards.

The article is structured as follows. First we review the literature on innovation adoption. Then we describe the data set that is used in the empirical analysis. Thereafter, we present our hypotheses and discuss the research model and results. The last section concludes.

INNOVATION ADOPTION: A GLANCE AT THE LITERATURE

Not all the potential users adopt at once new technologies that have superior characteristics compared to their predecessors. Two main approaches have been developed to explain this puzzling phenomenon (for overviews see *e.g.* Stoneman, 1983; Thirtle and Ruttan, 1987; Karshenas and Stoneman, 1995; Geroski, 2000; Sunding and Zilberman, 2001). The first approach regards the process of diffusion as a disequilibrium process. The appearance of an innovation on the market creates opportunities for improvements in efficiency, but these are not realised immediately because markets for new technologies are characterised by a lack of transparency and by imperfect information. This is not so much a lack of information on the existence of the innovation, but rather uncertainty about the operating conditions, risks and performance characteristics of the new technology. The number of adopters of the innovation increases as information is generated in the process of innovation implementation and spreads gradually among the potential adopters. The main model that describes innovation adoption as determined by such a process of information spread is the epidemic diffusion model (see *e.g.* Griliches, 1957; Mansfield, 1961 and 1968; Mahajan and Peterson, 1985).

The second approach is of a decision-theoretic nature and regards the diffusion process as an equilibrium process. From this perspective, gradual innovation diffusion is not due to market imperfection, but to variation of the adoption benefits over the potential adopters. The adoption benefits may vary over adopters for two reasons. On the one hand, adopters may differ among each other. Technically, the innovation may have superior characteristics compared to a previous technology, but whether these translate into economic benefits depends upon the adopter's structural characteristics. Potential adopters vary in such characteristics as firm size, market share, market structure, R&D expenditures, input prices, labour relations, firm ownership and current technology. Firm size and market share are the two variables that appear most often in the diffusion models and the usual hypotheses are that large (but not too large) firms and firms with substantial (but not too much) market power are most innovative (see *e.g.* Kamien and Schwartz, 1982;

Stoneman, 2002). These hypotheses have produced mixed results in empirical work (Cohen and Levin, 1989; Scherer and Ross, 1990, Cohen and Klepper, 1996; Brouwer and Kleinknecht, 1997). On the other hand, the benefits of adoption may vary over adopters because these benefits themselves depend upon the diffusion process. As potential adopters consecutively adopt the innovation, gross benefits of adoption change [2]. The variation of benefits over potential adopters explains why at any moment in time some of them actually adopt whilst others refrain from doing so. Diffusion of the innovation over time results when either characteristics of adopters or benefits of adoption change over time. The probit model (pioneered by Davies, 1979) is the main empirical model that relates innovation diffusion to variation in characteristics and in benefits.

The epidemic diffusion model has been used extensively in empirical research, mainly because of its convenient analytical properties. However, its drawbacks are well known (Karshenas and Stoneman, 1995; Geroski, 2000). The theoretical base of the model, the premise that innovation diffusion is in essence driven by information diffusion, is very narrow [3]. Equilibrium models of diffusion can accommodate a large number of variables, that may account for variation in adoption benefits over the potential users of an innovation but, as they assume the market for new technologies to be transparent, they usually do not take account of the effects of the generation and the spread of information, that is a product of the diffusion process itself [4]. Karshenas and Stoneman (1993) attempted to build an empirical model on a broader base, allowing for innovation diffusion to be driven both by variation in firm characteristics and by information diffusion.

In this paper we mainly draw upon the decision-theoretic literature on innovation adoption, taking into account variables that reflect structural farm characteristics. Structural characteristics are fixed in the short term. However, we also allow for the effects of spread of information that drive epidemic models. In particular, assuming imperfect informa-

[2] Karshenas and Stoneman (1993, 1995) distinguish two reasons for this phenomenon: i) as there are more users of an innovation, benefits for each may decline, for example because supply on the final goods markets increases (the stock effect); ii) every next adopter receives smaller benefits from adoption, for example through pre-emption effects (the order effect). The assumptions of stock and order effects have hardly been tested in empirical diffusion research.

[3] Apart from that, the epidemic model has several other limitations: it assumes for example a constant and homogeneous population of adopters, an unchanging innovation, a constant profitability of adoption, no active information search (see *e.g.* Karshenas and Stoneman, 1995, pp. 272-273).

[4] The two approaches have also different data requirements. For the epidemic model, the data correspond to aggregate diffusion level, while the adoption model requires richer and more disaggregated data at the firm level.

tion, we take account of behavioural variables that reflect the various efforts of a farmer to deal with information. Behavioural variables capture some aspects of management. In our case they express information gathering through learning and co-operation, information exploitation through follow-up activities, as well as information protection through secrecy or patenting. We explore whether these behavioural variables differentiate farmers who are innovators from farmers who are early adopters of innovations [5].

DATA

The issues we analyse are limited by the characteristics of the available data. For this reason, we first describe our data and then present our research questions and hypotheses.

We collected survey and interview data among 1075 farms participating in the Dutch Farm Accountancy Data Network (FADN), maintained at the Agricultural Economics Research Institute (Landbouw Economisch Instituut, LEI). The FADN-panel is a stratified sample of about 1500 farms in the Dutch agricultural and horticultural industry. The FADN-database contains detailed financial information, for example on labour costs, capital costs, depreciation and sales. The survey among panel members covered the period 1995-1997. Farmers in the FADN received a short questionnaire in which they were asked to answer two key questions: i) whether they had adopted and implemented an important innovation in this period, and ii) whether they could indicate for this innovation their position on the diffusion curve. Because farmers sometimes show a tendency to overstate their position on the diffusion curve, experts from the LEI checked the answers [6].

More than 80% of the reported innovations were process innovations. Most of them aim at cost reduction, or improvement of process control, environmental performance, labour conditions, or animal welfare. In horticulture innovation often means mechanisation. Examples of innovations reported to us are as follows [7]:

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[5] In another paper (Diederen *et al.*, 2003), we test an ordered probit model, using only structural characteristics as independent variables, on data drawn from the Dutch Farm Accountancy Data Network only.

[6] These LEI-experts are in close contact with many farmers and are able to judge whether a reported innovation is relatively new or already mature. Where necessary, these experts corrected the answers of the farmers regarding position on the diffusion curve.

[7] The set of innovations reported to us was diverse. Further classification of innovations into different categories, *e.g.* according to capital intensity, labour requirements, skills needed or knowledge intensity, has not been pursued due to data limitations.

– Automated systems for harvest registration per greenhouse lane recording volume and time of harvest.
– Logistic systems in greenhouses for potted plants that automatically measure plant growth and sort, transport and pack plants accordingly.
– The use of ultrasound as a means to exterminate insects in greenhouses.

Innovations reported from arable agriculture and livestock farming often concern technologies for the improvement of environmental quality. Examples are as follows:

– An integrated system of pig farming and tilapia farming (a species of fish), where manure was recycled on the farm and the algae that were grown in the process were used as an input for the pharmaceutical industry.
– A system for drying chicken manure to produce a manure of a quality comparable to artificial fertiliser.

On the basis of the survey answers, the farmers were classified into four groups:

– *Innovators* are the first farmers in their market to use a certain innovation [8].
– *Early adopters* are those farmers who indicate to belong to the first quarter of adopters of a certain innovation, relative to the full range of potential adopters.
– *Late adopters* are those farmers who adopted an innovation, but did not belong to the first quarter of potential users.
– *Non-adopters* are farmers who did not introduce any kind of new technology.

Of our FADN-sample, we classify farmers as indicated in Table 1. Innovators and early adopters make up a small part of the sample. Almost two-thirds of the farmers did not introduce any new technology on a substantial scale over the three-year period in question. In the FADN-sample there were 136 innovators and early adopters for whom the data are complete. From those respondents we obtained specific information on the adoption of innovations and thus for them there are data on both structural and behavioural characteristics. Experts using a standard questionnaire interviewed these frontrunners face-to-face. Laggards (late adopters and non-adopters) were not interviewed, and data are limited to structural characteristics.

Because the set of frontrunners was small (especially the number of innovators) we collected additional data on farmers and growers that were *a priori* identified as being in the technological lead. We received

[8] An innovator is commonly defined as the person who first applies an invention commercially. We use the term to designate the one who first applies an invention commercially in production for a specific market.

their addresses from the lists of firms applying for innovation subsidies at the Ministry of Agriculture, references from experts and other farmers, and from professional journals on agriculture. In this way we identified an additional 155 frontrunners. These farmers were visited by interviewers and asked the same questions as the frontrunners from the FADN. Thus, the total number of frontrunners in our sample is 291.

Table 1. **Classification of farmers in FADN and the additional innovation survey**

Class		FADN	FADN	Additional Survey
		Share (%)	# obs.	# obs.
Frontrunners	Innovators	3	29	116
	Early adopters	10	107	39
Laggards	Late adopters	24	259	
	Non-adopters	63	680	
Total		100	1 075	155

Due to the procedure of collecting data, the amount of information that is available per farm differs. Frontrunners were asked survey questions that were not posed to laggards. We have data from all respondents on structural variables, but we collected observations on behavioural variables only from frontrunners. Thus, we have a full data set on the dependent variable and on the following independent variables (see Table 2):

– *Farm size* (continuous variable), measured in nge's (divided by 100)[9]. The distribution of this variable is lopsided with a standard deviation of 1.15 times the average value.

– *Market position* (continuous variable) is an indicator variable that tries to capture the ability of a farm to benefit from product differentiation. As an indicator we use the share of a farm's output in the total Dutch production of the particular sector the farm belongs to, both measured in nge's. We use a subdivision of Dutch agricultural production into 40 sectors. The mean indicator is 0.075% and the distribution has a long tail to the right. Though actual market shares in any agricultural sector are small and market share may not be a meaningful variable in itself, differences in market share may well correlate with differences in the character of competition in markets.

[9] The nge (Nederlandse Grootte Eenheid) is a standardised measure of farm size that is calculated as follows: for each product a standard gross value added (SVGA) per unit (an animal or a hectare) is calculated. The number of nge's of a farm equals SVGA times the number of units of that farm, divided by a deflator (1310 in 1994) to correct for inflation. This method allows aggregation over different products, which is useful to determine the size of a diversified firm and to compare across sectors. For example, a farm that has two hectares of tomatoes (SVGA for one hectare of tomatoes totals 202,000 euros, that is 154,2 nge (= 202,000 / 1310)) has 308.4 nge's (which equals 2 times 154,2 nge for one hectare).

– *Solvency* (categorical variable), the ratio of equity capital (net worth) over total capital, is included to capture the differences in accessibility to risk bearing financial resources. The average FADN farm has a solvency of about 64%. Because of data limitations on the non-FADN farms we have to use a categorical indicator of solvency taking a value of 1 to 7, where 1 indicates a low solvency (< 5%) and 7 a high one (> 99%).

– *Age of the farmer* (continuous variable) is included to capture the time horizon of the farmer.

– *Sectoral dummies* (seven dummy variables), representing the sector of activity, indicate whether a farm is active in arable farming, dairy farming, intensive livestock farming, fruit farming, greenhouse vegetables, greenhouse flowers, mushrooms, or other horticulture. Fruit farming is used as a reference category.

These independent variables are indicators of structural characteristics of farms and traditional variables that frequently appear in probit analyses of innovation diffusion. In addition, we have observations on the following behavioural variables for the farms that are classified as innovators or early adopters:

– *Attitude regarding innovation* (dummy variable): innovation is reported as a permanent activity (1) or an occasional activity (0).

– *Valuation of internal sources of information* (categorical variable): in the questionnaire we asked about the importance of the farm itself (the employees, the family members) as a source of information relevant for innovation. This variable can take values ranging from 1 (unimportant) to 4 (very important).

– *Valuation of external sources of information* (continuous variable): farmers were asked to evaluate different sources of information on a scale from 1 (unimportant) to 4 (very important). Among the possible sources were: suppliers, customers, colleagues, professional organisations, fairs, periodicals, public extension services and private consultants. The value of this indicator is the average valuation over all external sources mentioned in the questionnaire.

– *Innovation expenditure ratio* (continuous variable): expenditures[10] on innovative activities per nge. Farmers were asked to indicate how much they spend on innovative activities annually. Innovative activities are all those activities that are not related to a specific innovation, but are linked to innovation processes in general, such as labour for experimenting, education, technical and economic advice, licenses, certification, etc.

[10] Expenditures related to the acquisition of the innovation itself are not included. Expenditures are denoted in guilders: 1 guilder is equal to 0.45 euro.

Table 2. **The data: descriptive statistics**

Variables	Types	N	Minimum	Maximum	Mean	Std. Deviation
Size	real values	1 230	541	323 801	13 181	15 083
Market position	values between 0 and 1	1 230	.00001	.09866	.00075	.00327
Solvency	values from set {1,2,3,4,5,6,7}	1 230	1	7	4.75	1.31
Age of the farmer	integer values	1 230	25	81	49.56	11.13
Arable farming	Dummy	1 230	0	1	.19	.
Other horticulture	Dummy	1 230	0	1	.10	.
Mushrooms	Dummy	1 230	0	1	.02	.
Greenhouse vegetables	Dummy	1 230	0	1	.06	.
Greenhouse flowers	Dummy	1 230	0	1	.11	.
Fruit	Dummy	1 230	0	1	.07	.
Dairy farming	Dummy	1 230	0	1	.34	.
Intensive livestock farming	Dummy	1 230	0	1	.11	.
Attitude regarding innovation	Dummy	291	0	1	.65	.
Valuation of internal sources of information	values from set {1,2,3,4}	291	0	4	2.71	1.17
Valuation of external sources of information	values between 1 and 4	291	.05	3.32	1.87	.50
Innovation expenditure ratio	integer values	291	0	35 590	424.24	2 671.81
Internal source as a source of innovative ideas	Dummy	291	0	1	.50	.
Supplier as a source of innovative ideas	Dummy	291	0	1	.20	.
Innovation developed by the farm itself	Dummy	291	0	1	.21	.
Innovation developed in co-operation with others	Dummy	291	0	1	.42	.
Innovation developed elsewhere, adapted to farm needs	Dummy	291	0	1	.21	.
Willingness to protect intellectual property	Dummy	291	0	1	.12	.
Follow-up activities	Dummy	291	0	1	.64	.

– *Source of innovative ideas* (two dummy variables): this indicator is linked to a specific innovation (the same innovation that was used to classify farmers as innovators, early, late or non-adopters). This indicator distinguishes between the farm itself (internal idea), suppliers and others (colleagues, customers, public extension services, consultants, research institutes, etc.) as a source of innovative ideas. The first category and the second one are expressed as dummies while the last category is used as a reference category.

– *Degree of co-operation* (three dummy variables): this indicator is linked to a specific innovation. The degree of co-operation is expressed as a set of three dummies, the first taking a value of one for farmers who developed the innovation by themselves, the second being one for farmers who developed the innovation in co-operation with others, and the third being one for farmers who bought the innovation that was developed elsewhere but was adapted to their needs. All dummies are zero for farmers who bought an innovation that was developed elsewhere and not specifically adapted for their needs. The latter category of farmers is the reference category.

– *Eagerness to protect intellectual property* (dummy variable): if farmers strive for protection of a new technology through secrecy, patents or plant breeder's rights the value is 1, else the value is 0.

– *Existence of follow-up activities* (dummy variable): farmers were asked whether a specific innovation did lead to some follow-up activities (1 means yes and 0 stands for no).

A well-known limitation of the use of several behavioural variables is that they may be interrelated. They might partly capture the same phenomena. A factor analysis showed that some variables are to some degree interrelated in our sample. Instead of dropping or merging some variables into new latent variables (with the help of factor analysis), we include all of them in our empirical analysis to avoid losing information.

RESEARCH QUESTIONS AND HYPOTHESES

If a farmer invests, he either chooses to innovate (to be the first user of an innovation among his competitors), or to adopt an innovation which is already used by others but which is still relatively new, or he chooses to adopt a mature technology. A farmer can also choose not to adopt anything new at all. The literature on innovation adoption reviewed above suggests a number of factors that might contribute to the explanation whether a farmer prefers to be an innovator, an early adopter, a late adopter or a non-adopter [11]. We tested the following hypotheses:

[11] For an overview of the literature on adoption in agriculture, see Feder *et al.* (1985) or Sunding and Zilberman (2001).

1. *Farm size*: farmers with larger businesses are more likely to adopt relatively new innovations.

Many innovations are characterised by fixed costs, for instance because some substantial investments in information gathering and learning are required (Feder, 1980; Feder and O'Mara, 1981). This leads to scale economies: the rate of return on adoption is higher for larger farms. Furthermore, larger farms tend to be characterised by some degree of division of labour, a more professional management and a larger capacity to bear risk. This may foster the willingness to invest in new technologies. Farm size is one of the first and most widely used factors on which the empirical adoption literature has focused. Most studies find a positive relationship between size and adoption (see *e.g.* David, 1969; Perrin and Winkelmann, 1976; Diederen *et al.,* 2002). Olmstead and Rhode (1993) and Hategekimana and Trant (2002) question this result because smaller farmers may cooperate or are more willing to take the risk and costs associated with early adoption because they are looking for new niches and opportunities.

2. *Market position*: farmers that produce for heterogeneous markets are likely to adopt innovations earlier.

Farmers are more likely to be able to capture the benefits of innovations when delivering to markets that allow for some degree of price differentiation. In agriculture the markets for flowers or for branded vegetables are more heterogeneous than the markets for fresh dairy and meat[12]. This hypothesis is rarely studied in the agriculture literature because most studies assume perfect competition in the output market. Falcon (1977) and Diederen *et al.* (2003) studied this hypothesis and found the expected impact.

3. *Solvency*: farmers that have larger financial resources of their own are likely to adopt innovations earlier.

Investments in innovations often require fixed expenditures and are more risky than investments in mature technologies. Due to information asymmetries, it is often difficult to raise external capital for risky investments. Credit constraints therefore may hamper adoption behaviour (Hoff *et al.,* 1993; Just and Zilbermann, 1983). The importance of this argument, though, may be limited to capital-intensive innovations. We have not been able to separate these out in our sample. There is mixed evidence on the credit constraint hypothesis. For example Lipton (1976)

[12] Markets for flowers are highly segmented as flowers are heterogeneous products (differentiated by characteristics like sub-species, colour, size, date of harvest) and the auction mechanism allows for price formation at a disaggregated level. Our data reflect this imperfectly, as we only distinguish between 40 sub-markets in total. However, observations for market position for farms in floriculture in our sample tend to be of relatively high value.

and Agriculture Issues Centre (1994) found evidence to support this hypothesis while von Pischke (1978) did not.

4. *Age of the farmer*: the younger the farmer, the more likely he is to adopt innovations early in his life cycle.

Older farmers on average have a lower level of education, which may be correlated with the ability to judge opportunities to innovate. Also they may have a shorter time horizon and be less inclined to invest in novelties. Schnitkey *et al.* (1992) argued that age is related to farm expertise. They will rely less on external information, and therefore do not get in touch with innovations in the market as early as their younger colleagues.

5. *Sectoral dummies*: the more technological opportunities a sector faces, the more farmers are inclined to adopt early. The more regulation and protection a sector faces, the less farmers are inclined to adopt early.

The number of technologies used in the production process differs from sector to sector. Greenhouse horticulture for example uses many different technologies (*e.g.* for climate control, light control, transport and logistics, sorting, feed composition). On the other hand the number of technologies used in the production process in dairy farming is very limited (feeding and milking systems mainly). New technologies that are relevant for greenhouse horticulture appear much more frequently on the market than new technologies for dairy farming. In horticulture, innovations are more likely to be superseded by new innovations before they reach an advanced stage of diffusion than in dairy farming. Hence, more farmers in horticulture will adopt innovations that are in an early stage of diffusion than in diary farming. Sectoral dummies can also capture the amount of regulation and market protection a sector faces.

All the above-mentioned hypotheses pertain to structural characteristics of farms. The next hypotheses are related to the behaviour of a farmer, especially regarding information and learning. We expect farmers to adopt innovations in an early stage if they search for and exploit information from various sources actively (Rogers, 1995). Behavioural characteristics are not very often used in the empirical studies on adoption in agriculture. Feder *et al.* (1985) showed that the results of studies using information proxies are mixed. A problem is a lack of good proxies. Different aspects of this phenomenon are expressed in the following hypotheses:

6. *Attitude regarding innovation, existence of follow-up activities* and *innovation expenditure ratio*: farmers adopt earlier if they regard the search for innovation as a permanent business activity and if innovations lead to follow-up activities; farmers adopt innovations earlier if they invest more in innovation related activities (courses, extension services, professional advice) on a regular basis.

7. *Valuation of internal sources of information, valuation of external sources of information* and *source of innovative ideas*: farmers who consider external sources of information to be important are more likely to adopt innovations early; farmers who consider internal sources of information to be important are less likely to adopt early. Farmers who get their ideas from external sources are more likely to adopt early in the life cycle.

8. *Degree of co-operation*: farmers who develop innovations by themselves or in co-operation with others, or who adapt innovations developed elsewhere are earlier adopters than those who buy new technologies off the shelf.

9. *Eagerness to protect intellectual property*: farmers that seek intellectual property protection are true innovators.

As mentioned before we have to stress that the behavioural hypotheses are to some extent related to each other and may partly capture the same phenomena.

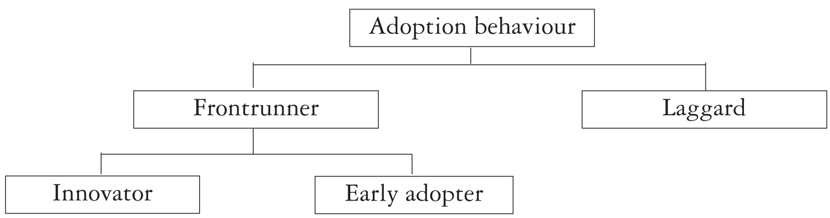
MODEL ESTIMATIONS AND RESULTS

Nested logit model

Choices between different strategies are commonly modelled using binary models like probit or logit. In our case we use a multinominal model because with regard to adoption behaviour a farmer can choose to be a laggard, an early adopter or an innovator. We have information on structural characteristics for all farmers whereas we have information on behavioural characteristics for only those that choose to be early adopters or innovators. In this study we use a nested logit model that is an extension to a multinominal logit model (see McFadden, 1984; Greene, 2000; Train, 2003). Using a nested logit model a multi-level choice making process can be analysed. Nested logit models have been successfully applied in the analysis of product and service choice (Riddington *et al.*, 2000) as well as in the analysis of important life decisions like education (Montgomery, 2002). The choice to use a new technology on a farm can be considered as one of the important work-related decisions of a farmer.

The nested logit model used here has two levels. At the first level, a farmer chooses between being a frontrunner or a laggard. If he is a frontrunner then at the second level he has to choose between being an innovator or an early adopter (see the tree structure in Figure 1). The choice at the first level takes account of structural characteristics only while at the second level the full set of independent variables (including both structural and behavioural characteristics) is used as explanatory variables. At the first level the laggards constitute the reference group, and at the second level the early adopters constitute the reference group. We are using a nested approach instead of estimating the two choices separately because we cannot *a priori* assume that the two choices are independent. Each of the exogenous variables is linked to one of the hypotheses defined in the previous section. The estimation results are presented in Table 3.

Figure 1. **Tree structure of adoption behaviour**



The log-likelihood ratio (LR) against the constant-only model indicates that the model is significant (p-value = 0.0000). The inclusive value [13] (IV) parameters for a frontrunner and a laggard are 15.41 and 1, respectively. It is equal to 1 for a laggard because there is no choice at the second level for a laggard. The LR test of homoskedasticity is a test for the nesting (heteroskedasticity) against the null hypothesis of homoskedasticity, based upon the comparison of the log-likelihood of a non-nested conditional logit model against the nested logit model log-likelihood. The Chi squared value of 371.25 clearly supports the use of the nested logit model with these data. A pseudo R^2 of 0.72 (calculated as one minus the ratio of the model's log-likelihood over the log-likelihood of the constant-only model) indicates a satisfactory explanatory power of the estimated model.

[13] An inclusive value is an expected utility associated with the second level choice given the first level choice. It is calculated as a logarithm of a sum of the exponentials of the explanatory variables vector multiplied by the parameters vector; the exponentials are summed for all the second level choices connected with the given first level choice. See Greene, 2000, p. 866.

Table 3. **Structural and behavioural characteristics as determinants of adoption behaviour: the econometric results**

Exogenous variables	Coefficient	Standard error	z statistic	Prob>|z|
Adoption behaviour: frontrunner or laggard (first level)				
Size, in nge's	.15	.10	1.55	.12
Market position	1.76	.92	1.91	.06
Solvency	-.40	.12	-3.40	.00
Age of the farmer	-.03	.01	-2.32	.02
Sector:				
- Arable farming	-.93	.68	-1.36	.17
- Other Horticulture	-.54	.75	-.72	.47
- Mushrooms	-33.58	82.41	-.41	.68
- Greenhouse vegetables	.50	.73	.69	.49
- Greenhouse flowers	-.98	.72	-1.37	.17
- Dairy farming	-1.18	.60	-1.97	.05
- Intensive livestock farming	-.23	.63	-.37	.71
Frontrunner: innovator or early adopter (second level)				
Size, in nge's	.01	.11	.10	.92
Market position	-68.08	61.98	-1.10	.27
Solvency	-.10	.07	-1.49	.14
Age of the farmer	-.04	.01	-4.45	.00
Sector:				
- Arable farming	-.30	.33	-.91	.36
- Other Horticulture	-.54	.41	-1.34	.18
- Mushrooms	3.33	6.02	.55	.58
- Greenhouse vegetables	-.48	.44	-1.09	.28
- Greenhouse flowers	-.77	.42	-1.83	.07
- Dairy farming	-.76	.32	-2.38	.02
- Intensive livestock farming	-.93	.38	-2.45	.01
Attitude regarding innovation	.30	.26	1.13	.26
Valuation of internal sources of information	.10	.10	.97	.33
Valuation of external sources of information	1.05	.17	6.14	.00
Innovation expenditure ratio	.00033	.00039	.84	.40
Source of innovative ideas:				
- Internal source	.68	.26	2.62	.01
- Supplier	.83	.30	2.73	.01
Co-operation:				
- Innovation developed by the farm itself	.96	.36	2.66	.01
- Developed in co-operation with others	.87	.37	2.36	.02
- Developed elsewhere, adapted to farm needs	.25	.28	.91	.37
Willingness to protect intellectual property	-.31	.46	-.66	.51
Follow-up activities	.28	.22	1.27	.20
Inclusive value (IV) parameters				
Frontrunner	15.41	2.92	5.27	.00
Laggard	1	.	.	.
Number of observations	3690			
Log-likelihood	382.02			
Pseudo-R^2	0.72			
LR test	$Chi^2(34) = 1938.55$		$Pr > Chi^2 = .0000$	
LR test of homoskedasticity (IV = 1)	$Chi^2(1) = 371.25$		$Pr > Chi^2 = .0000$	

Econometric results for a choice between being a frontrunner or a laggard (the first level)

The regression results of the first level, which are depicted in the upper half of table 3, show that structural characteristics matter for the choice between being a frontrunner or a laggard. The size of a farm and market position have a positive impact on adoption behaviour as expected, though the coefficients are imprecisely measured being statistically significant at the 12% and 6% level respectively. This is in line with our hypotheses 1 and 2 that farms that are bigger or produce for heterogeneous markets adopt an innovation early.

Contrary to hypothesis 3, the solvency ratio has a negative impact on early adoption behaviour. The impact of solvency is statistically significant at the 0.1% level. The hypothesis of a positive relation between solvency and adoption behaviour can therefore be rejected. An explanation for this surprising result may be that solvency does not measure the amount of risk bearing resources available for risky investments, but rather the degree of risk-averse behaviour. Farmers may have high solvency ratios because they are risk-averse and "sit on their money", while those that invest in innovations may do so using debt capital, thereby decreasing their solvency ratio. Solvency may therefore rather be classified as an indicator of farmer attitude towards risk than of the farm financial condition.

In accordance with our hypothesis 4, the age of the farmer correlates negatively with the probability of being a frontrunner. The influence is statistically significant at the 2% level. Finally, contrary to the first part of our hypothesis 5, most of the estimated coefficients of the sectoral dummies are not significantly different from zero. This is somewhat surprising, as most studies tend to find that the main explanatory variable of the degree of innovativeness of a firm is its sector specific set of technological opportunities. Apparently, although technological opportunities vary quite substantially across sectors, this does not affect the probability that a farmer chooses to be a frontrunner in his field or not. Only farmers in the dairy sector seem to be less prone to be frontrunner than the rest. This is in line with the second part of hypothesis 5, given that regulations like the quota system and environmental regulation considerably limit development opportunities in the production of milk.

Econometric results for a choice between being an innovator or an early adopter (the second level)

At the second level we test whether the relationships that we found between innovativeness and structural variables like size, market power, age and solvency still hold if we compare innovators and early adopters, and whether behavioural characteristics matter in this case. Our results indicate that here the relationship between structural characteristics and innovativeness breaks down almost completely: innovators and early adopters cannot be distinguished on the basis of the general structural characteristics we use in our model (except for age and some sectoral dummies). Contrary to our expectations, innovators are not significantly larger or more powerful on the market than early adopters; they seem to have similar structural characteristics. The exception is that innovators are significantly younger than early adopters.

Whereas innovators and early adopters seem to have similar structural characteristics, they differ in some behavioural characteristics. Despite the expected (positive) signs of the coefficients, the regression results show that, contrary to hypothesis 6, innovators do not differ significantly from early adopters in their reported attitude regarding innovation, in their tendency to follow up on earlier innovations and in their expenditures on education, advice and extension.

In line with hypothesis 7, innovators differ from early adopters in their valuation and handling of different sources of information. Innovators value external sources of information more than early adopters, whereas the difference is not statistically significant with regard to internal sources of information. It seems that farmers that are at the very front of the diffusion curve get more information from external sources. Regarding the sources of ideas for innovation, the evidence is less conclusive. The survey question about the origin of innovative ideas is related to the main innovation introduced on the farm within a three-year period. Both farmers that reported that they got this idea from their suppliers and those that answered that the innovative idea had its origin on the farm grounds are more likely to be innovators than those that reported other sources like colleagues, customers, public extension services, consultants and research institutes.

As suggested by hypothesis 8, farmers who develop innovations by themselves or in co-operation with others tend to adopt earlier than those who buy technologies off the shelf. However, there is no difference in speed of adoption between those that adapt innovations developed elsewhere and those that buy them off the shelf. In general, early adopters seem to be more passively receiving new technologies than innovators.

After an innovation is developed, a farm has the choice to protect the innovation, either by secrecy, plant breeder's rights or patenting. Although one would expect innovators to differ from early adopters in this respect, we did not find any statistical difference, contrary to hypothesis 9. Apparently, intellectual property protection is not an issue among Dutch farmers. Most likely, secrecy or patenting is not a viable option for the farmer in most cases, as innovation in agriculture depends mostly on co-operation with equipment suppliers that would be in a strong position to claim intellectual property protection. Such protection may not be considered very useful if innovation diffusion has little effects on farmers' output prices. Finally, claiming innovations through property rights may be felt inappropriate as it runs counter to the traditional co-operative character of the agricultural sector in the Netherlands, where technology used to be shared with others.

Except for eagerness to protect intellectual property all the behavioural variables have the expected (positive) sign. Some variables are statistically significant while others are not. The latter may be caused by the overlapping nature of these variables that partly capture the same phenomena. Despite this limitation the main finding of this work remains that innovators differ from early adopters in their behavioural characteristics.

CONCLUDING REMARKS

In this paper we studied the choice with regard to adoption behaviour in agriculture at the farm level. Next to the structural characteristics traditionally used in decision-theoretic models, such as farm size, market position and solvency, we used behavioural variables that are generally recognised as important but rarely tested. Our behavioural variables reflect mainly search for, handling of and sharing of information, issues that drive innovation diffusion under imperfect market conditions, lack of transparency, as reflected in epidemic models. We tested our hypotheses using the data of a large sample of the Dutch farmers.

We found that innovators and early adopters differ from laggards with regard to structural characteristics like size, market position, age and solvency. However, we also discovered that these structural characteristics (except for age) do not distinguish innovators from early adopters. Instead we found that innovators differ from early adopters with regard to behavioural characteristics such as the valuation of external information, the source of innovative ideas and the way they co-operate. Thus we found that in our case variables figuring commonly in probit models of diffusion help to distinguish earlier from later adopters at a higher level of aggregation. Due to the data limitations, we do not know whether variables reflecting aspects of information would do so, but we found that those information variables distinguish between innovators and early adopters at a lower level of aggregation.

REFERENCES

Agricultural Issues Center (1994). Financing agriculture in California's new risk environment, *in:* Proceedings of a conference on December 1, 1993, Sacramento, California, Blank S.C. and Weber S.

Brouwer E., Kleinknecht A. (1997). Determinants of innovation. A micro-econometric analysis of three alternative innovation output indicators, *in: Determinants of Innovation*, Kleinknecht A. (ed.), London, Macmillan Press, pp. 99-124.

Cohen W.M., Klepper S. (1996). A reprise of size and R&D, *Economic Journal*, vol. 106, pp. 925-952.

Cohen W.M., Levin R.C. (1989). Empirical studies of innovation and market structure, *in: Handbook of Industrial Organization*, Schmalensee R., Willig R.D. (eds), Amsterdam, North Holland.

David P. (1969). A contribution to the theory of diffusion, Memorandum n° 71, Stanford Centre for Research in Economic Growth.

Davies S. (1979). *The Diffusion of Process Innovations*, Cambridge, Cambridge University Press.

Diederen P.J.M., van Meijl J.C.M. and Wolters A.M. (2003). Modernisation in agriculture: what makes a farmer adopt an innovation?, *International Journal of Technology Management*, (forthcoming).

Diederen P.J.M., van Meijl J.C.M. and Wolters A.M. (2002). Innovation and farm performance: the case of Dutch agriculture, *in: Innovation and Firm Performance: Econometric Explorations of Survey Data*, Kleinknecht A., Mohnen P., London, Palgrave MacMillan.

Falcon W.P. (1977). The green revolution: generation of problems, *American Journal of Agricultural Economics*, vol. 59, pp. 698-709.

Feder G. (1980). Farm size, risk aversion and the adoption of new technology under uncertainty, *Oxford Economic Papers*, vol. 32, pp. 263-83.

Feder G., Just R.E. and Zilberman D. (1985). Adoption of agricultural innovations in developing countries: a survey, *Economic Development and Cultural Change*, vol. 33, 2, pp. 255-298.

Feder G., O'Mara G.T. (1981). Farm size and the adoption of green revolution technology, *Economic Development and Cultural Change*, vol. 30, pp. 59-76.

Geroski P.A. (2000). Models of technology diffusion, *Research Policy*, vol. 29, pp. 603-625.

Griliches Z. (1957). Hybrid corn: an exploration in the economics of technological change, *Econometrica*, vol. 25, 4, pp. 501-522.

Greene W. (2000). *Econometric Analyses*, Fourth Edition, New York, Prentice-Hall.

Hategekimana B., Trant, M. (2002). Adoption and diffusion of new technology in agriculture: genetically modified corn and soybeans, *Canadian Journal Of Agricultural Economics*, vol. 50, pp. 357-371.

Hoff K., Braverman A. and Stiglitz J. (1993). *The Economics of Rural Organisation: Theory, Practice and Policy*, New York, Oxford University Press.

Huang J., Ruifa H., van Meijl J.C.M. and van Tongeren F. (forthcoming). Biotechnology boosts to crop productivity in China: trade and welfare implications, *Journal of Development Economics*.

Just R.E., Zilberman D. (1983). Stochastic structure, farm size, and technology adoption in developing agriculture, *Oxford Economic Papers*, vol. 25, pp. 307-328.

Kamien M.I., Schwartz N.L. (1982). *Market Structure and Innovation,* Cambridge, Cambridge University Press.

Karshenas M., Stoneman, P. (1995). Technological diffusion, *in*: *Handbook of the Economics of Innovation and Technological Change*, Stoneman P. (ed.), Oxford, Blackwell.

Karshenas M., Stoneman P. (1993). Rank, stock order and epidemic effects in the diffusion of new process technologies: an empirical model, *Rand Journal of Economics*, vol. 24, 4, pp. 503-528.

Lipton M. (1976). Agricultural finance and rural credit in poor countries, *World Development*, vol. 4, pp. 543-54.

Mahajan V., Peterson R.A. (1985). *Models of Innovation Diffusion*, Beverly Hills, Sage Publications.

Mansfield E. (1968). *Industrial Research and Technological Innovation*, New York, Norton.

Mansfield E. (1961). Technical change and the rate of imitation, *Econometrica*, October, pp. 741-766.

McFadden D.L. (1984). Econometric analysis of qualitative response models, *in: Handbook of Econometric*s, Griliches Z., Intrigilator M.D. (eds), Amsterdam, Elsevier Science Publishers.

Montgomery M. (2002). A nested logit model of the choice of a graduate business school, *Economics of Education Review*, vol. 21, 5, pp. 471-480.

Olmstead A.L., Rhode P. (1993). Induced innovation in American agriculture: a reconsideration, *Journal of Political Economy*, vol. 101, pp. 100-118.

Perrin R., Winkelmann D. (1976). Impediment to technical progress on small *versus* large farms, *American Journal of Agricultural Economics*, vol. 58, pp. 888-894.

Pischke (von) J. (1978). When is a smallholder credit necessary ?, *Development Digest*, vol. 26, pp. 6-14.

Riddington G., Sinclair C. and Milne N. (2000). Modelling choice and switching behaviour between Scottish ski centres, *Applied Economics*, vol. 32, 8, pp. 1011-1018.

Rogers E.M. (1995). *Diffusion of Innovations*, New York, The Free Press, 4th edition.

Scherer F.M., Ross D. (1990). *Industrial Market Structure and Economic Performance*, Boston, Houghton Mifflin Company.

Schnitkey G., Batte M., Jones E. and Botomogno J. (1992). Information preferences of Ohio commercial farmers : implementation and extension, *American Journal of Agricultural Economics*, vol. 74, pp. 486-496.

Stoneman P. (2002). *The Economics of Technological Diffusion*, Malden (Massachusetts), Backwell Publishers.

Stoneman P. (1983). *The Economic Analysis of Technological Change*, Oxford, Oxford University Press.

Sunding D., Zilberman D. (2001). The agricultural innovation process : research and technology adoption in a changing agricultural sector, *in : Handbook of Agricultural Economics*, Gardner B.L., Rausser G.C. (eds), vol. 1, Amsterdam, Elsevier Science.

Thirtle C.G., Ruttan V.W. (1987). The role of demand and supply in the generation of technological change, *Fundamentals of Pure and Applied Economics Series*, vol. 21.

Train K. (2003). *Discrete Choice Methods with Simulation*, Cambridge, Cambridge University Press.