Modernisation in Agriculture: What Makes a Farmer Adopt an Innovation?

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Abstract
This paper addresses the question which factors influence a farmer in deciding to adopt an innovation. We differentiate between innovations that are new to the farmer, but already well established in the sector, innovations that are early in their process of diffusion, and innovations that are new to the farmer's sector. We use an ordered probit approach to relate adoption behaviour to variables that capture characteristics of the farm (labour and financial resources and market position), of the business environment of the farm (type of production and market, degree of regulation) and of the farmer (access to information, capabilities, preferences). We use data on 865 Dutch farms and find that innovation adoption is positively related to labour resources, market position, access to information and past adoption behaviour, and negatively to solvency and the degree of market regulation.

1. Introduction

Over the second half of the last century total factor productivity of Dutch agriculture has increased at an average rate of around 3 per cent annually (Rutten, 1992). Various factors account for these increases in productivity. One of them has been the successful introduction of numerous new production techniques and their rapid diffusion among thousands of Dutch farmers. Another factor has been a strong tendency of concentration in Dutch agriculture. In 1950 there were still over 241.000 agricultural and horticultural businesses in The Netherlands, of which barely 97.000 are left nowadays. Concentration has typically involved the liquidation of the least productive, usually smaller, farms and a progressive exploitation of scale economies in the remaining farms. This paper examines the determinants of the former factor, the introduction and diffusion of innovations in agriculture.

Agriculture is a typical example of what Pavitt (1984) would classify as a supplier dominated sector, a sector that is dependent upon supplying industries for its innovations and its technical progress. The sector consists of numerous small firms, most of which produce a relatively homogeneous output that is used as an input in the food processing industries. These type of sector characteristics are little conducive to entrepreneurial behaviour and innovation. The individual farming operation usually lacks both the means and the scale of operations to appropriate the benefits of investments in R&D and therefore has little incentive to develop the necessary capabilities. Consequently, technological change in agriculture has mostly been described as a process of adoption "of the shelf" of innovations produced elsewhere, be it by commercial suppliers of farm equipment or of inputs like seeds and fertilisers, or by public research and development facilities. Expanding upon Griliches (1957), who analysed the diffusion of hybrid corn, an extensive adoption literature has developed in agricultural economics.

Unlike hybrid corn, though, many innovations are not bought of the shelf; this increasingly tends to hold in agriculture as well as elsewhere. They often do require adjustments to local circumstances and adaptations to specific uses. Adoption usually involves substantial investments in search, information gathering and risk assessment, and in learning processes to use or operate the new technology (the 'software', necessary to make the 'hardware' work). Thus, although most farmers are not engaged in formal R&D, many do invest in innovation related activities.

The central issue addressed by the adoption literature is: why do different farmers adopt a specific innovation at different moments in time. In this paper, we do not consider any particular innovation, but we look at adoption behaviour in general. At any moment in time, every farmer is faced with a range of innovations that have reached the market and thus with various adoption opportunities. Some of those farmers invest in some innovation and other do not. We distinguish between farmers that have adopted an innovation over the past year and those that have not. Moreover, among adopters, we identify three groups: innovators, early adopters and late adopters. The main question we tackle in this paper is: what factors make a farmer an innovator, an early adopter, a late adopter or a non-adopter?

The paper is structured as follows. In section 2, we briefly review the literature and develop the conceptual framework for our analysis. In section 3, we introduce our data and our estimation model, and we develop some hypotheses. Section 4 gives results and section 5 concludes.

2. Conceptual framework

What determines innovation adoption by a farmer? Two main classes of models have been used to describe adoption behaviour (see e.g. Stoneman, 1983, Thirtle and Ruttan, 1987, Geroski, 2000 for overviews). First, there are population models of diffusion, which describe the dynamics of population development. The epidemic diffusion model is an example of this class. This model describes innovation diffusion as driven by an endogenous process of information propagation. Second, there are decision theoretic models of innovation adoption, of which the probit model is the most prominent. Within this class, there are also game theoretic models of innovation adoption, but these have had little impact upon empirical research. The probit model of adoption (pioneered by Davies, 1979) assumes a decision to adopt or not to adopt an innovation at a specific moment in time as the outcome of profit maximising behaviour. Heterogeneity among potential adopters makes some of them adopt while others abstain. Over time, the parameters of the decision problem change. This accounts for the fact that at a later moment in time, farmers that first abstained later decide to adopt. Thus a heterogeneous population of farmers and some exogenous process of change generates heterogeneity in adoption dates.

In this paper we consider adoption behaviour (of any type of innovation) in a specific year; we are not concerned with diffusion over time. To arrive at our hypotheses, we draw upon the lines of reasoning common in the probit approach to specify the relevant factors that impact upon the decision to adopt. Generally, probit studies relate innovation adoption to firm characteristics and to factors that characterise the environment within which the farm operates. Most probit studies assume rational decision making under full information. We relax this assumption and allow for differences between farmers in information, capabilities and time preference.

Firm characteristics

Probably the most commonly explored explanatory variables figuring in adoption models are in some way related to firm size. A larger firm size is assumed to lead to earlier adoption for various reasons (that can be traced back to Schumpeter, 1947, but have been explored further e.g. in Kamien and Schwartz, 1982):

- larger firms have more access to risk bearing financial resources to invest in innovation (they have deeper pockets);
- if there are increasing returns to scale to investment in the innovation (which is frequently the case), adoption is more profitable for larger firms;
- as there is more division of labour and labour specialisation in larger firms, it is more likely that there are people specifically dealing with issues of long term business development and technological change.

Another firm characteristic that is likely to influence adoption of a new technology, is the current technology in use, again for various reasons:

- the difference between the current technology and the innovation to be adopted, in terms of the knowledge, skills and provisions needed to make it work, determine the switching costs (cf. Rogers, 1995, who relates adoption to factors like complexity and compatibility);
- the benefits of adoption of the innovation are determined by the difference in performance between the old and new technology and by the degree to which the investments in the old technology are sunk.

Whereas the effects related to firm size stated above all work in the same direction (larger firms adopt earlier), are the effects related to the current technology likely to pull in opposite directions. If the difference between the old and the new technology are smaller, the switching costs are likely to be smaller, but the opportunity costs of sticking with the old technology and not depreciating the earlier investments may also be smaller.

A third firm characteristic that often figures in innovation adoption studies is market share. The idea (also going back to Schumpeter, 1947) is that both firms in perfectly competitive markets and monopolists experience little incentive to invest in innovation, the former because they largely lack the possibility to appropriate the benefits, and the latter because the competitive threat does not force them to innovate. Intermediate levels of market concentration are supposed to induce innovation most; empirical results on this issue have been mixed, though (see e.g. Kamien and Schwartz, 1982; Scherer and Ross, 1990; Cohen and Levin, 1989; Brouwer and Kleinknecht, 1997). In agriculture, market share is not a variable which is likely to be of importance. The average farm has only a negligible share of the market, particularly in meat, grain and dairy production. In some parts of horticulture, though, market share may be substantial. In flower growing there is a great deal of product differentiation and products are increasingly sold under brand names owned by growers (see e.g. Hendrikse and Bijman, 2002). Similar tendencies can be discerned in vegetable growing, though not as strong.

Environmental characteristics

By environmental characteristics we mean those factors that are not particular to a specific farm but affect a whole sector or group of farms producing for the same market. Examples of this type of characteristics are (see e.g. Gatignon an Xuereb, 1997, Li and Calantone, 1999): the growth of the market, the intensity of competition, demand uncertainty, the sort of technologies being used, the speed of technological change. In agricultural markets, three characteristics of particular importance are:

- the amount of technology used in the production process: production under more controlled circumstances, like e.g. in greenhouses, involves the application of more different technologies and therefore a higher probability that there are innovations that may be adopted;
- opportunities for product differentiation: more heterogeneity offers more scope for adopting product innovations;
- the degree and type of government regulation: on the one hand, regulation implies constraints to the adoption of innovations, on the other hand, it may also provide incentives for adoption of specific types innovations.

For instance, in greenhouse horticulture and mushroom growing, the number of different technologies involved in the production process (for climate control, growth monitoring and automatic harvesting, green house construction, fertilizing, CO2-control, transport, sorting and packaging, and so on) is much larger than in arable farming or fruit growing. Product heterogeneity is an issue in flower growing and to some extent in vegetable growing, but hardly in life stock, dairy or arable farming. Regulated markets, figuring quota or price arrangements, are the markets for wheat, milk, beef and sugar, but not the markets for flowers, vegetables, fruit and pork. Dairy farming and arable farming are highly government regulated sectors.

Information, capabilities and preferences

Given farm characteristics and market conditions, farmers perform a cost-benefit analysis to decide to either adopt an innovation or not. However, given the same parameters, not every farmer will take the same decision. A number of specific characteristics of the decision maker and the decision making process may be important. We distinguish three categories:

- information availability: farmers may differ in their access to and command of information necessary to inform their decision making process;
- capabilities: farmers may differ in entrepreneurship, the degree to which they are capable to anticipate the strategic consequences of innovation adoption (i.e., the effect of their adoption decision on their competitive position in the market and the actions among competitors it induces; see e.g. Dixit, 1980, Reinganum, 1989, Geroski, 2000, on pre-emptive effects of investments and adoption);
- preferences: farmers may differ in degrees of risk aversion, time preference (their discount rate), or time horizon.

3. Data, model and hypotheses

We use data from the Dutch Farm Accountancy Data Network (FADN), which covers about 1500 farms out of a total of 100.000, and which is maintained at the Agricultural Economics Research Institute (LEI). All sorts of financial data are collected from participants in the FADN on a yearly basis. It is a stratified sample, largely representative of the Dutch agricultural and horticultural industry (with some limitations, e.g. very large enterprises are not included, which may lead to an underestimation of innovativeness). These data have been supplemented by data from the annual survey carried out among all Dutch farmers by the Dutch Central Bureau of Statistics.

All participants in the FADN received a questionnaire on the subject of innovation in 1997 and in 1998. The 1997 questionnaire covered the period 1995 – 1997 while the 1998 questionnaire only covered that single year. The response rate was about 75% in both years. We have a sample of 865 farms for which we have data from both questionnaires. Farmers were asked about the important innovations they adopted. An innovation was defined as a anything that is new to the farm (e.g., a new type of machine, a new variety of a species, a new product) and that is important for the operations of the farm. Mere replacements of old equipment without any improvement in functionality, design or efficiency were not classified as innovations. Those farmers that had adopted an innovation were then asked to rate themselves as an innovator, an early adopter or a late adopter (i.e., to indicate their position on the diffusion curve). An innovator was defined as a first adopter of an innovation among farmers working in the same market; an early adopter was defined as belonging to the first quarter of actual adopters of a particular innovation out of the total of potential adopters. The answers of the farmers were checked by experts and if necessary amended. On the basis of these data, farmers were classified into four groups: innovators, early adopters, late adopters and non-adopters. For the year 1998, we classify 17 farmers in our sample as innovators, 27 as early adopters, and 44 as late adopters out of a total of 865 observations.

Model description

We assume that a farmer, confronted with the choice out of a range of innovations that he might invest in, decides not to adopt any new technology to operate his farm (to be a non-adopter), to adopt some technology that is new for him, but that is already well established among his competitors (to be a late adopter), to invest in some technology that is in the early stages of diffusion (to be an early adopter), or to invest in an innovation that is new to his sector (to be an innovator). To analyse this type of adoption behaviour of farmers for the year 1998, we relate the classification of a farmer as an innovator, an early adopter, a late adopter or a non-adopter, to a number of variables in an ordered probit model. We thus model the incidence that a farmer falls into one of four groups, each characterised by a certain type of adoption behaviour, as a function of a number of variables. These variables are indicators of characteristics of the farm, the environment and the farmer. We present each of these variables in turn and state a hypothesis as to their effect on adoption behaviour.

Farm characteristics

We use four variables to model farm specific characteristics:

- "Labour resources" is taken to capture the effects of farm size and division of labour. The size of the labour force is measured in full-time equivalents (fte); the average farm in the Netherlands employs 3.1 fte. The distribution of this variable is lopsided, and therefore we used a log-transformation.

  Hypothesis H1: The more labour resources farms have, the more likely they are to adopt an innovation early.
- "Solvency" is included to capture the effects of availability of access to risk bearing financial resources. This variable is measured as the ratio of equity capital (net worth) over total capital. The average farm has a solvency of about 64 percent; the distribution is approximately normal around the mean.

Hypothesis H2: The higher the farm's solvency ratio, the more likely a farmer is to invest in innovation adoption.

- "Profit rate" is measured as net income (total sales minus total costs (including depreciation) per unit of farm size (where the latter is measured in terms of "nge's", which is a product specific deflated standard gross value added per unit, e.g. per animal or hectare). This variable is included to capture the effect of current profits on adoption behaviour (profits affect the cost of capital). We assume that farmers also have an incentive to reduce their pre-tax profits for fiscal reasons and therefore tend to invest more in innovation adoption in years of higher profits.

  Hypothesis H3: Higher net incomes (relative to size) lead to higher investments in innovation adoption in the same year.
- "Market position" is an indicator variable that tries to capture the ability of a farm to capture benefits of product differentiation. As an indicator we use the share of a farm's output in the total Dutch production of that particular sector the farm belongs to (market share). We use a subdivision of Dutch agricultural production into 40 sectors; the mean indicator is .06% 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 over markets. We use the natural logarithm.

  Hypothesis H4: The larger a farm's market position indicator, the more likely a farmer is to invest in a new technology.

Environmental characteristics

We include four dummy variables to characterise relevant environmental conditions:

- "Control" is a dummy variable that indicates whether production takes place indoors under controlled circumstances and therefore involves a large number of different technologies. This dummy is set to one for all horticulture under glass and for mushroom growing (161 farms) and to zero for the others.

  Hypothesis H5: The more production can be controlled, the more likely a farmer is to adopt new technologies.
- "Heterogeneity" is a dummy variable that captures the opportunities for a farmer to use product differentiation as a development strategy. This variable takes on the value of one for farmers in floriculture (90 farms in the sample) and zero for all the others.

  Hypothesis H6: The more opportunities for product differentiation a market offers, the more likely is a farmer to invest in innovation adoption.
- "Regulation" is a dummy variable that indicates whether a farmer produces for a widely regulated market, like dairy and arable farming (479 farms).

  Hypothesis H7: The more markets are regulated, the less a farmer is likely is to invest in adoption of innovations.
- "Intensive livestock" is an additional dummy variable that is set at one for those farms that are in intensive livestock production, and that has been included here to control for the fact that the year 1998 was a year in which the effects of a swine fever epidemic affected the sector.

  Hypothesis H8: Farmers in intensive livestock farming are less likely to invest in innovation adoption in 1998.

Information, capabilities and preferences

Finally, we include a set of four variables to capture characteristics of the farmer him- or herself:

- "Education" measures the level of education of a farmer. We assume education is an indicator for innovative capabilities. About 52% of the farmers has no education beyond primary education or lower professional education, 40% has medium level professional education, and about 8% has completed higher or academic education. The level of education is captured by two dummy variables, one indicating whether a farmer has completed medium level professional education, and the other indicating that he has completed higher level professional or university education.

  Hypothesis H9: The higher the level of education a farmer has attained, the more likely he is to adopt innovations early.

- "Co-operation" is included to capture partly the intensity of the stream of external information a farmer is exposed to. It measures the number of agricultural collaborative initiatives (aimed e.g. at marketing and sales, at collective sourcing of machinery, labour or inputs, at environmental protection or nature conservation, at benchmarking and information exchange) a farmer is a member of. The average number is membership of 1.5 collaborative initiative . About one-fifth of the farmers is not a member of any collaborative initiative, while about half of the farmers has two or more memberships. Remind that we measure only the formal contacts of the farmer. Informal contacts may be even more important, but we do not have data on them.

  Hypothesis H10: The more farmers are involved in agricultural co-operative networks, the more likely the are to adopt innovations early.

- "Time horizon" is a dummy variable that takes the value of zero if the farmer is over 50 years of age and has no successor (commonly a son or a daughter willing to take over the farm) and the value of one otherwise. This variable is included to capture the effect of a short time horizon on adoption behaviour. About one quarter of the farmers in this sample is older than fifty years and has no one to take over the farm.

  Hypothesis H11: If a farmer is young or if he is elderly but has a successor, he is more inclined to invest in innovations than if he is old and without successor.

- "Past adoption" is a set of three dummy variables that indicate whether a farmer was classified as a late adopter, early adopter or innovator in our survey covering the period 1995-1997 (and where the way of measuring and classifying was basically the same). This variable is included to capture persistency in innovative behaviour. Over the period 1995-1997 (which covers three years whereas the present survey covers one year) 4% of the sample was classified as innovators 9% as early adopters and 26% as late adopters (see also Table 1).

  Hypothesis H12: Innovation adoption behaviour shows some degree of persistence; farmers that were frontrunners in the past, have a higher probability to be a frontrunners at present, and farmers that were laggards in the past are likely to remain so.

Table 1: Classification of farmers in 1998 versus 1995-1997

	non-adopter in 1995-1997	late adopter in 1995-1997	early adopter in 1995-1997	innovator in 1995-1997	total
Non-adopter in 1998	495	193	65	24	777
Late adopter in 1998	22	17	4	1	44
Early adopter in 1998	11	9	4	3	27
innovator in 1998	7	5	2	3	17
Total	535	224	75	31	865

The means, standard deviations, and correlations among a number of variables are shown in Table 2. The simple correlation matrix in Table 2 shows that innovation adoption in 1998 is positively correlated with labour resources, profit rate, market position, co-operation, time horizon and past adoption. The correlation coefficient is negative for solvency. Among the explanatory variables, labour resources, market position, co-operation, time horizon and profit rate are positively correlated. Solvency is negatively correlated with all the other explanatory variables. All correlations are fairly weak. The various levels of education are not statistically significantly correlated with any of the endogenous or explanatory variables and therefore not shown in Table 2.

Table 2: Basic statistics and correlation coefficients

	Adoption in 1998	Labour resources	Solvency	Profit rate	Market position	Co-operation	Time horizon
Mean		3.04	.64	-9.76	0.05	1.58	
Percentage							76%
Standard deviation		2.88	.27	14.66	0.08	1.23	
Correlation coefficient / significance							
Adoption	1.00						
Labour resources	.27	1.00					
	.0						
Solvency	-.11	-.14	1.00				
	.0	.0					
Profit rate	.10	.29	-.14	1.00			
	.0	.0	.0				
Market position	.20	.33	-.12	.11	1.00		
	.0	.0	.0	.0			
Co-operation	.13	.19	-.03	.22	.04	1.00	
	.0	.0	.36	.0	.19		
Time horizon	.08	.11	-.22	.16	.07	.14	1.00
	.02	.0	.0	.0	.05	.0	
- Innovator 95/97	.12	.11	-.14	.11	.09	.01	.10
	.0	.0	.0	.0	.01	.89	.01
- Early adopter 95/97	.04	.14	-.08	.08	.16	.06	.10
	.28	.0	.03	.02	.0	.09	.0
- Late adopter 95/97	.05	.05	-.02	.04	.00	.08	.08
	.12	.16	.49	.30	.99	.02	.03

A low level of significance indicates a high probability that the correlation coefficient differs from zero.

4. Results

We estimate the probability that a firm is classified as an innovator, early adopter, late adopter or non-adopter. This probability is assumed to be influenced by independent variables, each of which is linked to one of our hypotheses. Because adoption behaviour (the dependent variable) consists of four discrete choices that can inherently be ordered, we estimate an ordered probit model as described in section 3 (Zavoina and McElvey, 1975, Greene, 2000), using LIMDEP (Greene, 1995). The estimation results are shown in Table 3.

Table 3: Determinants of adoption behaviour: results of ordered probit analyses

Exogenous variable	***Coefficient***	***Coefficient/ Standard Error***	***Mean of Variable***
Farm characteristics			
Labour resources	.04	1.57*	3.04
Solvency	-.55	-2.08**	0.64
Profit rate	-.01	-1.27	-9.76
Market position	2.09	2.16**	0.05
Environmental characteristics			
Control	-.08	-0.38	0.19
Heterogeneity	.00	0.02	0.10
Regulation	-.80	-4.25**	0.55
Intensive livestock	-1.05	-3.10**	0.09
Information, capabilities and preferences			
Education - higher education	-.27	-.91	0.08
- middle education	.06	.45	0.41
Co-operation	.13	2.04**	1.58
Time horizon	.16	0.93	0.76
Past adoption			
- innovator 97	.55	2.09**	0.04
- early adopter 97	.04	.15	0.09
- late adopter 97	.29	1.95*	0.26
Constant	-1.27	-3.60**	-
μ_1	*0.44*	*6.5***	
μ_2	*0.96*	*7.8***	
Number of observations		*865*	
Log likelihood function		*-322.53*	
Restricted Log likelihood		*-374.83*	
Chi-squared		*104.59*	
Significance level		*0.00*	

** and **: significant at the 10% and 5% level respectively.*

Ordered probit models an unobserved variable y, where the observed value* y_i *of the dependent variable y equals 0 if* $y_i^* \leq \mu_0$ *, equals 1 if* $\mu_0 \leq y_i^* \leq \mu_1$ *, equals 2 if* $\mu_1 \leq y_i^* \leq \mu_2$ *, and finally equals 3 if* $y_i^* \geq \mu_2$ *. Of the μ's, only two can be estimated – one is set at zero (see Appendix).*

Farm characteristics

Labour resources and market position have a positive impact on adoption behaviour that is statistically significant at respectively the 10% and 5% level. This confirms hypothesis 1 and 4 that farms that are bigger or have a larger market share adopt an innovation early. Contrary to hypothesis 2 and 3, the solvency ratio and the profit rate have a negative impact on adoption behaviour. The impact of solvency is statistically significant while the impact of the profit rate is not significant. The expected positive relation between solvency and adoption behaviour can therefore be rejected. An explanation for this surprising result maybe that solvency not just measures the amount of risk bearing resources available for risky investments, but rather is an indicator of risk averse behaviour. Farmers may have high solvency ratios because they "sit on their money", while those that do invest in innovations may do so using debt capital, thereby decreasing their solvency ratio. Solvency may therefore be better classified as a characteristic of the farmer than of the farm.

Environmental characteristics
Table 3 shows that the influence of heterogeneity and control is limited and not statistically significant. However, confirming hypothesis 7, more regulation of a market has a negative impact on adoption behaviour that is statistically significant at the 5% level. Also, the influence of swine fever in the intensive livestock sector has had a statistically significant negative impact on innovation adoption in 1998[1].

Information, capabilities and preferences
Estimation results are mixed with regard to the four variables that capture farmer characteristics. The impact of education as an indicator of innovative capabilities and time horizon turn out to be statistically insignificant. In line with hypothesis 9, though, the impact of "co-operation" as an indicator of access to external sources of information is positive and statistically significant at the 10% level. Finally, confirming hypothesis 12, there is evidence that innovation adoption behaviour shows some degree of persistence. Both being an innovator or a late adopter in 1995-1997 has a significantly positive influence on adoption behaviour. The coefficient for an innovator (0.55) is higher than for a late adopter (0.29) indicating that being an innovator in the past has a larger impact on the probability of being an innovator in the present than being a late adopter in the past.

5. Conclusion

This paper provides empirical evidence on the determinants of adoption behaviour in Dutch agriculture in 1998. The results show that innovative activities are, as expected, positively related to labour resources (which is highly correlated to farm size), market position (indicating whether a farm produces for a market that permits product differentiation), and a farmer's access to information (where an indicator of the extent of his network is used as a proxy). Surprisingly, innovative activities are negatively related to solvency. This may indicate that farms with a high solvency rate are risk averse and not eager to innovate. Furthermore, we found that adoption behaviour shows some persistence in time: being an innovator (or a late adopter) in the past increases the probability of being an innovator (a late adopter) in the current period. Finally, we found that characteristics of the business environment matter. Especially, a high degree of market regulation seems to have a negative impact on adoption behaviour.

Appendix 1: Description of an ordered probit model

The ordered probit model should be used if multinomial-choice variables are inherently ordered (Green 200, p.875). A (non-ordered) multinomial probit model would fail to account for

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[1] It is interesting to see whether the estimated relationships hold for different subsectors (e.g. dairy farming, intensive livestock farming, greenhouse horticulture and arable farming) as well. However, the data do not allow for this elaboration of the model. The numbers of innovators, early and late adopters per sector are very small, causing relationships to be insignificant.

the ordinal nature of the dependent variable, while an ordinary regression would err in the opposite direction. Take for example the outcome of an opinion survey. If the responses were coded 0,1,2 or 3, then linear regression would treat the difference between a 3 and a 2 the same as that between a 2 and a 1, whereas in fact they are only a ranking.

The ordered probit model is built around a latent regression (Zavoina and McElvey, 1975):

$y_i^* = \beta' x_i + \varepsilon_i$ with ε_i distributed N[0,1]

The unobserved y_i^* depends on certain measurable factors x_i and certain unobservable factors ε_i. y_i^* is unobserved. What we do observe is

$$y_i = \begin{matrix} 0 & if & y_i^* \leq \mu_0 \\ 1 & if & \mu_0 \leq y_i^* \leq \mu_1 \\ 2 & if & \mu_1 \leq y_i^* \leq \mu_2 \\ j & if & y_i^* \geq \mu_{j-1} \end{matrix}$$

which is a form of censoring. The μ's are unknown parameters to be estimated with β'. In our case we have an ordered probit model with four groups. There are thus three μ's, of which two can be estimated because they are free parameters (see e.g. Greene).

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