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The Joint Labour Decisions of Farm Couples: A Censored Response Analysis of On-farm and Off-farm Work

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THE JOINT LABOUR DECISIONS OF FARM COUPLES: A CENSORED RESPONSE ANALYSIS OF ON-FARM AND OFF-FARM WORK

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Abstract: Farm couples' labour market responses are partly the qualitative choice of entering the off-farm labour market and partly the continuous choice of the number of on-farm and off-farm working hours, given entry. Such a setting is interesting when examining the increasing occurrence of multiple job-holdings among farmers in western economies. This paper presents a unified framework for handling such discrete/continuous choices, involving optimisation of farm production, household consumption, and multiple job-holdings for both husband and wife. A two-equation censoring panel data model is implemented and estimated from Norwegian panel data for 342 farms observed over a ten-year period.

Keywords: Labour supply. Agriculture. Multiple job-holding. Time allocation. Bivariate censoring. Panel data. Heterogeneity

JEL classification: C34, D21, J22, J43

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1 Introduction

The objective of this essay is to model and estimate the off-farm labour supply responses of farm couples, when off-farm hours are censored. This problem is rather complex since it involves a common pecuniary budget condition, non-negativity constraints on hours for both spouses, optimisation of both household consumption, farm production and multiple job-holdings for both husband and wife, including possible interdependencies between the the decisions. Most research on labour decisions of farm households in existing literature is based on neoclassical theory. A reference framework for a farm household model was introduced by Huffman (1980), which has since had widespread use in applied research. Its central assumption is that a typical household maximises its joint utility, specified as a function of consumed quantities and leisure time, subject to constraints on time, income and farm production. This, so called *unitary household model*, has been criticised for not giving an adequate description of human behaviour. The critique concerns partly the shortcomings of modelling labour decisions within a static and deterministic framework and partly the assumption of joint preferences within the household. An earlier contribution to the theory of time allocation on home work, work in the market, and leisure, although not specifically related to farm households, is Gronau (1977).

It has been argued that choice behaviour should be modelled as a probabilistic process to account for individuals' uncertainty and for observed inconsistency [Tversky (1972)]. People do not usually have perfect information of the alternatives they can choose among, and their present choices are not necessarily consistent with past behaviour. Moreover, preferences may change over time, depending on new information or shocks occurring. The probabilistic approach implies that probabilities are attached to all possible outcomes, which means that one also need to make assumptions about the relative importance of the relevant random processes, and to decide which processes to account for. In our case, we can distinguish between (i) models with deterministic utility and stochastic decision rule (random noise), (ii) models with stochastic utility and deterministic decision rule, and (iii) models representing both kind of randomness. Approaches (i) and (ii) both mimic aspects of neoclassical theory, while (iii) is more general. There are several reasons why we may not be able to model labour decisions of multiple-job holding households correctly. A common, and more or less unavoidable, problem is that we cannot fully observe all the factors that enter the household's utility function. For instance, we may have insufficient knowledge of preferences for farming and attachment to the farm property (maintenance of family traditions etc.). This kind of preference heterogeneity will not only lead to less precise estimates, but may also induce biases. Another source of uncertainty may stem from insufficient recordings of observable variables like farm characteristics, household characteristics and regional characteristics. Omitted variables also reduce the variation in the endogenous variables explained by the model and sometimes also lead to biased inference. Manski (1977) distinguishes between four kinds of uncertainty: non-observable characteristics, non-observable variation in individual utilities, measurement errors, and functional mis-specifications.

Discarding the static framework in favour of a dynamic model may give important insights, particularly when looking at life-cycle labour supply or transitions between different states (multiple job-holding, retirement, moonlighting etc.). However, the extension to intertemporal preferences leads to restrictions on within-period preferences [Blundell and Walker (1986)]. Another complication lies in specifying functional relationships involving current and future wages, taxes and transfers on labour supply, in particular because wage rates in certain jobes are not observed for those not working in such jobs. Heckman (1993), in a survey article, concludes that existing empirical evidence gives little scope for intertemporal substitution to explain life-cycle labour supply, unless also entry and exit decisions are specifically incorporated. In an article on female labour supply, Heckman and MaCurdy (1980), find that married women do not respond to transistory shocks in household income, but that labour supply is consistent with the permanent income hypothesis.

Chiappori (1992) has criticised the unitary household model for not being grounded on methodological individualism, arguing that the basic decision unit should be the individual rather than a group of individuals with collective preferences [cf. Fortin and Lacroix (1997)]. Several collective models have been introduced to account for the individualistic element, in which the (farm) couple's preferences are represented by a pair of individual utility functions [Chiappori (1992)]. Collective models typically rely on game theory, with a distinction between cooperative and non-cooperative situations. The cooperative models generate Pareto-efficient outcomes and seem to be preferred when modelling household labour supply, while the non-cooperative models are based on Nash equilibrium. Even though collective models have gained popularity in recent years, it is far from obvious that individualistic preferences are preferable to the joint preferences of the unitary model. We still observe large differences in husband and wife's supply of labour hours and wives often have much higher estimated wage elasticities than husbands [cf. *e.g.*, Aaberge, Columbino and Strøm (1999)]. There is thus reason to believe that in a case of Nash-bargaining, husbands will have much stronger bargaining power than wives. Limitations of the data will usually also cause problems in identifying the threat points of the bargaining process between husband and wife.

We conclude that the design of the available data, in combination with the complexity of the estimation problem favours the established farm household model introduced by

Huffman (1980). Since the farm household is a producing unit, and since many farm operators works full-time on the farm and often participates in off-farm labour as well, a collective model based on individual preferences, even when it accounts for household production, as in Chiappori (1997), appears as less attractive. Our aim therefore will be to further develop the Huffman model by to some extent increasing its complexity and making it more general.

The rest of the paper is organised as follows. Section 2 describes the theoretical framework, accounting for the possibility that the farm-couple optimization may lead to zero boundary solutions for some of the time allocation variables, including off-farm labour. The case with positive, boundary solutions for all variables is considered as a benchmark case in Section 3. In this case, the solution can be obtained recursively, such that farm output, on-farm labour input, and other inputs in farm production are determined first, from profit maximization. Second, household income is determined from farm profits, and exogenous income; third consumption and leisure is determined as a residual from income-constrained utility maximization; and fourth, off-farm labour supply is determined from the time budget constraints of the two farmers. Section 4 elaborates various cases with boundary solutions for the time-use variables, with focus on the case where off-farm hours are the only censored variables for both persons. Next, in Section 5 we consider the stochastic specification of the two-equation censoring model and the main ingredients in maximum likelihood estimation of the off-farm labour supply responses. Section 6 presents the data sources, sample selection and definitions, which Section 7 presents descriptive statistics, with emphasis on the change in the labour supply pattern for on-farm and off-farm work which has taken place during the sample period. Estimation and test results are presented in Section 8. Concluding remarks follow in Section 9.

2 Theoretical framework

We view the decision to participate in off-farm wage work by farm operators and their spouses through an agricultural household model framework that determines jointly agricultural production, consumption and labour supply decisions. The model bears resemblance to models used by Huffman and Lange (1989), Gould and Saupe (1989), Lass and Gempesaw (1992), Huffman and El-Osta (1997), and Weersink, Nicholson and Weerhewa (1998), and also is a basis for Bjørnsen (2006). The population of farm households is assumed to face the same choice set of alternative occupations. The actual time allocations are allowed to vary between households, depending on socio-demographic, regional, technical and institutional background variables, latent heterogeneity, as well as random elements in the choice mechanisms.

The typical household is assumed to maximise its utility subject to constraints on time, income, and farm production in a static framework. Utility is derived from purchased goods (C) and the farm couples' leisure time (L^O, L^S), where superscripts O and S denote operator and spouse, respectively, and is affected by human capital characteristics (H^O, H^S) (education, work experience, etc.) as well as other household and regional characteristics (Z_H) (age of operator, number and age of children, and other demographic characteristics) that are considered exogenous to current consumption decisions, as well as unobserved heterogeneity in preferences, a_U. The utility function,

$$(1) \qquad U = U(C, L^O, L^S, H^O, H^S, Z_H, a_U), \qquad U'_C > 0, \qquad U'_{Li} > 0, \qquad (i = O, S),$$

is assumed to be ordinal and strictly concave. We let T be the total time endowment, in hours, for both operator and spouse and assume that time for operator and for spouse are heterogeneous both with respect to the preference structure of the household and as inputs in on-farm and off-farm production. Time can be spent on home leisure, including work, rest, sleep, recreation, etc. (L^O, L^S), farm work (F^O, F^S), and wage work (M^O, M^S), all measured in hours. By assumption, at least one member of all farm households, the operator, supplies a positive number of on-farm labour hours, but it may be zero for the spouse ($F^O > 0,\ F^S \geq 0$), that all individuals enjoy a non-negative number of non-working hours ($L^O \geq 0,\ L^S \geq 0$) and spend a non-negative number of working hours in the off-farm sector ($M^O \geq 0,\ M^S \geq 0$). The time budgets are therefore given by

$$(2) \qquad F^i + M^i + L^i = T \qquad (i = O, S).$$

The consumption of market goods is constrained by income earned from farm profits, net income from off-farm wage work, and other household net income (production and investment grants etc.) after deduction of taxes, interest payments and losses, V. The farm is assumed to be a price taker in input and output markets, and farm profit is set equal to the value of the farm output, PQ, minus the variable cost of production RX, where P is the output price, Q is the output quantity, R is the input price vector and X is the vector of quantities of purchased farm inputs (capital services, hired labour, other material input). Off-farm work is paid at the wage rates W^O, W^S. For simplicity, we do not specifically include tax rates and other aspects of the tax system in the model and normalise the price of consumption to one. The pecuniary budget constraint of the household in the decision period can then be written

$$(3) \qquad PQ - RX + W^O M^O + W^S M^S + V = C.$$

The off-farm wage rates that the operator and spouse face are assumed to depend on their respective human capital characteristics H^O and H^S, the local labour market conditions Z_M (centrality indicator, distance to labour market, etc.), which we consider as exogenous, as well as unobserved individual heterogeneity, indicated by a_W^O and a_W^S:

$$(4) \qquad W^i = W^i(H^i, Z_M, a_W^i) \qquad (i = O, S).$$

We assume flexible work schedules in off-farm employment, so that the operator and spouse can maximise household utility by behaving as price-takers and offering an optimal number of off-farm work hours at wage rates determined independently of the number of hours worked. In the following, we will often, for simplicity, consider W^O and W^S as exogenous variables, even if, strictly speaking, it is the arguments of (4) that have this property. Assuming that the wage rates are (conditionally) exogenous relative to labour supply is not without problems. For instance, many farmers take on small commissions, *e.g.*, from neighbours, where prices and the quantities are negotiated simultaneously.

The production technology of the farm represents the third and final constraint on the household's consumption possibilities. Farm output depends specifically on the labour hours put down in farm production from operator and spouse (F^O, F^S), a vector of purchased farm inputs (X), human capital characteristics (H^O, H^S), observed farm specific characteristics (Z_F) (area, quality of land, soil, livestock, etc., meteorological conditions, distance to markets and food processing factories, etc.), as well as unobserved heterogeneity in the technology of the farm etc., a_Q. While off-farm wages are assumed to be independent of the number of hours worked, the marginal returns to farm labour are assumed to be diminishing. The production function representing these technical constraints is assumed to be strictly concave and to have the form

$$(5) \qquad Q = f(F^O, F^S, X, H^O, H^S, Z_F, a_Q), \quad f'_{Fi} > 0, \; f'_X > 0 \quad (i = O, S),$$

where F^O and F^S are not perfect substitutes.

The Lagrangian of the farm couple's decision problem with respect to inputs, consumption, leisure, and labour supply, subject to $F^i \geq 0, \; M^i \geq 0, \; L^i \geq 0 \; (i = O, S)$, is

$$\begin{aligned}(6) \qquad \mathcal{L} &= \mathcal{L}(C, L^O, L^S, M^O, M^S, F^O, F^S, X, a_U, a_Q) \\ &= U(C, L^O, L^S, H^O, H^S, Z_H, a_U) \\ &\quad - \textstyle\sum_i \lambda_i [F^i + M^i + L^i - T] \\ &\quad - \textstyle\sum_i \mu_i [-F^i] - \sum_i \eta_i [-M^i] - \sum_i \xi_i [-L^i] \\ &\quad - \gamma [C + RX - Pf(F^O, F^S, X, H^O, H^S, Z_F, a_Q) - \textstyle\sum_i W^i M^i - V],\end{aligned}$$

where $\sum_i$ means $\sum_{i \in (O,S)}$ and $\lambda_i, \mu_i, \eta_i, \xi_i \, (i = O, S)$, and γ are Lagrange multipliers associated with the nine constraints. Since $U(\cdot)$ and $f(\cdot)$ are concave, $\mathcal{L}(\cdot)$ is concave and we therefore know from the Kuhn-Tucker conditions that the solution determined by setting all its first-derivatives equal to zero, solves the farmers' optimization problem, provided that $\gamma > 0,\ \lambda_i > 0,\ \mu_i \geq 0,\ \eta_i \geq 0,\ \xi_i \geq 0$ at the solution point. Complementary slackness implies $\mu_i = 0$, $\eta_i = 0$, and $\xi_i = 0$ when $F^i > 0$, $M^i > 0$, and $L^i > 0$ $(i = O, S)$, respectively. [See, *e.g.*, Sydsæter, Strøm and Berck (1999, p. 97).] Differentiation of $\mathcal{L}$ with respect to $C, L^O, L^S, M^O, M^S, F^O, F^S, X$, respectively, gives the eight first-order conditions

$$W^i = \frac{\lambda_i - \eta_i}{\gamma}, \quad Pf'_{Fi} = \frac{\lambda_i - \mu_i}{\gamma}, \quad Pf'_X = R, \quad U'_C = \gamma, \quad U'_{Li} = \lambda_i - \xi_i \qquad (i = O, S),$$

and hence

$$\frac{\lambda_i}{\gamma} = \frac{U'_{Li}}{U'_C} + \frac{\xi_i}{\gamma} = Pf'_{Fi} + \frac{\mu_i}{\gamma} = W^i + \frac{\eta_i}{\gamma} \qquad (i = O, S). \tag{7}$$

With respect to the time-use variables, four cases are of interest:

Case 1. All variables strictly positive: If F^i, L^i, and M^i are all strictly positive at optimum, we can set $\xi_i = \eta_i = \mu_i = 0$, to obtain

$$\frac{U'_{Li}}{U'_C} = Pf'_{Fi} = W^i \qquad (i = O, S). \tag{8}$$

Then the off-farm wage rate coincides with both the marginal productivity of labour in the farm, Pf'_{Fi}, and the marginal valuation of leisure expressed in consumption units.

Case 2. Zero solution for off-farm work: If F^i and L^i are positive and $M^i = 0$ at optimum, we have $\xi_i = \mu_i = 0,\ \eta_i > 0$, and hence

$$\frac{U'_{Li}}{U'_C} = Pf'_{Fi} = W^i + \frac{\eta_i}{\gamma} \qquad (i = O, S). \tag{9}$$

In this case, $L^i + F^i = T$, $Pf'_{Fi} > W^i$, so that there is a wedge, equal to η_i/γ, between the marginal productivity of labour in the farm and the off-farm wage rate. The off-farm wage rate is smaller than the reservation wage rate, Pf'_{Fi}.

Case 3. Zero solution for on-farm work: If M^i and L^i are positive and $F^i = 0$ at optimum, then $\xi_i = \eta_i = 0,\ \mu_i > 0$, and we obtain

$$\frac{U'_{Li}}{U'_C} = W^i = Pf'_{Fi} + \frac{\mu_i}{\gamma} \qquad (i = O, S). \tag{10}$$

In this case, $L^i + M^i = T$, $W^i > Pf'_{Fi}$, so that there is a wedge, equal to μ_i/γ, between the off-farm wage rate and the marginal productivity of labour in the farm. The off-farm wage rate is larger than the reservation wage rate, Pf'_{Fi}.

Case 4. Zero solution for leisure: If F^i and M^i are positive and $L^i = 0$ at optimum, we have $\eta_i = \mu_i = 0,\ \xi_i > 0$, and hence

$$(11) \qquad W^i = Pf'_{Fi} = \frac{U'_{Li}}{U'_C} + \frac{\xi_i}{\gamma} \qquad (i = O, S).$$

In this case, $F^i + M^i = T$, $W^i > U'_{Li}/U'_C$, so that there is a wedge, equal to ξ_i/γ, between the off-farm wage rate, which is equal to the value of the marginal productivity of labour in the farm, and the rate of substitution between leisure and consumption. The off-farm wage rate exceeds the marginal valuation of leisure expressed in consumption units.

3 The case with positive solution values for all variables. Recursive model

Consider first, as a benchmark case, the case where the optimization leads to positive boundary solutions for all endogenous variables, *i.e.*, *case 1*. The 12 equations in (2)–(5) and (8) determine X, Q, C, L^i, F^i, M^i, W^i, as well as λ_i/γ for given V, R, P, H^i, Z_F, Z_H, Z_M, T $(i = O, S)$. Conditional on H^i and Z_M, the off-farm wage rates W^i $(i = O, S)$ can be considered exogenous, as already remarked. Then the full solution can be obtained recursively in four steps as follows:

A. Determination of output and inputs: From (5) and (8) we obtain factor input functions and an output supply function of the form:

$$(12) \qquad X = \Phi_X(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q),$$

$$(13) \qquad F^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) \qquad (i = O, S),$$

$$(14) \qquad Q = \Phi_Q(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q).$$

B. Determination of income: Eliminating M^O, M^S from (3) by using (2), and letting

$$(15) \qquad Y = PQ - RX + V + W^O(T - F^O) + W^S(T - F^S)$$

where $W^O F^O$ and $W^S F^S$ represent the imputed opportunity labour cost when working on-farm instead of off-farm, and Y represents 'full income' spent on consumption and leisure, we can write the household's pecuniary budget constraint as

$$(16) \qquad C + W^O L^O + W^S L^S = Y.$$

Since all variables after the equality sign of (15), and hence Y, are either exogenous or determined in step A, *i.e.*, from (12)–(14), we can write

$$
\begin{aligned}
Y = {} & P\Phi_Q(P,R,W^O,W^S,H^O,H^S,Z_F,a_Q) - R\Phi_X(P,R,W^O,W^S,H^O,H^S,Z_F,a_Q) \\
& + V + (W^O{+}W^S)T - W^O\Phi_{FO}(P,R,W^O,W^S,H^O,H^S,Z_F,a_Q) \\
& - W^S\Phi_{FS}(P,R,W^O,W^S,H^O,H^S,Z_F,a_Q) \\
= {} & \Psi_Y(P,R,W^O,W^S,H^O,H^S,V,T,Z_F,a_Q),
\end{aligned} \tag{17}
$$

where $\Psi_Y(\cdot)$ is defined by the last equality, and consider 'full income' Y as predetermined when solving the consumption-leisure optimization problem.

C. Determination of consumption and leisure: Combining (8) and (16) we obtain demand functions for consumption and leisure of the form:

$$C = \Phi_C(W^O,W^S,H^O,H^S,Y,Z_H,a_U), \tag{18}$$

$$L^i = \Phi_{Li}(W^O,W^S,H^O,H^S,Y,Z_H,a_U), \qquad (i=O,S). \tag{19}$$

D. Determination of off-farm labour supply. Combining (2), (13), and (19) we get the following supply functions for off-farm labour

$$
\begin{aligned}
M^i &= T - \Phi_{Fi}(P,R,W^O,W^S,H^O,H^S,Z_F,a_Q) - \Phi_{Li}(W^O,W^S,H^O,H^S,Y,Z_H,a_U) \\
&= \Phi_{Mi}(P,R,W^O,W^S,H^O,H^S,Y,Z_F,Z_H,T,a_U,a_Q).
\end{aligned} \tag{20}
$$

where $\Phi_{Mi}(\cdot)$ is defined by the last equality. Note that labour supply is affected by the latent heterogeneity in both preferences and production technology, represented by the arguments a_U and a_Q. In this case, *the positive off-farm labour supply is determined residually, as the number of hours left when on-farm hours and leisure have been chosen* in steps A–C.

4 Cases with boundary solutions

We next describe modifications of the on-farm and off-farm labour supply functions (13) and (20) and of the leisure demand function (19) when, respectively, off-farm work, on-farm work or leisure is censored. As a common term for these variables we use *time allocation, or time use, variables.* We first describe the deterministic version of the problem and discuss its stochastic specification in Section 5.

The primary case: Off-farm hours censored

Assume that utility maximization, as described in Section 2, leads to *a boundary solution to at least one of M^O and M^S*. Then the Kuhn-Tucker conditions obtained from (9) lead to $F^i + L^i = T$ for either $i = O$ or $i = S$, *i.e.*, $\eta_O > 0$ or $\eta_S > 0$. In this case, the optimal time allocation has to be solved within a *non-recursive* equation system consisting of Equations (2)–(5) and (9). The problem of translating this theoretical framework to a stochastically specified econometric model can be met in different ways. Huffman and Lange (1989), when considering this case, propose a solution which seems somewhat *ad hoc*, by saying "The model is recursive.... This four-equation system is modified *to permit structural changes caused by binding non-negativity constraints*" [Huffman and Lange (1989, p. 473), our italics]. Their interpretation of the term 'structural change' is not clear to us. It obviously departs from the way the term is used in classical econometrics, see *e.g.*, Marschak (1953, Section 5) and Koopmans and Hood (1953, p. 133). See also Greene (2003, Chapter 7). Our econometric model version also focus on the two off-farm labour supply functions, but otherwise, the approach is different.

If at least one of the operator's and the spouse's off-farm labour supply as determined by (20) are non-positive, they can be said to represent *virtual* off-farm labour supply. We furnish the virtual time allocation variables with tildes and let their actual values be non-tilded. From (13), (19), and (20) we obtain the virtual on-farm labour supply, leisure, and off-farm labour supply, respectively, as

$$\begin{aligned}
&\widetilde{F}^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&\widetilde{L}^i = \Phi_{Li}(W^O, W^S, H^O, H^S, \widetilde{Y}, Z_H, a_U) > 0,\\
&\widetilde{M}^i = T - \widetilde{F}^i - \widetilde{L}^i = \Phi_{Mi}(P, R, W^O, W^S, H^O, H^S, \widetilde{Y}, Z_F, Z_H, T, a_U, a_Q) \gtreqless 0.
\end{aligned}$$

Since F^i and L^i are non-censored and M^i is censored from below, the values realised are

$$\begin{aligned}
&F^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&L^i = \Phi_{Li}(W^O, W^S, H^O, H^S, Y, Z_H, a_U) > 0, \qquad\qquad (i = O, S).\\
&M^i = \max[\Phi_{Mi}(P, R, W^O, W^S, H^O, H^S, Y, Z_F, Z_H, T, a_U, a_Q), 0],
\end{aligned} \tag{21}$$

Secondary cases

The above case, where off-farm hours is the only variable subject to censoring for at least one of the two persons, is the one that will be given most attention in the rest of the paper and is the only case to be considered in the empirical application. This kind of boundary solution is also by far the one which is strongest represented in our data set; see Section 6, in particular Tables 3 and 4. We will, however, outline three other cases, to illustrate the generality of the approach.

a. On-farm hours censored. If the optimization leads to *a boundary solution to either* F^O *or* F^S, the Kuhn-Tucker conditions obtained from (10) lead to $M^i + L^i = T$ for either $i = O$ or $i = S$, *i.e.*, $\mu_O > 0$ or $\mu_S > 0$. Therefore optimal time allocation must be solved within an interdependent system consisting of Equations (2)–(5) and (10). From (13), (19), and (20) we obtain the following expressions for virtual on-farm labour supply, leisure and off-farm labour supply, respectively,

$$\begin{aligned}
&\widetilde{F}^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) \gtreqless 0,\\
&\widetilde{L}^i = \Phi_{Li}(W^O, W^S, H^O, H^S, \widetilde{Y}, Z_H, a_U) > 0,\\
&\widetilde{M}^i = T - \widetilde{F}^i - \widetilde{L}^i = \Phi_{Mi}(P, R, W^O, W^S, H^O, H^S, \widetilde{Y}, Z_F, Z_H, T, a_U, a_Q) > 0.
\end{aligned}$$

Since L^i and M^i are non-censored and F^i is censored from below, the values realised are

$$\begin{aligned}
&F^i = \max[\Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q), 0],\\
&L^i = \Phi_{Li}(W^O, W^S, H^O, H^S, Y, Z_H, a_U) > 0, \qquad (i = O, S).\\
&M^i = T - F^i - L^i > 0,
\end{aligned} \tag{22}$$

b. Leisure time censored. If the optimization leads to *a boundary solution to at least one of* L^O *and* L^S (maybe after some fixed constant representing necessary rest, meals, personal service time, etc. has been deducted), the Kuhn-Tucker conditions obtained from (11) lead to $M^i + F^i = T$ for either $i = O$ or $i = S$, *i.e.*, $\mu_O > 0$ or $\mu_S > 0$, and hence the optimal time allocation has to be solved within an interdependent equation system consisting of (2)–(5) and (11). From Equations (13), (19), and (20) we obtain the following expressions for virtual on-farm labour supply, leisure and off-farm labour supply, respectively,

$$\begin{aligned}
&\widetilde{F}^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&\widetilde{L}^i = \Phi_{Li}(W^O, W^S, H^O, H^S, \widetilde{Y}, Z_H, a_U) \gtreqless 0,\\
&\widetilde{M}^i = T - \widetilde{F}^i - \widetilde{L}^i > 0.
\end{aligned}$$

Since F^i and M^i are non-censored and L^i is censored from below, the values realised are

$$\begin{aligned}
&F^i = \Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&L^i = \max[\Phi_{Li}(W^O, W^S, H^O, H^S, Y, Z_H, a_U), 0], \qquad (i = O, S).\\
&M^i = T - F^i - L^i > 0,
\end{aligned} \tag{23}$$

c. Different variables censored for operator and spouse. Assume now that (7) leads to *zero boundary solutions to* M^O *and* F^S, *i.e.*, a kind of *'full specialization'*, where the operator only works on-farm and the spouse only works off-farm. Then the Kuhn-Tucker conditions obtained from (7) lead to $F^O + L^O = M^S + L^S = T$, *i.e.*, $\eta_O > 0$ and $\mu_S > 0$. In this case, the optimal time allocation has to be solved from an interdependent system consisting of Equations (2)–(5) as well as (9) for $i = O$ and (10) for $i = S$. We then get the following virtual time allocation:

$$\begin{aligned}
&\widetilde{L}^O = \Phi_{LO}(W^O, W^S, H^O, H^S, \widetilde{Y}, Z_H, a_U) > 0,\\
&\widetilde{L}^S = \Phi_{LS}(W^O, W^S, H^O, H^S, \widetilde{Y}, Z_H, a_U) > 0,\\
&\widetilde{F}^O = \Phi_{FO}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&\widetilde{F}^S = \Phi_{FS}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) \gtreqless 0,\\
&\widetilde{M}^O = T - \widetilde{F}^O - \widetilde{L}^O \gtreqless 0,\\
&\widetilde{M}^S = T - \widetilde{F}^S - \widetilde{L}^S > 0.
\end{aligned}$$

Since L^O, L^S, F^O and M^S are non-censored and M^O and F^S are censored from below, the actual time allocation is determined by

$$\begin{aligned}
&L^O = \Phi_{LS}(W^O, W^S, H^O, H^S, Y, Z_H, a_U) > 0,\\
&L^S = \Phi_{LO}(W^O, W^S, H^O, H^S, Y, Z_H, a_U) > 0,\\
&F^O = \Phi_{FO}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q) > 0,\\
&F^S = \max[\Phi_{Fi}(P, R, W^O, W^S, H^O, H^S, Z_F, a_Q), 0],\\
&M^O = \max[\Phi_{MO}(P, R, W^O, W^S, H^O, H^S, Y, Z_F, Z_H, T, a_U, a_Q), 0],\\
&M^S = T - F^S - L^S > 0.
\end{aligned} \tag{24}$$

Extensions

Even if our primary interest is on off-farm labour supply, extensions accounting for three or more variables being subject to censoring, may be of interest. We could for instance combine the primary case, case **a** or case **c** with the additional restriction that either the operator or the spouse is also censored with respect to leisure time. Farms which are rationed with respect to non-labour inputs could also be accounted for. Such extensions would, however, lead to stochastic model versions where, for instance, normal distributions of dimension three or higher and, accordingly, higher-dimensional multiple integration, would be involved; see Section 5.

5 Stochastic specification and estimation

All model versions allowing for boundary solutions described in Section 4 contain six specified equations in the six endogenous time allocation variables, $(F^O, F^S, L^O, L^S, M^O, M^S)$, which is a subset of the nine endogenous variables (or variable vectors) in the basic theory-model (when the off-farm wage rates are treated as exogenous). Two of these six time allocation variables are subject to censoring. Our data set does not contain observations on all the nine endogenous variables. Among the unobserved variables are household consumption, C, and non-labour input in farm production, X.

In this section we *operationalise the stochastic version of the equations determining the two variables which are subject to censoring*, leaving the other four equations aside. Specifically, we consider *the two off-farm labour supply functions under censoring*, formalised by the two last equations in (21). We let, for symmetry reasons, the arguments in the functions $\Phi_{MO}(\cdot)$ and $\Phi_{MS}(\cdot)$ be denoted as the vectors x_O (for the operator) and x_S (for the spouse), although they coincide in our application ($x_O = x_S = x$).

The distribution of virtual labour supply

We represent the stochastic version of the two last equations of (21) for our balanced panel data set, comprising H farms and T years, with unobserved household specific heterogeneity allowed for, by

$$\begin{aligned} y^*_{Oht} &= x_{Oht}\beta_O + \alpha_{Oh} + \varepsilon_{Oht}, \\ y^*_{Sht} &= x_{Sht}\beta_S + \alpha_{Sh} + \varepsilon_{Sht}, \end{aligned} \qquad h = 1, \dots, H;\; t = 1, \dots, T, \tag{25}$$

where $(y^*_{Oht}, y^*_{Sht}, x_{Oht}, x_{Sht})$ correspond to $(\widetilde{M}^O, \widetilde{M}^S, x_O, x_S)$ for household h in year t. We consider $(\varepsilon_{Oht}, \varepsilon_{Sht})$ as genuine disturbances, assumed to be *binormally* distributed with zero means, variances $(\sigma^2_{O\varepsilon}, \sigma^2_{S\varepsilon})$, and correlation coefficient ρ. We also consider the household specific effects $(\alpha_{Oh}, \alpha_{Sh})$ as *binormally* distributed with zero means, variances $(\sigma^2_{O\alpha}, \sigma^2_{S\alpha})$, and correlation coefficient θ. These latent household specific effects represent jointly a_U and a_Q in the theory-model, *i.e.*, heterogeneity in the production function of farm h and in the utility function of household h. Formally, $(\alpha_{Oh}, \alpha_{Sh})$ may be interpreted as household specific disturbance components. It follows that $(v_{Oht} = \varepsilon_{Oht}/\sigma_{O\varepsilon}, v_{Sht} = \varepsilon_{Sht}/\sigma_{S\varepsilon})$ and $(v_{Oh} = \alpha_{Oh}/\sigma_{O\alpha}, v_{Sh} = \alpha_{Sh}/\sigma_{S\alpha})$ are binormal with parameters $(0, 0, 1, 1, \rho)$ and $(0, 0, 1, 1, \theta)$, respectively, and density functions

$$\psi(v_O, v_S; r) = \frac{1}{2\pi\sqrt{1-r^2}} e^{-\frac{1}{2}(v_O^2 - 2r\, v_O v_S + v_S^2)/(1-r^2)},$$

where $r = \rho$ for $(v_O, v_S) = (v_{Oht}, v_{Sht})$ and $r = \theta$ for $(v_O, v_S) = (v_{Oh}, v_{Sh})$. The density functions of $(\varepsilon_{Oht}, \varepsilon_{Sht})$ and $(\alpha_{Oh}, \alpha_{Sh})$ can therefore be expressed in terms of the $\psi(\cdot)$ function as, respectively,

$$f_\varepsilon(\varepsilon_{Oht}, \varepsilon_{Sht}) = \sigma^{-1}_{O\varepsilon}\sigma^{-1}_{S\varepsilon}\, \psi(\varepsilon_{Oht}/\sigma_{O\varepsilon}, \varepsilon_{Sht}/\sigma_{S\varepsilon}; \rho), \qquad h = 1, \dots, H,\; t = 1, \dots, T, \tag{26}$$

$$f_\alpha(\alpha_{Oh}, \alpha_{Sh}) = \sigma^{-1}_{O\alpha}\sigma^{-1}_{S\alpha}\, \psi(\alpha_{Oh}/\sigma_{O\alpha}, \alpha_{Sh}/\sigma_{S\alpha}; \theta), \qquad h = 1, \dots, H. \tag{27}$$

It follows, by combining (25) with (26)–(27), that the virtual off-farm labour supplies (y^*_{Oht}, y^*_{Sht}) have joint density function conditional on $(\alpha_{Oh}, \alpha_{Sh})$ and on (x_{Oht}, x_{Sht}), given by

$$g_{y*}(y^*_{Oht}, y^*_{Sht}, x_{Oht}, x_{Sht}; \alpha_{Oh}, \alpha_{Sh}) = f_\varepsilon(y^*_{Oht} - x_{Oht}\beta_O - \alpha_{Oh}, y^*_{Sht} - x_{Sht}\beta_S - \alpha_{Sh}; \rho) \tag{28}$$

This setup can be modified rather easily, to be valid for the three secondary cases, **a**, **b**, and **c**, cf. (22), (23) and (24), *inter alia*, by reinterpreting y_O, y_S, x_O, x_S. We will not, however, implement these alternative model versions in the empirical part of the paper.

A remark on the interpretation of the two sets of disturbance components in (25) is in order. The genuine disturbances, and to some extent also the farm specific effects, capture errors in the optimization, for instance imperfect fulfillment of the marginal conditions (7), as well as other errors the farm couples make when solving their decision problems [see McElroy (1987) for a careful discussion of such issues in a general neo-classical production model context]. They may also represent the simplifications and omissions the econometricians commit when attempting to trace the farm couples' decision process, say treating the coefficient vectors (β_O, β_S) as common to all households, neglecting imperfect measurements and unmeasurable variables, etc. One obvious simplification also is linearisation of the functions $\Phi_{Mi}(\cdot)$; cf. (20) and (21).

Censoring and likelihood function

It is convenient to define the following four off-farm *labour participation regimes:*

Regime 11:	Both O and S participate:	$y_{Oht} > 0, y_{Sht} > 0,$
Regime 10:	Only O participates:	$y_{Oht} > 0, y_{Sht} = 0,$
Regime 01:	Only S participates:	$y_{Oht} = 0, y_{Sht} > 0,$
Regime 00:	Neither O nor S participates:	$y_{Oht} = 0, y_{Sht} = 0.$

The censored values of (y^*_{Oht}, y^*_{Sht}), *i.e.*, the actual off-farm labour supply of the operator and spouse, can then be written as, respectively,

$$
\begin{aligned}
y_{Oht} &= \max[x_{Oht}\beta_O - \alpha_{Oh} - \varepsilon_{Oht}, 0], \\
y_{Sht} &= \max[x_{Sht}\beta_S - \alpha_{Sh} - \varepsilon_{Sht}, 0].
\end{aligned} \tag{29}
$$

The panel data design apart, this bivariate model is related to the 'Type 3 Tobit model', according to Amemiya's typology, see Amemiya (1985, Section 10.8). In the latter, however, one of the two variables determines the censoring of both variables. We first condition on the values of the household specific effects $\alpha_O = (\alpha_{O1}, \ldots, \alpha_{OH})$, and $\alpha_S = (\alpha_{S1}, \ldots, \alpha_{SH})$. The *conditional likelihood functions of household h* in the four regimes for year t are symbolised by $\mathcal{L}_{11ht}(\alpha_{Oh}, \alpha_{Sh})$, $\mathcal{L}_{10ht}(\alpha_{Oh}, \alpha_{Sh})$, $\mathcal{L}_{01ht}(\alpha_{Oh}, \alpha_{Sh})$, and $\mathcal{L}_{00ht}(\alpha_{Oh}, \alpha_{Sh})$, respectively, Using (28) and integrating $g_{y^*}(\cdot)$ over the ranges relevant for the respective regimes, we then obtain the 'regime specific' conditional likelihood functions:

$$
(30)\quad
\begin{aligned}
\mathcal{L}_{11ht}(\alpha_{Oh},\alpha_{Sh}) &= g_{y*}(y_{Oht},y_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh}),\\
&= g_{11}(y_{Oht},y_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh}),\\
\mathcal{L}_{10ht}(\alpha_{Oh},\alpha_{Sh}) &= \textstyle\int_{-\infty}^{0} g_{y*}(y_{Oht},y^*_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh})dy^*_{Sht}\\
&= g_{10}(y_{Oht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh}),\\
\mathcal{L}_{01ht}(\alpha_{Oh},\alpha_{Sh}) &= \textstyle\int_{-\infty}^{0} g_{y*}(y^*_{Oht},y_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh})dy^*_{Oht}\\
&= g_{01}(y_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh}),\\
\mathcal{L}_{00ht}(\alpha_{Oh},\alpha_{Sh}) &= \textstyle\int_{-\infty}^{0}\int_{-\infty}^{0} g_{y*}(y^*_{Oht},y^*_{Sht},x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh})dy^*_{Oht}dy^*_{Sht}\\
&= g_{00}(x_{Oht},x_{Sht};\alpha_{Oh},\alpha_{Sh}),
\end{aligned}
$$

where the functions $g_{11}(\cdot)$, $g_{10}(\cdot)$, $g_{01}(\cdot)$, $g_{00}(\cdot)$ are defined by the last equalities. In these functions, $\beta_O,\beta_S,\sigma_{O\varepsilon},\sigma_{S\varepsilon}$ occur as parameters.

Since all realizations from the H farms are independent, we can write the likelihood function of $(y_{Oht},y_{Sht}),\ h=1,\dots,H,\ t=1,\dots,T$, still conditional on the latent household specific effects, as follows:

$$
(31)\quad \mathcal{L}(\alpha_O,\alpha_S)=\prod_{h=1}^{H}\Bigg(\prod_{t:\,\text{Regime }11}\mathcal{L}_{11ht}(\alpha_{Oh},\alpha_{Sh})\prod_{t:\,\text{Regime }10}\mathcal{L}_{10ht}(\alpha_{Oh},\alpha_{Sh})\times\prod_{t:\,\text{Regime }01}\mathcal{L}_{01ht}(\alpha_{Oh},\alpha_{Sh})\prod_{t:\,\text{Regime }00}\mathcal{L}_{00ht}(\alpha_{Oh},\alpha_{Sh})\Bigg),
$$

where $\prod_{t:\,\text{Both}}$, $\prod_{t:\,\text{OnlyO}}$, $\prod_{t:\,\text{OnlyS}}$, and $\prod_{t:\,\text{Neither}}$ indicate products taken over the observations which belong to the specific regimes. Integrating out the conditioning variables, whose distributions are characterised by $\sigma^2_{O\alpha}$, $\sigma^2_{S\alpha}$ and θ, we finally obtain the marginal likelihood function:

$$
(32)\quad \mathcal{L}=\prod_{h=1}^{H}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\Bigg(\prod_{t:\,\text{Regime }11}\mathcal{L}_{11ht}(\alpha_{Oh},\alpha_{Sh})\prod_{t:\,\text{Regime }10}\mathcal{L}_{10ht}(\alpha_{Oh},\alpha_{Sh})\times\prod_{t:\,\text{Regime }01}\mathcal{L}_{01ht}(\alpha_{Oh},\alpha_{Sh})\prod_{t:\,\text{Regime }00}\mathcal{L}_{00ht}(\alpha_{Oh},\alpha_{Sh})\Bigg)f_\alpha(\alpha_{Oh},\alpha_{Sh})\,d\alpha_{Oh}\,d\alpha_{Sh}.
$$

This function, or simpler its logarithm, is to be maximised with respect to β_O, β_S, $\sigma^2_{O\varepsilon}$, $\sigma^2_{S\varepsilon}$, ρ, $\sigma^2_{O\alpha}$, $\sigma^2_{S\alpha}$, and θ.

This model setup can be substantially simplified if $\theta=\rho=0$, since $\psi(v_O,v_S;0)$ can be factorised into $\phi(v_O)\phi(v_S)$, where $\phi(\cdot)$ is the density function of the standardised univariate normal distribution, so that (26)–(28) and (30)–(32) get corresponding multiplicatively separable (and the log-likelihood function additively separable) forms. Although zero cross-equation correlation is often assumed between disturbances in binary Tobit models, such a simplification may not seem realistic in the present context, partly owing to common omitted variables in the vectors of explanatory variables (x_{Oht},x_{Sht}), and partly for the reason that the virtual labour supply of the two persons, (y^*_{Oht}, y^*_{Sht}) are determined as parts of the same optimization problem.

The secondary cases, with on-farm hours censored, leisure time censored, and different variables censored for operator and spouse, can be accommodated to this model setup by changing the interpretations of $(x_{Oht}, x_{Sht}, y^*_{Oht}, y^*_{Sht})$ and the functions (25)–(28) accordingly.

Estimation and software

The software used in the numerical solution is LIMDEP Econometric Software, Version 8.0; see LIMDEP (2002). This package offers a number of pre-programmed estimation and test routines for various model setups, although none that permit estimation of bivariate censoring models for panel data with random heterogeneity, like the one considered here. Taking account of the limitations of this software, we have therefore, , in the empirical implementation, confined attention to two special versions of the general setup above: (i) *two separate univariate* censoring models *with random farm-specific heterogeneity in the intercepts*, corresponding to $\rho = \theta = 0, \sigma^2_{O\alpha} > 0, \sigma^2_{S\alpha} > 0$ [see LIMDEP (2002, Section E21.5)] and (ii) *one bivariate* censoring model *without farm-specific heterogeneity*, corresponding to $\rho \neq 0,\ \theta = \sigma^2_{O\alpha} = \sigma^2_{S\alpha} = 0$ [see LIMDEP (2002, Section E21.4.3)].

6 Data

Sources

The data are mainly obtained from an annual survey of Norwegian farm households (Account Results in Agriculture and Forestry) collected by the Norwegian Agricultural Economics Research Institute (Norsk institutt for landbruksforskning, NILF). This is one of the more comprehensive sources of farm statistics in Norway and dates back to the beginning of the 20th century, and has since 1950 included approximately 1000 farm households, representing different regions and agricultural products (grain, dairy, livestock, etc.). Participation in the survey is voluntary, but restricted to farmers younger than 67 years of age (retirement age) and to farm households working at least 400 on-farm hours annually. Farms that produce both grain and swine products, and dairy farms (pure dairy farms or dairy in combination with livestock production) have the highest representation both in absolute numbers and relative to the total population. Most farm households in the survey report between 1800 and 6000 on-farm work hours yearly, while a standard man-labour year in the agricultural sector is set to 1875 hours. The survey consists of management accounts drawn from tax accounts and additional information about the use of farmland, yields obtained and labour input. Approximately 20 per cent of the farm units are also involved in a separate survey of accounts for farm forestry.

This *panel data set* is rotating. Between five and ten percent of the panel is replaced each year, most commonly because of refusal to continue participation. The data collectors follow no specific rule used when including replacement households. A primary aim is to enter respondents who hold more or less the same characteristics (with respect to region, size, and production) as those exiting, in order to preserve its 'representativeness'.

This survey is the most elaborate source of information on Norwegian farm households' financial matters both in a regional and a production type of context. Daily or weekly *labour hours* are reported for all household members, family members, and hired help and in all kind of employment. On-farm labour compensation, corrected for holiday allowances and social security payments, is calculated from the cost of hired help. *Off-farm income* is divided into wage income and other income. The survey also includes data on the total area of cultivated land and the division of land into different uses and the yield of and income from different agricultural crops, fruit, garden berries, and vegetables. To allow calculation of prices obtained from farm sales, the turnover from all farm products are registered. Also the households' consumption of own production is registered. The input cost is reported for each input. Finally, the survey includes information on detailed balance sheets and profit and loss accounts for all households, including production grants, interest and tax payments, and investment grants. The data set does not, unfortunately, contain sufficient information on personal characteristics such as education, or any information about characteristics of the local labour market in different regions. In other empirical investigations, *e.g.*, Huffman (1980) and Weersink (1992), these variables have been found to be important in explaining farmers' off-farm labour supply.We have been able to include some of the relevant information from other data sources, mainly by merging the survey data with official statistics.

Sample selection

Selectivity problems may be present in the data we utilize in our analysis. Participation in the 'Account results' survey is voluntary and it requires a minimum of 400 on-farm annual work hours. For this reason, we may suspect that the households included in the sample are more dedicated than those who do not enter the survey. It is thus possible that the survey does not fully reflect the structural changes in the industry because the farm households that are most likely to exit farming are not included. Selectivity bias may also occur from the fact that the unit of analysis is *farm couples* and not *farm units.* This implies that we have to exclude all farm units where there has been a (generational) change in farm management during the ten year period, and also all farm units where the operator has no partner. The selectivity criteria leave us with a balanced panel of 342 households to be included in the analysis. The remaining sample is, however, representative of the survey farms with respect to factors as location, production composition, and farm size.

The selected sample contains a few outliers which we have reason to believe is measurement error in the narrow sense. A total of four annual observations on off-farm labour hours and off-farm wage for four different individuals differ substantially from those observed for the same individuals in the other nine years. When replacing these extreme observations on off-farm hours with the mean value for the other nine years, we also obtain reasonable values for wage rates. We have thus changed the values for these four individuals. Other outliers remain.

Definitions

Most of the farm operators report off-farm work in at least some years, but a closer look at the data reveals than many supply only a marginal number of hours. As we will see from the following tables, more than 80 per cent of all farm operators work less than 500 hours per year in off-farm sector. Of these, only 40 per cent work more than a standard labour week. As much as 35 per cent of the whole sample work between 0 and 37.5 hours annually. The finding is not surprising because it is well known that many farmers take on small commissions, *e.g.*, from neighbours (road mending, snow clearing, holiday relief), for which price taking behaviour may not provide a good description, although measurement errors may also be an explanation. Whatever the reason, the high proportion of farm operators working only a few off-farm hours challenges the postulated symmetric distribution of the disturbance terms, cf. Equations (26)–(28), and therefore has an undesirable effect on the results of the econometric analysis . For this reason, we have decided to *define working off the farm as working more than 37.5 annual hours*, which equals one standard labour week. Operators working less than one week off the farm, are defined as not working off-farm. The problem concerning few reported off-farm hours is not equally present for spouses, but we choose the same definition of off-farm work for both operator and spouse. The wages rates W^O (for operator) and W^S (for spouse) are calculated by dividing net yearly off-farm income by hours worked and then deflated by the consumer price index (1998=100).

7 A descriptive analysis

Descriptive statistics for exogenous variables

The dependent variables in the econometric implementation of the model, is off-farm labour hours for operator and spouse, M^O and M^S, respectively. They are measured in annual hours. The four mutually exclusive labour regimes, as defined in Section 5, are

Regime 11 where both operator and spouse participate in off-farm work, Regime 10 where only operator participates in off-farm work, Regime 01 where only the spouse participates in off-farm work and, finally, Regime 00 where neither participates in off-farm work. When compiling the descriptive statistics for the exogenous variables, in Tables 2–4, we let the households be grouped according to these regimes in order to better illustrate structural changes over time. Among the descriptive statistics below are tables showing annual distribution of farms by labour regimes and number of transitions between regimes.

The vector of explanatory variables for off-farm labour supply, cf. Equation (21), consists of four categories of variables: *household specific characteristics* (Z_H), that enter the household's utility function, Equation (1), *human capital characteristics* (H^O,H^S), that enter both the utility function and the production function, Equation (5), *farm specific characteristics*, Z_F, that enter the production function, and *local labour market variables*, Z_M, that enter the wage function, Equation (4). Strictly, we should not include local labour market variables among the explanatory variables because their effect of these variables is reflected through the market wage rate. Even so, we have included one such variable, namely a centrality dummy as a proxy for commuting distance (COMMUTE). This is the only regional variable included in the analysis and could alternatively be included in the household s utility function (Equation (1)) or even the production function (Equation (5)). We believe that centrality in location may be of direct importance for the decision making process, at least for off-farm work hours [cf. Bjørnsen and Johansen (2006)]. The variables included in the analysis and their precise definitions, are given in Table 1.

As household specific variables, we have included age (AGE) and its square (AGESQU) for operator and spouse, and number of children in age groups 0–5 years (CHILD6) and 6–16 years (CHILD16). Compulsory schooling (in Norway) lasts the ten years from age 6 to 16, while children younger than 6 are nursed at home, in kindergarten or in other private care. From Table 2A we see that average age is 44 years for operators and 42 years for spouses, with no obvious variation across labour regimes. The average number of small children is 0.3, and of school-aged children 0.8. The number of small children is highest for households in Regime 00, for which we also find the youngest farm couples, on average.

The vector of human capital characteristics consists of the operator's and spouse's level of education. We distinguish between compulsory education only (COMEDU), upper secondary education (SECEDU), higher education (HIGHEDU) and agricultural education (AGREDU). The first three, mutually exclusive, categories are represented by dummies with upper secondary education as default category. The dummy for agricultural education is independent of the other three and takes the value one if an individual has agricultural or other relevant education at secondary or higher level. We see from Table 2A that more spouses than operators have higher education. On average 22 per cent of all spouses and nine per cent of all operators have higher education. It is particularly in Regimes 11 and 01, where spouses participate in off-farm work, that we find a high proportion of highly educated spouses. In Regime 00, where neither works off-farm, only six per cent of both operators and spouses have higher education. Farming in Norway is typically a family industry where the farm is passed down from parents to child. We see that the majority of farm operators choose education that is relevant to farming. On average, 66 per cent of all operators have agricultural education and the relative number is higher in Regime 00, and lower in Regime 11. Only ten per cent of the spouses in the data set have agricultural education.

Among the farm specific characteristics, we have included a dummy for dairy production (DAIRY), as well as farm size in acres (FARMSIZE) and net financial income (INTDIFF). Dairy production is the most important produce on the farm, but not necessarily the only farm produce. Almost 60 per cent of all farm units in the sample are dairy farms. The proportion of dairy farms is higher in Regime 00 and lower in Regime 11, where both operator and spouse have off-farm jobs. The reason why we distinguish between dairy and all other farm produce is because dairy production is supposed to be particularly labour intensive. Dairy cows need attendance at regular hours several times per day and for this reason it may be particularly difficult to combine dairy farming with an off-farm job. Farm size is tillable acreage. Outlying fields are not included. Farm size is another variable that may say something about labour input required on the farm, but the relation is not unambiguous. A priori, we assume positive correlation between farm size and labour input, but large farms are often grain producing and thus not very labour intensive throughout the year. From official statistics we know that a substantial proportion of all grain farms are located near medium sized or large cities and that grain farmers often work off the farm. On the other hand, large farms often generate high incomes and consequently high reservation wages. Net financial income is measured as the difference between interest earned on assets and interest paid on debts. On average, the farm households have higher debts than assets and average net financial income is -36 000 NOK. The INTDIFF-variable may indicate investment level on the farm and thus of stage in life cycle or dedication to farming. The intdiff-variable may also indicate the farm couple's need of liquid assets and consequently their preferences for off-farm work and income diversification.

The only local labour market characteristic included is a dummy for commuting distance (COMMUTE), taking the value one if the farm unit is located within one hour travel distance from a city counting at least 15 000 inhabitants. From Table 2B we see that approximately half the sample is located within commuting distance of a larger city.

Households in Regime 00 are, on average, less centrally located. As mentioned above, local labour market characteristics are assumed to be reflected in market wages. From Table 2A we see that average wage rate does not vary much between labour regimes and that operators, on average, obtain slightly higher wages than spouses.

The vector of explanatory variables included in the econometric model version is consistent with the off-farm labour supply functions in the theoretical model, Equation (21), except that we have omitted output prices. Because the demand and supply functions are homogeneous of degree zero and consumer prices can be normalised to 1, this omission may create a bias if the relative prices of input, output and consumption actually change over the observation period. We could have captured the effect of relative input and output prices by including a time specific dummy variable in the econometric model but it is not obvious how to generate a feasible price vector when both factors and prices are negotiated centrally (politically determined) and prices vary with production quantities. To avoid complicating the estimations further, we have thus decided to omit factor prices which are, anyway, of second order to the estimation problem. This means that we will not be able to directly observe how factor prices affect off-farm labour supply.

Table 5 reports results of a decomposition of selected variables which vary both across farms and over years, as well as the on-farm and off-farm labour supplies, into 'between farm' and 'within farm' variation. These measures indicate the relative importance of the cross-sectional and the time-serial variation of the $NT = 3420$ observations, respectively. More than 90 per cent of the overall panel data variation in the dairy dummy and the farm size indicator is between-farm (household) variation. About 80 percent of the variation in the *on-farm* labour supply is between-farm variation for both operator and spouse and about 80 percent of the variation in the *off-farm* labour supply is between-farm variation, whereas the same statistic for the spouse is lower, 75 per cent. On the other hand, the between-farm variation accounts for less than half of the overall variation in the off-farm wage rate variables, 36 per cent for the operator and 46 per cent for the spouse. Not surprisingly, there is relatively smaller between-farm variation in the number of children below 6 years of age than for the older children.

Descriptive statistics for labour supply

Farm operators work more hours in total than their spouses. From Table 3A we see that operators work more than 2300 hours annually and, on average, they work more than a standard man labour year on the farm which was 1875 annual hours during the observation period. The spouses work less than a man-labour year in all years, but increase their labour supply by 20 per cent from 1991 to 2000. Operators spend a small, but increasing amount of their time in off-farm labour, but still spend 86 per cent of their total working hours on the farm in 2000. This is 3.4 percentage points less than in 1991, as shown in Table 3B. Spouses, on average, divide their time more evenly between on- and off-farm labour, but reduce their on-farm hours somewhat during the observation period while off-farm hours increase by almost 60 per cent, or 14 percentage points.

Table 3C reports average annual hours for all operators and spouses who supply a strictly positive number of off-farm hours and Table 3D reports the sub-sample of at least 37.5 off-farm hours, *i.e.*, the threshold we define for off-farm participation. We see that the average number of off-farm hours increases from 287 annual hours in Table 3A to 344 hours in Table 3C, and 573 hours in Table 3D for operators. The great leap from Tables 3C to 3D means that a substantial number of operators work only few off-farm hours. We see that [(3420-2894)/3420=] 15 per cent of all operators work zero off-farm hours and [(2894-1711)/3420=] 34 percent work a positive amount of hours, but less than 37.5 annual hours. For spouses, the picture is somewhat different. The difference in average annual off-farm hours from Table 3A to 3C and 3D give evidence that many spouses supply zero off-farm hours (45 per cent), while only a few work less than 37.5 hours (seven per cent).

In Table 4, we report annual work hours by labour regime. As mentioned above, the farm operators in the sample supply a large number of working hours, particularly on the farm, but increasingly also in off-farm labour. Operators that work off-farm, supply less on-farm hours than those who only work on the farm, but off-farm working operators supply more working hours in total. Operators in Regime 00 are the only ones who have reduced total working hours during the ten years. The largest increase in work hours is among operators in Regime 10, while operators in Regime 01 are the only ones who have increased the number of on-farm hours. The overall trend is that on-farm hours decrease for both operators and spouses. Farm spouses work more than twice as many hours as operators in off-farm sector, but supply only 25 per cent as many on-farm hours. The global means show that spouses work almost as much on-farm as off-farm, but when we divide the data set into sub-samples according to labour regimes, we see that the spouses with off-farm jobs work far more in off-farm sector. We find the largest increase in number of total working hours among spouses in Regime 00. Within this regime, spouse more than compensate for the decrease in operators on-farm hours.

Table 6 shows the annual distribution of farms by labour regime. We see that the farm households are evenly distributed between the four labour regimes in 1991. The most obvious changes during the ten-year period is the increase in Regime11-households (+12.3 percent) and the simultaneous drop in Regime 00-households (-9.4). More spouses than operators work off-farm during all years and we also see that the proportion of spouses working off-farm increases at a higher rate than for operators. Although the number of operators who work off-farm increases by 10 per cent (5 percentage points) from 1991 to 2000, the proportion of Regime 10-households falls by 7.3 per cent during the same time span. This, in combination with the increase in the number of Regime 01-households indicates that there still is a movement of spouses (women) into the labour market.

Transitions between labour supply regimes – a description

It is interesting, before presenting the econometric results and pointing out explanatory mechanisms, to give an overview of some of the labour-market transitions which have taken place during the sample period, according to our balanced panel data set. Tables 7 through 10 display, in various ways, the transitions of the $N = 342$ farms/households between the four labour supply regimes during the $T = 10$ year period of observation. As remarked in the introduction, our sample period, 1991–2000 was characterised by major transitions of the agricultural sector in Norway. The population of farms and farm households have been far from stationary.

Tables 7 and 8 give a rather condensed overview. From Table 7 we see that 64 of the 342 farms, *i.e.*, less than 20 per cent, have stayed in the same regime throughout the entire period. In only 8 farms have both operator and spouse worked fully on-farm during these 10 years, while in 30 farms both have worked off-farm in all the years, in 16 farms the spouse has worked off-farm, but the operator only on-farm throughout the period, while the opposite has been the case for 10 farms. Table 8 shows the number of moves between the regimes from one year to the next. In total, 770 such moves have taken place. This is slightly above 20 per cent of the maximal possible number of moves, *i.e.*, $342 \times 9 = 3762$, which would have occurred if all farm had changed their position every year, the latter being, of course a hypothetical extreme. Of these 770 year-to-year moves, 209 go *from* Regime 11 (Both work off-farm), 251 go *to* Regime 11, *i.e.*, the 'surplus' going into the Regime is 42 farms. There have been 176 moves from Regime 10 (Only operator works off-farm) and 151 in the opposite direction, *i.e.*, the 'surplus' going out of the regime is 25 farms. From Regime 01 (Only spouse works off-farm) 215 farms have moves out, while 230 have gone in, giving a 'surplus' of in-going farms of 15. Finally, from Regime 00 (Neither work off-farm) 170 farms have moved out, while 138 have gone in, giving a 'surplus' of out-going farms of 32. Overall, 11 and 01 emerge as 'net-receiving' regimes and 10 and 00 as 'net-delivering' regimes.

Tables 9 and 10 give more nuances to this overall picture. The four symmetric (10×10) matrices in Table 9 specify the number of farms in each of the four regimes 11, 10, 01, and 00, in all pairs of years in the sample period. From the main diagonals of these matrices, we see that the number of farms in Regimes 11 and 01 has been gradually increasing during the sample period, parallel with a decline for Regimes 10 and 00. These diagonal elements when added across regimes, of course, add to $N = 342$ in each year. An inspection of the off-diagonal entries in Table 9, in particular the corners, are also interesting. For example, while in 126 farms both operator and spouse worked off-farm in the final sample year (2000), only 51 had this characteristic in both the first and final sample years (1991 and 2000). While in 108 farms only the spouse worked off-farm in the last year, only 53 farms had this characteristic in both the first and last years.

Table 10, in four parts (A–D), each having three (10×10) panels, describe the transitions between labour supply regimes more concisely, in the form of one-year, two-year, ..., nine-year *transition rates*. The entries *below* the main diagonal in each of the twelve panels specify, *for all pairs of years* $(t, s: \ t = 2, \dots, T; s = 1, \dots, t)$*, the number of farms relative to the number of farms in year* t for, respectively, the *'receiving regime'* 11, 10, 01, and 00 vis-à-vis all the other *'delivering regimes'*. The entries *above* the main diagonal specify, *for all pairs of years* $(t = 1, \dots, T-1; s = t+1, \dots, T)$*, the number of farms relative to the number of farms in year* t for, respectively, the *'delivering regime'* 11, 10, 01, and 00 vis-à-vis all the other *'receiving regimes'*. Of particular interest may be the north-eastern and the south-western corners of the matrices. From the second and third panels of Table 10.D we see, for example, that the number of farms in Regime 00 in 1991 and Regime 10 in 2000 is 27.8 per cent of the number of farms *in Regime 00 in 1991*, and that the number of farms in Regime 00 in 1991 and Regime 01 in 2000 is 72.9 per cent of the number of farms *in Regime 00 in 1991.* Considering also their counterparts in Tables 10.B, third panel, and Table 10.C, third panel is interesting. These rates, representing the same transitions, differ because of the different normalizations: the number of farms in Regime 00 in 1991 and Regime 10 in 2000 is 19.0 per cent of the number of farms *in Regime 10 in 2000*, and the number of farms in Regime 00 in 1991 and Regime 01 in 2000 is 25.8 per cent of the number of farms *in Regime 01 in 2000*, etc. We have not, however, set out to *model* the transitions by means of, say, a multivariate dynamic system representing both latent and observed heterogeneity as explanatory elements. Although this might have given some new insights, it could not have provided a full answer to our basic problem of modelling the bivariate labour supply in quantitative terms. The model described in Sections 4 and 5, although static and therefore neglecting autoregressive and other lag effects, in our view provides a better overall solution.

8 Estimation and test results

Wage equations

Before analyzing the labour supply of operator and spouse, we must account for the incidental truncation of the market wage rates. Wage rates can only be observed for those participating in off-farm work. For individuals who do not work off the farm, we must assume that the reservation wage rate exceeds the market wage rate, in correspondence with Equation (9). We do, however, observe whether or not an individual participates in off-farm work, *i.e.*, when off-farm hours are greater than zero.

Heckman (1974, 1976) has considered a way of estimating labour supply when wages and hours worked are endogenous variables. The model consists of a market wage equation for which labour hours are positive and the market wage observed, and a shadow wage equation for which hours worked are non-positive and the wage rate is not observed. Heckman assumed that hours of work adjust so that the shadow wage equals the market wage [Maddala (1983, p. 231)]. The first step of the two-stage estimation of Heckmans model is to estimate the probability of observing the wage rate, *i.e.*, the probability of an individual supplying a positive number of labour hours. We then obtain expected values of the truncated residuals. The second stage is to insert these estimates into the original wage equation to predict the wage of those not supplying any labour hours. The predicted wage rates are thus computed from the data of those individuals supplying positive labour hours. The two-stage estimation methods has been wildly applied and extended since Heckmans seminal works [see *e.g.*, Amemiya (1979) and Lee, Maddala, and Trost (1980)].

In order to predict market wage for those not participating in off-farm work, we make use of the Heckman two-stage procedure for sample selection and let the participation decision be the selection mechanism. The procedure is described in Greene (2003, pp. 781-787) and in LIMDEP (2002, pp. E23-38-E23-47). Let the observed participation decision be indicated by

$$z_{iht} = \begin{cases} 1 & \text{if } z^*_{iht} > 0 \\ 0 & \text{otherwise} \end{cases}, \qquad (i = O, S),$$

with the underlying continuous latent variable determined by

$$z^*_{iht} = q_{iht}\delta_i + \nu_{ih} + \zeta_{iht}, \qquad (i = O, S),$$

where q_{iht} is a vector of selected observed personal and farm specific characteristics from the off-farm labour supply function.

The wage equation is given by

$$w_{iht} = s_{iht}\gamma_i + \omega_{ih} + \xi_{iht}, \qquad (i = O, S).$$

where s_{iht} is a vector of observed characteristics relating to human capital and the local labour market. The genuine disturbances (ζ_{iht}, ξ_{iht}) are binormal with zero means, variances $(\sigma^2_\zeta, \sigma^2_\xi)$, and correlation coefficient τ. We consider ω_{ih} as an individual specific random effect. The wage equation is the empirical equivalent to Equation (4) in the theoretical model.

The Heckman procedure goes as follows. First we make a probit estimation of the participation decision, represented by z_{iht}, to find estimates of 'Heckman's lambda', λ_{iht}, for each observation in the selected sample. The probit regression is equivalent to the problem analyzed in Bjørnsen (2006). We then run a 2SLS estimation of the wage rate on s_{iht} and $\widehat{\lambda}_{iht}$, to produce starting values for $\widehat{\gamma}_i$ and $\widehat{\omega}_i$, and finally we use the estimated starting values in a maximum likelihood regression of the wage equation and use the values of the estimated parameters $\widehat{\gamma}_i$ and $\widehat{\omega}_i$ to predict wage rates for those not participating in off-farm work. The estimation results for the wage equations are given in Table 11.

The sample selection-corrected estimation results give evidence of latent heterogeneity in the operator's wage equation. The individual-specific effect is large and positive, with correspondingly high variance. For spouses, the individual effect is close to zero, indicating no unobserved heterogeneity, but instead the true disturbance is extremely large. The negative correlation between the selection equation and the estimation equation may indicate that the model does not fit the data very well for spouses. Moreover, we see that higher education has a significantly negative effect on spouse's wage, a result which, *a priori*, does not seem reasonable. For operators, we find that higher education has a large positive effect on wages, just as we would expect. The regional effects indicate that wages are higher in the eastern region. This also agrees with *a priori* expectations, as the eastern region is the most densely populated part of the country, where the labour market is both larger and more diversified than in other regions.

Labour supply functions

The labour supplies of operator and spouse are estimated separately as well as simultaneously. For the single-equation estimation results, we compare four different model specifications that differ in two respects. Firstly, we distinguish between models with individual specific heterogeneity and models with no heterogeneity. Secondly, we distinguish between censoring and non-censoring of the dependent variable. When including heterogeneity, we compare a censoring model with a generalised regression model, both of which including a random household-specific effect. When accounting for heterogeneity, we compare the censoring model with a standard regression model. The censoring model is described in LIMDEP (2002, Section E21) and the OLS and GLS models in LIMDEP (2002, Chapters E5 and E8). The motivation for comparing different model specifications is to examine what can be gained with respect to bias reduction and increase in explanatory power by increasing the methodological complexity. Initially, we know that least squares regressions are inappropriate because of the large number of the individuals who work zero hours off-farm in one or more years. For the simultaneous estimation of operator and spouse's labour supply, we compare a bivariate censoring model with a SURE-regression.

The SURE model is described in LIMDEP (2002, Chapter E13.2). Unfortunately, we are unable to account for heterogeneity in the simultaneous case because there is no pre-programmed model specification in LIMDEP that supports random effects estimation in these models.

The estimation results of the four univariate estimations of respectively operators' and spouses' off-farm labour supply are given in Table 12. The bivariate estimation results are given in Table 13. When comparing the estimation results of the four model specifications as reported in Table 12, part A for operator and part B for spouse, we find, as we *a priori* expected, that the censoring model accounting for heterogeneity gives the better fit. The least squares estimations are mainly interesting as a benchmark to see what is gained in form of explanatory power by applying a more appropriate model specification. Given heterogeneity, the censored model gives the highest log likelihood value for both operator and spouse, but without heterogeneity, the log-likelihood value of the least squares model actually exceeds that of the censoring model. Even so, we find that a LM-test strongly favours the censoring model above least squares and a LR-test strongly favours random effects above no heterogeneity. The estimated standard deviations of the random effects ($\sigma_{O\alpha}, \sigma_{S\alpha}$) exceed those of the genuine disturbance ($\sigma_{O\epsilon}, \sigma_{S\epsilon}$) for both operator and spouse in the censoring random effects model. As in Bjørnsen (2006), we find larger heterogeneity among spouses than among operators, something we believe is due to operators having common background and principal occupation, while may have nothing other in common than marrying a farmer.

In Bjørnsen (2006), we also found that the operator and spouse's decision to participate in off-farm work was uncorrelated and that their participation probabilities could be estimated separately. From the bivariate censoring model reported in Table 13 we see that correlation between operator and spouse s off-farm labour supply is small also for off-farm labour supply, but here the correlation coefficient is statistically significant. Unfortunately, we are not able to include heterogeneity in the bivariate model, so the univariate random effects censoring models of Table 12 are probably better fitted. We see that the parameter estimates of the no heterogeneity censoring models in Table 13 correspond well with the no heterogeneity censoring models in Table 12. Equivalently, the least squares no heterogeneity estimates in Tables 13 and 12 are almost identical. Our preferred model, the censoring random effects models in the first panel of Table 12, parts A and B, gives somewhat different parameter estimates. We comment the main results of the models in all three tables together.

The general pattern is that off-farm labour supply is concave in own age and convex in spouse's age. This mean that both operators and spouses supply more off-farm hours up to a certain age, from which they start reducing it again. This is what we, *a priori*, would assume. The convex relationship between spouse's off-farm labour supply is not that self-explanatory, but the parameter estimates are typically not statistically significant. There are some exceptions from this pattern in the univariate estimations of operator's labour supply. From Table 12, part A we see that operator's own age effect is convex, with significant parameter estimates in the random effects Tobit model and that operator's off-farm labour supply is concave in spouse's age in three of the four estimations. In the univariate models, we see from Table 12, part B that spouses' own age effect is stronger than for operators, particularly in the random effects Tobit model. The marginal effect on off-farm labour supply of ageing one year is 178 more work hours for spouses and 34 fewer work hours for operators in the random effects Tobit model. From Table 13 we see that the estimates are more even between the operators and the spouses when based on the bivariate model versions. According to the censoring model, operators increase their labour supply with 112 hours and spouses with 93 hours when growing one year older. In the no-censoring model the effects are smaller.

The effect of own education agrees with *a priori* expectations. Compared with the default group of upper secondary education, both operators and spouses work more off-farm hours if they have higher education, and fewer hours if they only have completed compulsory education. The cross effects are, on the other hand, opposite for operators and spouses. Operators work more hours off-farm if the spouse have higher education and less hours if the spouse have compulsory education, while spouses work more if operator has compulsory education and less if operator has higher education. One interpretation of this result may be that the household income effect dominates over the substitution effect for spouses, while the opposite is the case for operators. It is possible that this reflects persistence of traditional gender roles. Spouses' (especially wives') motivation for working off-farm would then be to increase household income rather than reflecting ambitions of having an own professional career. When the operator (husband) has higher education and, presumably, a well-paid off-farm job, the spouse can spend more time on family matters, but when the spouse (wife) has higher education, the operator (husband) works more off-farm hours. In the univariate random effects Tobit model, in Table 12, the effect of spouse's higher education is in fact larger than the effect of own education for operator's off-farm labour supply. It thus seems that different mechanisms may be at work in the labour supply decisions of operator and spouse. The effect of own education on off-farm labour supply is generally larger for spouses than for operators. This result is as we would expect because off-farm work is supposed to be the primary occupation of spouses and the secondary occupation of operators. The exception is agricultural education for which the negative effect on off-farm labour supply is almost twice as large for operators than for spouses. The parameter estimates of own education is statistically significant in all models. These results supplement Table 2, which gives overall sample means of labour supply and its explanatory variables, conditional on the choice of labour supply regime. The latter is, of course, endogenously determined in the model we are now considering.

The effect on off-farm labour supply of having children is negative for both operator and spouse. For spouses, the effect of having small children (younger than 6 years of age) is both larger and more significant than the effect of having children in school-age. For operators, the effect is opposite. This may seem to reflect that small children are still primarily the spouse's (mother's) responsibility, maybe because it is not very practical to combine child caring with working on the farm. When children are older and more independent, operators seem to take a greater responsibility by working less off-farm.

Wage raises have a positive effect on labour supply of both operator and spouse, and the effect seems to be larger in the non-heterogeneous models. The cross effect of wage increases are negative in all but the univariate random effects Tobit models. For this model specification, an increase in the spouse's wage rate will increase the operator's off-farm labour supply almost as much as if his own wage increased, but for spouses, the cross-effect is both small and insignificant. For both operator and spouse, we see that the own wage effect typically exceeds the cross-wage effect in absolute numbers. Wage effects are larger in the bivariate models than in the univariate models. From Table 13, we see that a wage increase of 1 NOK, increases off-farm labour supply by almost 7 hours for operators and 4 hours for spouses. Operators seem to be more responsive to wage increases than spouses are.

The parameter estimate of financial income (INTDIFF) is not very significant and most often small and negative. This indicates that increases in net financial income reduce off-farm labour supply, *i.e.*, the income effect exceeds the substitution effect. There is no obvious difference between the operators and the spouses except for the univariate random effects Tobit estimation of operator's labour supply, for which the effect is positive and significant. A positive parameter estimate for operators may be a reasonable result. If net financial income is an indication of the investment level on the farm, a net increase in financial income may mean lower investment level and consequently more time available for off-farm work. At least if we assume that financial investments on the farm also means more labour hours on the farm. The result is supported by the convex effect of age on off-farm labour supply.

Farm size has a negative and significant effect on operator's off-farm labour supply according to all univariate and bivariate estimations. For spouses, on the other hand, the effect is opposite. Larger farm units result in more off-farm hours, although the results are not very significant. If we assume that larger farm units are more labour intensive than smaller farms, the time available for off-farm labour is consequently less for operators.

Likewise, we would, *a priori*, assume that the effect of dairy production on off-farm hours would be negative because dairy production is particularly labour intensive. The effect is actually positive in the univariate random effects Tobit estimation for operator, but negative in all other estimations. In the univariate cases, the negative effect of dairy farming on off-farm hours is larger in the models where we do not account for heterogeneity. The effect is also larger, and more significant, for spouses than for operators. In the bivariate estimations the effect is more equal for operator and spouse. Having a dairy farm, compared to other productions, reduces off-farm annual labour supply by 200-300 hours.

The effect of living near a city region is another variable that affects off-farm labour supply oppositely for operator and spouse. Operators supply more off-farm hours when living near a city region while spouses supply fewer. The results for spouses are, however, small and not very significant. A priori, we would assume a short commuting distance, *cet. par.*, to have a positive effect on off-farm hours.

Table 14 supplements Table 12, by giving summary statistics for the residuals corresponding to the four versions of the single-equation model. Taking 0 and 3, which correspond to a normal (Gaussian) distribution, as benchmark values for the skewness and the kurtosis, respectively, we find larger discrepancies for the operators than for the spouses. For the operators, the sample skewness exceeds 1.5 and the sample kurtosis exceeds 5, indicating right-skewed and heavy-tailed (leptokurtic) error distributions. The corresponding statistics for the spouses are less than 0.5 and less than 2.5, respectively. The latter indeed suggests more thin-tailed residual distributions than under normality. It is also worth noting that whereas the residuals, by construction, have zero means when censoring is not accounted for, the residual distributions for the versions in which censoring is modelled, are somewhat 'off-centered'. The effect is largest for the random effects, censoring model, more pronounced for spouses than for operators.

9 Concluding remarks

In this paper we have presented a unified framework for handling discrete-continuous choices of farming-couples when they decide between different uses of their time-budgets, and we have tried to implement it econometrically on Norwegian data for farm households. The farmers may earn income by supplying working hours on-farm or off-farm while optimizing between consumption and leisure. This optimization involves jointly the operator (usually a male) and the spouse (usually a female) since they are assumed to have (i) both a common production technology, relating output to individual labour inputs and other inputs, and (ii) a common preference ordering for consumption and individual leisure.

Using a bivariate censoring model for panel data as the stochastically specified, econometric 'translation' of this neo-classical theory-model, in which both interior solutions and boundary solutions to the two off-farm labour supplies are accounted for, seems to fit well into this framework. Needless to say, certain modifications and short-cuts in the model formulation have had to be made to implement this fairly complex framework and make it 'work', as described in the paper.

This kind of random choice model – representing jointly bivariate interrelated decisions, bivariate censoring, and a panel data design with latent heterogeneity – seems to be appropriate when we consider a few basic characteristics of the data: (a) Farm operators work on average more hours in total than their spouses, and more than a standard man-year on-farm. (b) A substantial share of the operators choose not to work off-farm. (c) The spouses work on average less than a man-labour year, but increase their labour supply over the sample period, 1990–2000, while reducing their on-farm shares of these hours. (d) A substantial number of transitions between labour supply regimes occur during the ten-year sample period.

The censored labour supply functions of operator and spouse are estimated separately as well as jointly, exploiting the 10-year panel design of the data, one reason being certain limitations of the econometric software applied. For the single-equation estimation results, we have compared model specifications that differ in two respects: accounting/not accounting for household specific heterogeneity and accounting/not accounting for censoring of the labour supply. Due to the limitations of the applied software, the joint estimations of operator and spouse's labour supply do not account for heterogeneity.

A main finding is that overall, both operators and spouses work more off-farm hours if they have higher education. The effect of own education on off-farm labour supply is generally larger for spouses than for operators. Another basic, not unexpected, finding is that the effect of having small children is negative for both operator and spouse. As expected, wage raises have a positive effect on off-farm labour supply of both operator and spouse, and the effect seems to be larger when latent heterogeneity is not accounted for. Increasing net financial income tends to reduce off-farm labour supply. Farm size has a negative and significant effect on operator's off-farm labour supply, while it is positive for spouses. The presence of substantial dairy production also affects off-farm hours negatively, which is not surprising because dairy production is particularly labour intensive. Operating a farm near a city region tends to induce operators to supply more off-farm hours and spouses to supply fewer.

Although our primary interest is on off-farm labour supply, extensions accounting for three or more variables being subject to censoring, may be interesting topics for further research. We could for instance extend the case considered in the empirical part of the paper to also account for a censoring of the leisure time. Farms which are rationed with respect to non-labour inputs could also be accounted for. Such extensions would, however, lead to stochastic model versions involving, for instance, normal distributions of dimension three or higher and, accordingly, higher-dimensional truncated distributions and multiple integration. A further elaboration of the submodel for predicting off-farm wage rates for those not supplying off-farm labour, as well as of the treatment of the potential endogeneity of the wage rates of those who supply off-farm work, should also be considered. A further extension could be to investigate whether a dynamic model could give a better representation of the transitions between labour supply regimes.

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Table 1: Definition of variables

$i = O$: Operator, $i = S$: Spouse

Symbol	Definition
F^i	On-farm annual labour supply in hours
M^i	Off-farm annual labour supply in hours
W^i	Off-farm wage rate in NOK per hour. Observed when $M^i > 0$, predicted when $M^i = 0$
AGE^i	Age
AGESQ^i	Age squared
COMEDU^i	Dummy for compulsory education only
SECEDU^i	Dummy for completed upper secondary education
HIGEDU^i	Dummy for completed higher education (more than 13 years of schooling)
AGREDU^i	Dummy for agricultural education (secondary or higher level)
DAIRY	Dummy for dairy farm
FARMSIZE	Farm size in acres
INTDIFF	Interest income minus interest payments 1000 NOK
FEMALE	Dummy for female operator
CHILD6	Number of children younger than 6 years of age
CHILD16	Number of children aged 6 to 16 years
COMMUTE	Dummy for central and fairly central location

Table 2: Means and standard deviations, by regime

A. Individual specific variables, by regime and farmer status.
Standard deviations below means

	Regime 11		*Regime 10*		*Regime 01*		*Regime 00*		*Overall*	
	Operator	*Spouse*	*Operator*	*Spouse*	*Operator*	*Spouse*	*Operator*	*Spouse*	*Operator*	*Spouse*
M^O, M^S	589.560	1001.743	543.541	0.000	0.000	1051.892	0.000	0.000	286.448	642.995
	639.530	605.920	610.043			568.901			529.025	680.757
W^O, W^S	123.802	117.218	119.631	—	—	117.686	—	—	117.532	115.601
	33.519	22.964	32.455			27.813			28.096	21.554
F^O, F^S	1897.522	426.443	1897.445	728.502	2248.899	365.886	2271.181	738.324	2077.302	522.351
	768.902	488.802	782.447	626.674	624.068	423.315	584.246	624.881	719.168	551.653
AGE	44.316	41.985	43.362	41.820	45.236	42.465	43.288	40.451	44.237	41.814
	8.034	8.328	8.503	8.473	8.556	8.118	10.008	10.057	8.715	8.738
COMEDU	0.070	0.034	0.068	0.119	0.136	0.075	0.133	0.136	0.102	0.082
	0.256	0.182	0.252	0.324	0.343	0.264	0.340	0.343	0.303	0.274
SECEDU	0.771	0.638	0.867	0.767	0.812	0.659	0.816	0.800	0.810	0.699
	0.420	0.481	0.340	0.423	0.391	0.474	0.388	0.400	0.392	0.459
HIGEDU	0.159	0.328	0.065	0.114	0.052	0.266	0.064	0.064	0.087	0.219
	0.365	0.470	0.246	0.318	0.222	0.442	0.244	0.244	0.283	0.414
AGREDU	0.628	0.096	0.668	0.114	0.666	0.079	0.715	0.108	0.664	0.097
	0.483	0.295	0.471	0.318	0.472	0.270	0.452	0.311	0.472	0.295

B. Household specific and farm specific variables, by regime.
Standard deviations below means

	Regime 11	*Regime 10*	*Regime 01*	*Regime 00*	*Overall*
CHILD6	0.320	0.307	0.326	0.460	0.346
	0.631	0.683	0.680	0.750	0.681
CHILD16	0.887	0.717	0.897	0.782	0.839
	1.057	0.936	1.029	1.024	1.023
FEMALE	0.019	0.035	0.021	0.040	0.026
	0.135	0.183	0.142	0.197	0.160
INTDIF	-35.395	-38.316	-36.781	-33.823	-36.069
	55.040	58.263	51.690	53.376	54.325
FARMSIZE	50.879	50.919	60.450	52.411	54.151
	33.553	28.156	36.753	29.931	33.288
DAIRY	0.488	0.642	0.583	0.726	0.591
	0.500	0.480	0.493	0.446	0.492
COMMUTE	0.486	0.505	0.504	0.451	0.488
	0.500	0.500	0.500	0.498	0.500

Table 3: Annual means of labour supply

Off-farm supply: Operator: M^O. Spouse: M^S.
On-farm supply: Operator: F^O. Spouse: F^S.

A. Mean supply of hours in full sample. $N = 342$

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Overall
M^O	247.4	242.2	275.7	263.8	277.7	304.5	319.5	294.2	304.7	334.7	286.5
F^O	2078.3	2099.7	2091.4	2076.0	2075.4	2082.5	2077.5	2084.8	2064.7	2042.8	2077.3
M^S	487.7	531.1	571.8	611.4	621.8	675.5	691.0	734.2	741.2	764.4	643.0
F^S	543.2	561.6	544.4	517.3	514.0	523.3	534.2	517.5	482.7	485.3	522.4
Sum ^{O}	2325.7	2341.9	2367.1	2339.8	2353.1	2387.0	2397.0	2379.0	2369.4	2377.5	2363.8
Sum ^{S}	1030.9	1092.7	1116.2	1128.7	1135.8	1198.8	1225.2	1251.7	1223.9	1249.7	1165.4

B. Relative supply of hours off-farm/on-farm, per cent of total supply, in full sample. $N = 342$

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Overall
M^O	10.64	10.34	11.65	11.27	11.80	12.76	13.33	12.37	12.86	14.08	12.12
F^O	89.36	89.66	88.35	88.73	88.20	87.24	86.67	87.63	87.14	85.92	87.88
M^S	47.31	48.60	51.23	54.17	54.75	56.35	56.40	58.66	60.56	61.17	55.17
F^S	52.69	51.40	48.77	45.83	45.25	43.65	43.60	41.34	39.44	38.83	44.83
Sum ^{O}	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sum ^{S}	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

C. Mean supply of hours in subsample where off-farm labour supply is strictly positive

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Overall
M^O	310.7	292.5	331.4	308.0	324.4	362.5	387.1	355.6	363.0	400.6	343.5
F^O	2055.5	2081.5	2084.8	2051.0	2054.9	2061.9	2051.4	2064.1	2058.9	2001.3	2056.5
Nobs ^{O}	277	288	289	298	298	291	286	287	291	289	2894
M^S	823.1	842.6	890.5	902.6	884.4	968.0	947.3	974.6	995.0	1034.5	930.6
F^S	500.2	496.1	477.3	447.2	447.4	422.8	461.0	452.7	409.6	399.8	449.5
Nobs ^{S}	203	216	220	232	241	239	250	258	255	253	2367

D. Mean no. of hours in subsample where off-farm labour supply is at least 37.5 annual hours

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Overall
M^O	519.1	520.9	551.4	521.4	562	591.7	642.8	581.6	588.8	636.0	572.6
F^O	1884.4	1930	1901.8	1900.6	1877.2	1890.5	1882.4	1912.5	1918.4	1878.7	1897.5
Nobs ^{O}	163	159	171	173	169	176	170	173	177	180	1711
M^S	942.3	946	992.7	1000.5	1003.2	1064.6	1045.6	1050.6	1060.6	1117.1	1026.6
F^S	434.3	420.9	405.5	369.5	381.4	360.1	423.0	420.0	377.1	381.1	396.4
Nobs ^{S}	177	192	197	209	212	217	226	239	239	234	2142

Table 4: Labour supply by farmer status and regime. Annual means

Regime 11: Both work off-farm. Regime 10: Only operator works off-farm.
Regime 01: Only spouse works off-farm. Regime 00: Neither work off-farm

A. Operator

	Regime 11		*Regime 10*		*Regime 01*		*Regime 00*		*Global mean*	
Year	*Off*	*On*	*Off*	*On*	*Off*	*On*	*Off*	*On*	*Off*	*On*
1991	587.8	1892.6	446.0	1875.7	0.0	2208.0	0.0	2305.3	247.4	2078.3
1992	498.7	1958.2	554.6	1886.9	0.0	2210.3	0.0	2288.0	242.2	2099.7
1993	573.1	1883.5	522.4	1926.4	0.0	2216.8	0.0	2369.1	275.7	2091.4
1994	506.0	1921.2	545.8	1868.0	0.0	2260.1	0.0	2248.5	263.8	2076.0
1995	548.8	1854.4	583.3	1913.8	0.0	2264.1	0.0	2277.1	277.7	2075.4
1996	604.0	1908.2	569.0	1857.8	0.0	2293.8	0.0	2273.7	304.5	2082.5
1997	647.0	1851.0	634.7	1944.7	0.0	2227.4	0.0	2352.3	319.5	2077.5
1998	629.0	1873.8	479.9	1995.5	0.0	2263.9	0.0	2254.1	294.2	2084.8
1999	619.9	1947.4	523.3	1857.5	0.0	2253.3	0.0	2139.6	304.7	2064.7
2000	646.3	1887.9	612.0	1857.1	0.0	2279.9	0.0	2115.6	334.7	2042.8
Mean	589.6	1897.5	543.1	1897.4	0.0	2248.9	0.0	2271.2	286.4	2077.3

B. Spouse

	Regime 11		*Regime 10*		*Regime 01*		*Regime 00*		*Global mean*	
Year	*Off*	*On*	*Off*	*On*	*Off*	*On*	*Off*	*On*	*Off*	*On*
1991	894.2	496.4	0.0	778.0	985.7	378.2	0.0	551.7	487.7	543.2
1992	914.7	509.6	0.0	703.3	977.3	332.2	0.0	769.3	531.1	561.6
1993	944.0	449.9	0.0	708.9	1040.8	361.5	0.0	758.0	571.8	544.4
1994	979.9	393.1	0.0	805.8	1021.7	345.2	0.0	692.5	611.4	517.3
1995	967.7	398.4	0.0	700.0	1037.3	365.1	0.0	760.6	621.8	514.0
1996	1033.4	387.1	0.0	823.2	1099.0	330.1	0.0	790.3	675.5	523.3
1997	1068.5	437.4	0.0	725.8	1022.7	408.6	0.0	774.9	691.0	534.2
1998	1022.5	432.5	0.0	722.7	1078.0	407.9	0.0	767.9	734.2	517.5
1999	1035.9	408.1	0.0	652.9	1085.5	345.9	0.0	819.9	741.2	482.7
2000	1090.7	387.0	0.0	630.1	1048.0	374.2	0.0	792.1	764.4	485.3
Mean	1001.7	426.4	0.0	728.5	1051.9	365.9	0.0	738.3	643.0	522.4

Table 5: Between/Within household variation of selected variables

Variable, z	$b = \dfrac{T\sum_i(\bar{z}_{i\cdot} - \bar{z})^2}{\sum_i\sum_t(z_{it} - \bar{z})^2}$	$w = \dfrac{\sum_i\sum_t(z_{it} - \bar{z}_{i\cdot})^2}{\sum_i\sum_t(z_{it} - \bar{z})^2}$
Exogenous:		
DAIRY	0.9434	0.0566
FARMSIZE	0.9243	0.0757
FARMINC	0.6464	0.3536
INTDIFF	0.7543	0.2457
AGE	0.8869	0.1131
EAGE	0.8863	0.1137
CHILD6	0.5465	0.4535
CHILD16	0.7795	0.2205
Endogenous:		
F^O	0.8179	0.1821
F^S	0.7833	0.2167
M^O	0.7999	0.2001
M^S	0.7446	0.2554
$W^O, \widehat{W}^O$	0.3576	0.6424
$W^S, \widehat{W}^S$	0.4564	0.5436

Table 6: Annual distribution of farms by labour regime

Regime 11: Both work off-farm. Regime 10: Only operator works off-farm.
Regime 01: Only spouse works off-farm. Regime 00: Neither work off-farm

Year	*Number of farms*					*Frequency, per cent*				
	11	10	01	00	Sum	11	10	01	00	Sum
1991	84	79	93	86	342	24.56	23.10	27.19	25.15	100
1992	96	63	96	87	342	28.07	18.42	28.07	25.44	100
1993	98	73	99	72	342	28.65	21.35	28.95	21.05	100
1994	106	67	103	66	342	30.99	19.59	30.12	19.30	100
1995	104	65	108	65	342	30.41	19.01	31.58	19.01	100
1996	114	62	103	63	342	33.33	18.13	30.12	18.42	100
1997	113	57	113	59	342	33.04	16.67	33.04	17.25	100
1998	118	55	121	48	342	34.50	16.08	35.38	14.04	100
1999	120	57	119	46	342	35.09	16.67	34.80	13.45	100
2000	126	54	108	54	342	36.84	15.79	31.58	15.79	100

Table 7: Number of farms staying in the same regime in all years.

Regime 11: Both work off-farm.
Regime 10: Only operator works off-farm.
Regime 01: Only spouse works off-farm.
Regime 00: Neither work off-farm

$N = 342 \qquad T = 10$

Regime	*No. of farms*
11	30
10	10
01	16
00	8
Sum	64

Table 8: Number of moves between regimes, from one year to the next

Regime 11: Both work off-farm.
’ Regime 10: Only operator works off-farm.
Regime 01: Only spouse works off-farm.
Regime 00: Neither work off-farm

$t = 1992, \ldots, 2000,$
$N = 342,\ T = 10$

Regime in year $t-1$	*Regime in year t*				Sum
	11	10	01	00	
11	–	60	141	8	209
10	80	–	20	76	176
01	147	14	–	54	215
00	24	77	69	–	170
Sum	251	151	230	138	770

Table 9: Number of farms in the same regime in year t and year s

Regime 11: Both work off-farm

$t\downarrow$ $s\rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	84									
1992	66	96								
1993	59	73	98							
1994	61	70	79	106						
1995	56	66	71	81	104					
1996	53	61	69	77	79	114				
1997	55	59	64	69	75	89	113			
1998	53	60	64	72	70	83	93	118		
1999	50	59	59	65	68	82	85	90	120	
2000	51	61	60	67	67	79	82	84	94	126

Regime 10: Only operator works off-farm

$t\downarrow$ $s\rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	79									
1992	47	63								
1993	47	44	73							
1994	45	44	51	67						
1995	40	37	47	50	65					
1996	37	33	36	41	42	62				
1997	37	33	35	38	44	42	57			
1998	33	29	32	35	35	36	44	55		
1999	31	28	30	36	37	35	42	43	57	
2000	27	25	30	32	30	28	32	37	39	54

Regime 01: Only spouse works off-farm

$t\downarrow$ $s\rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	93									
1992	69	96								
1993	66	76	99							
1994	66	75	83	103						
1995	63	70	74	81	108					
1996	51	56	64	66	72	103				
1997	54	58	68	68	74	84	113			
1998	58	63	71	72	73	80	95	121		
1999	54	62	66	64	71	76	79	92	119	
2000	53	58	62	62	60	62	72	81	88	108

Regime 00: Neither work off-farm

$t\downarrow$ $s\rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	86									
1992	63	87								
1993	50	57	72							
1994	45	55	55	66						
1995	39	46	48	51	65					
1996	31	38	38	40	45	63				
1997	30	37	39	37	43	43	59			
1998	25	32	33	29	33	32	39	48		
1999	24	33	31	28	31	30	31	32	46	
2000	26	33	32	28	30	28	31	33	37	54

Table 10: Moves between regimes, by year

A. Moves to/from Regime 11: Both off-farm

Below diagonal: # in Regime 10 in year $s(< t)$ & in Regime 11 in year t/# in Regime 11 in year t.
Above diagonal: # in Regime 11 in year t & in Regime 10 in year $s(> t)$/# in Regime 11 in year t.

$t \downarrow \quad s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.042	0.092	0.057	0.067	0.053	0.044	0.059	0.075	0.079
1992	0.155	–	0.071	0.094	0.087	0.079	0.062	0.068	0.100	0.087
1993	0.179	0.104	–	0.094	0.067	0.088	0.106	0.110	0.133	0.103
1994	0.202	0.125	0.102	–	0.038	0.044	0.080	0.068	0.075	0.079
1995	0.214	0.125	0.143	0.085	–	0.053	0.062	0.076	0.083	0.095
1996	0.250	0.156	0.194	0.113	0.087	–	0.097	0.076	0.092	0.087
1997	0.214	0.167	0.184	0.123	0.096	0.079	–	0.034	0.050	0.071
1998	0.310	0.208	0.265	0.160	0.173	0.140	0.080	–	0.058	0.071
1999	0.262	0.198	0.245	0.142	0.144	0.114	0.053	0.042	–	0.056
2000	0.321	0.198	0.245	0.160	0.144	0.149	0.106	0.059	0.050	–

Below diagonal: # in Regime 01 in year $s(< t)$ & in Regime 11 in year t/# in Regime 11 in year t.
Above diagonal: # in Regime 11 in year t & in Regime 01 in year $s(> t)$/# in Regime 11 in year t.

$t \downarrow \quad s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.135	0.143	0.123	0.173	0.184	0.204	0.186	0.192	0.175
1992	0.190	–	0.153	0.132	0.173	0.184	0.221	0.212	0.208	0.175
1993	0.226	0.135	–	0.085	0.154	0.140	0.159	0.161	0.183	0.159
1994	0.238	0.188	0.133	–	0.192	0.193	0.221	0.195	0.242	0.198
1995	0.202	0.167	0.153	0.123	–	0.158	0.186	0.212	0.208	0.190
1996	0.298	0.260	0.194	0.189	0.240	–	0.124	0.186	0.167	0.175
1997	0.310	0.281	0.224	0.236	0.231	0.096	–	0.136	0.175	0.175
1998	0.298	0.260	0.194	0.217	0.250	0.096	0.080	–	0.167	0.175
1999	0.333	0.271	0.255	0.283	0.260	0.132	0.186	0.186	–	0.127
2000	0.321	0.271	0.255	0.264	0.308	0.202	0.195	0.237	0.208	–

Below diagonal: # in Regime 00 in year $s(< t)$ & in Regime 11 in year t/# in Regime 11 in year t.
Above diagonal: # in Regime 11 in year t & in Regime 00 in year $s(> t)$/# in Regime 11 in year t.

$t \downarrow \quad s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.010	0.020	0.038	0.029	0.035	0.009	0.017	0.017	0.008
1992	0.012	–	0.010	0.019	0.029	0.044	0.044	0.025	0.000	0.016
1993	0.060	0.021	–	0.000	0.038	0.026	0.035	0.017	0.008	0.040
1994	0.095	0.063	0.041	–	0.010	0.018	0.027	0.025	0.025	0.032
1995	0.155	0.104	0.041	0.009	–	0.009	0.009	0.000	0.008	0.008
1996	0.179	0.135	0.071	0.047	0.010	–	0.000	0.000	0.008	0.016
1997	0.167	0.115	0.092	0.057	0.038	0.035	–	0.000	0.008	0.000
1998	0.167	0.135	0.092	0.057	0.038	0.070	0.062	–	0.008	0.024
1999	0.238	0.167	0.122	0.094	0.096	0.088	0.071	0.025	–	0.024
2000	0.250	0.208	0.173	0.132	0.115	0.061	0.088	0.059	0.008	–

Table 10: Moves between regimes, by year (cont.)

B. Moves to/from Regime 10: Only operator off-farm

Below diagonal: # in Regime 11 in year $s(< t)$ & in Regime 10 in year t/# in Regime 10 in year t.
Above diagonal: # in Regime 10 in year t & in Regime 11 in year $s(> t)$/# in Regime 10 in year t.

$t \downarrow \ s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.206	0.205	0.254	0.277	0.339	0.316	0.473	0.386	0.500
1992	0.051	–	0.137	0.179	0.185	0.242	0.281	0.364	0.333	0.352
1993	0.114	0.111	–	0.149	0.215	0.306	0.316	0.473	0.421	0.444
1994	0.076	0.159	0.137	–	0.138	0.194	0.228	0.309	0.263	0.315
1995	0.089	0.143	0.096	0.060	–	0.145	0.175	0.327	0.263	0.278
1996	0.076	0.143	0.137	0.075	0.092	–	0.158	0.291	0.228	0.315
1997	0.063	0.111	0.164	0.134	0.108	0.177	–	0.164	0.105	0.222
1998	0.089	0.127	0.178	0.119	0.138	0.145	0.070	–	0.088	0.130
1999	0.114	0.190	0.219	0.134	0.154	0.177	0.105	0.127	–	0.111
2000	0.127	0.175	0.178	0.149	0.185	0.177	0.158	0.164	0.123	–

Below diagonal: # in Regime 01 in year $s(< t)$ & in Regime 10 in year t/# in Regime 10 in year t.
Above diagonal: # in Regime 10 in year t & in Regime 01 in year $s(> t)$/# in Regime 10 in year t.

$t \downarrow \ s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.032	0.041	0.060	0.123	0.065	0.123	0.109	0.211	0.167
1992	0.025	–	0.000	0.000	0.077	0.065	0.088	0.109	0.123	0.130
1993	0.025	0.032	–	0.060	0.108	0.113	0.228	0.182	0.193	0.185
1994	0.038	0.016	0.000	–	0.031	0.065	0.123	0.109	0.123	0.093
1995	0.038	0.048	0.027	0.030	–	0.065	0.088	0.073	0.088	0.148
1996	0.076	0.095	0.068	0.090	0.062	–	0.053	0.073	0.140	0.111
1997	0.025	0.048	0.000	0.000	0.015	0.000	–	0.036	0.070	0.056
1998	0.038	0.048	0.014	0.015	0.031	0.032	0.035	–	0.018	0.037
1999	0.063	0.063	0.027	0.045	0.062	0.048	0.070	0.000	–	0.037
2000	0.025	0.079	0.055	0.060	0.077	0.081	0.105	0.055	0.035	–

Below diagonal: # in Regime 00 in year $s(< t)$ & in Regime 10 in year t/# in Regime 10 in year t.
Above diagonal: # in Regime 10 in year t & in Regime 00 in year $s(> t)$/# in Regime 10 in year t.

$t \downarrow \ s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.270	0.192	0.194	0.200	0.274	0.298	0.255	0.246	0.296
1992	0.127	–	0.123	0.104	0.138	0.177	0.158	0.145	0.158	0.222
1993	0.190	0.317	–	0.119	0.077	0.177	0.123	0.091	0.140	0.167
1994	0.165	0.190	0.082	–	0.092	0.161	0.158	0.164	0.158	0.241
1995	0.190	0.254	0.123	0.134	–	0.161	0.105	0.145	0.140	0.222
1996	0.165	0.222	0.151	0.149	0.154	–	0.140	0.109	0.105	0.204
1997	0.165	0.222	0.137	0.149	0.077	0.065	–	0.036	0.088	0.185
1998	0.152	0.238	0.123	0.164	0.138	0.129	0.088	–	0.105	0.167
1999	0.152	0.206	0.123	0.134	0.092	0.129	0.088	0.127	–	0.185
2000	0.190	0.206	0.096	0.119	0.108	0.161	0.123	0.091	0.105	–

Table 10: Moves between regimes, by year (cont.)

C. Moves to/from Regime 01: Only Spouse off-farm

Below diagonal: # in Regime 11 in year $s(< t)$ & in Regime 01 in year t/# in Regime 01 in year t.
Above diagonal: # in Regime 01 in year t & in Regime 11 in year $s(> t)$/# in Regime 01 in year t.

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.167	0.192	0.194	0.157	0.243	0.230	0.207	0.235	0.250
1992	0.140	–	0.131	0.175	0.148	0.243	0.239	0.207	0.218	0.241
1993	0.151	0.156	–	0.126	0.139	0.184	0.195	0.157	0.210	0.231
1994	0.140	0.146	0.091	–	0.120	0.194	0.221	0.190	0.252	0.259
1995	0.194	0.188	0.162	0.194	–	0.243	0.212	0.215	0.227	0.296
1996	0.226	0.219	0.162	0.214	0.167	–	0.097	0.091	0.126	0.213
1997	0.247	0.260	0.182	0.243	0.194	0.136	–	0.074	0.176	0.204
1998	0.237	0.260	0.192	0.223	0.231	0.214	0.142	–	0.185	0.259
1999	0.247	0.260	0.222	0.282	0.231	0.194	0.186	0.165	–	0.231
2000	0.237	0.229	0.202	0.243	0.222	0.214	0.195	0.182	0.134	–

Below diagonal: # in Regime 10 in year $s(< t)$ & in Regime 01 in year t/# in Regime 01 in year t.
Above diagonal: # in Regime 01 in year t & in Regime 10 in year $s(> t)$/# in Regime 01 in year t.

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.021	0.020	0.029	0.028	0.058	0.018	0.025	0.042	0.019
1992	0.022	–	0.020	0.010	0.028	0.058	0.027	0.025	0.034	0.046
1993	0.032	0.000	–	0.000	0.019	0.049	0.000	0.008	0.017	0.037
1994	0.043	0.000	0.040	–	0.019	0.058	0.000	0.008	0.025	0.037
1995	0.086	0.052	0.071	0.019	–	0.039	0.009	0.017	0.034	0.046
1996	0.043	0.042	0.071	0.039	0.037	–	0.000	0.017	0.025	0.046
1997	0.075	0.052	0.131	0.068	0.046	0.029	–	0.017	0.034	0.056
1998	0.065	0.063	0.101	0.058	0.037	0.039	0.018	–	0.000	0.028
1999	0.129	0.073	0.111	0.068	0.046	0.078	0.035	0.008	–	0.019
2000	0.097	0.073	0.101	0.049	0.074	0.058	0.027	0.017	0.017	–

Below diagonal: # in Regime 00 in year $s(< t)$ & in Regime 01 in year t/# in Regime 01 in year t.
Above diagonal: # in Regime 01 in year t & in Regime 00 in year $s(> t)$/# in Regime 01 in year t

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.063	0.061	0.039	0.093	0.107	0.097	0.058	0.050	0.102
1992	0.129	–	0.051	0.019	0.065	0.087	0.071	0.041	0.034	0.065
1993	0.172	0.083	–	0.029	0.074	0.107	0.080	0.066	0.050	0.074
1994	0.215	0.146	0.071	–	0.065	0.107	0.088	0.058	0.050	0.083
1995	0.204	0.156	0.111	0.049	–	0.068	0.080	0.058	0.050	0.102
1996	0.290	0.229	0.162	0.107	0.083	–	0.071	0.083	0.076	0.120
1997	0.312	0.260	0.141	0.126	0.120	0.117	–	0.058	0.076	0.120
1998	0.376	0.281	0.212	0.194	0.176	0.146	0.071	–	0.059	0.083
1999	0.323	0.260	0.202	0.184	0.167	0.146	0.133	0.050	–	0.037
2000	0.258	0.219	0.162	0.155	0.148	0.175	0.097	0.025	0.017	–

Table 10: Moves between regimes, by year (cont.)

D. Moves to/from Regime 00: Neither work off-farm

Below diagonal: # in Regime 11 in year $s(< t)$ & in Regime 00 in year t/# in Regime 00 in year t.
Above diagonal: # in Regime 00 in year t & in Regime 11 in year $s(> t)$/# in Regime 00 in year t.

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.011	0.069	0.121	0.200	0.238	0.237	0.292	0.435	0.389
1992	0.012	–	0.028	0.091	0.154	0.206	0.186	0.271	0.348	0.370
1993	0.023	0.011	–	0.061	0.062	0.111	0.153	0.188	0.261	0.315
1994	0.047	0.023	0.000	–	0.015	0.079	0.102	0.125	0.217	0.259
1995	0.035	0.034	0.056	0.015	–	0.016	0.068	0.083	0.217	0.222
1996	0.047	0.057	0.042	0.030	0.015	–	0.068	0.167	0.217	0.130
1997	0.012	0.057	0.056	0.045	0.015	0.000	–	0.146	0.174	0.185
1998	0.023	0.034	0.028	0.045	0.000	0.000	0.000	–	0.065	0.130
1999	0.023	0.000	0.014	0.045	0.015	0.016	0.017	0.021	–	0.019
2000	0.012	0.023	0.069	0.061	0.015	0.032	0.000	0.063	0.065	–

Below diagonal: # in Regime 10 in year $s(< t)$ & in Regime 00 in year t/# in Regime 00 in year t.
Above diagonal: # in Regime 00 in year t & in Regime 10 in year $s(> t)$/# in Regime 00 in year t.

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.115	0.208	0.197	0.231	0.206	0.220	0.250	0.261	0.278
1992	0.198	–	0.278	0.182	0.246	0.222	0.237	0.313	0.283	0.241
1993	0.163	0.103	–	0.091	0.138	0.175	0.169	0.188	0.196	0.130
1994	0.151	0.080	0.111	–	0.138	0.159	0.169	0.229	0.196	0.148
1995	0.151	0.103	0.069	0.091	–	0.159	0.085	0.188	0.130	0.130
1996	0.198	0.126	0.153	0.152	0.154	–	0.068	0.167	0.174	0.185
1997	0.198	0.103	0.097	0.136	0.092	0.127	–	0.104	0.109	0.130
1998	0.163	0.092	0.069	0.136	0.123	0.095	0.034	–	0.152	0.093
1999	0.163	0.103	0.111	0.136	0.123	0.095	0.085	0.125	–	0.111
2000	0.186	0.138	0.125	0.197	0.185	0.175	0.169	0.188	0.217	–

Below diagonal: # in Regime 01 in year $s(< t)$ & in Regime 00 in year t/# in Regime 00 in year t.
Above diagonal: # in Regime 00 in year t & in Regime 01 in year $s(> t)$/# in Regime 00 in year t.

$t \downarrow$ $s \rightarrow$	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1991	–	0.138	0.222	0.303	0.292	0.429	0.492	0.729	0.652	0.444
1992	0.070	–	0.111	0.212	0.231	0.349	0.424	0.563	0.543	0.389
1993	0.070	0.057	–	0.106	0.169	0.254	0.237	0.438	0.435	0.296
1994	0.047	0.023	0.042	–	0.077	0.175	0.220	0.417	0.413	0.296
1995	0.116	0.080	0.111	0.106	–	0.143	0.220	0.396	0.391	0.296
1996	0.128	0.103	0.153	0.167	0.108	–	0.203	0.313	0.326	0.333
1997	0.128	0.092	0.125	0.152	0.138	0.127	–	0.167	0.326	0.204
1998	0.081	0.057	0.111	0.106	0.108	0.159	0.119	–	0.130	0.056
1999	0.070	0.046	0.083	0.091	0.092	0.143	0.153	0.146	–	0.037
2000	0.128	0.080	0.111	0.136	0.169	0.206	0.220	0.188	0.087	–

Table 11: EQUATIONS FOR PREDICTION OF UNOBSERVED WAGE RATES

COEFFICIENT ESTIMATES. STANDARD ERRORS BELOW

	Operator	Spouse
CONSTANT	134.2653	-15.1373
	14.4165	8.9925
AGE	-1.0643	-0.0532
	0.6846	0.4195
AGESQ	0.0743	0.0031
	0.0078	0.0048
COMEDU	-2.7282	28.5402
	3.6768	2.0362
HIGHEDU	22.4909	-13.9983
	1.8885	0.6792
SOUTH	-13.3524	-19.831
	4.7966	1.1803
WEST	-12.8354	-9.9862
	4.0711	0.8693
MID	-7.7276	-16.3928
	3.6428	0.8477
NORTH	-12.1772	9.9313
	3.8125	1.1031
σ_ω^2	16.7348	0.0000
	0.6465	0.3971
σ_ξ^2	25.6036	91.1767
	0.1290	0.2182
τ	0.9311	-0.0165
	3.96E+08	0.0048

Table 12: Off-farm labour supply functions

A. Single-equation results for operator

Standard errors below coefficient estimates

	Censoring Random effects Tobit	No censoring Random effects GLS	Censoring No heterogeneity Tobit	No censoring No heterogeneity OLS
Constant	-497.1603	-792.9297	-2072.5245	-788.6080
	103.7792	182.8538	337.2095	184.9244
AGE ^{O}	-34.8014	25.2844	112.8812	40.7538
	8.9623	16.1501	23.4551	12.2632
AGESQ ^{O}	0.4338	-0.3675	-1.5329	-0.5663
	0.1053	0.1737	0.2652	0.1374
AGE ^{S}	57.5866	22.0782	-2.4695	11.7404
	14.6263	15.2843	20.8973	11.0935
AGESQ ^{S}	-0.7308	-0.0733	0.2403	-0.0468
	0.1777	0.1714	0.2408	0.1269
COMEDU ^{O}	- 168.1345	-189.8976	-368.4777	-155.4258
	38.6228	86.6008	60.1149	32.0680
HIGHEDU ^{O}	137.4340	329.5816	250.1917	198.5105
	29.3347	82.0900	52.1871	30.7408
AGEREDU ^{O}	-176.8507	-167.6749	-233.2744	-144.2405
	20.9008	54.2647	34.9519	19.8840
COMEDU ^{S}	0.4383	-127.7815	-204.3305	-99.6666
	37.0462	82.8657	58.1003	30.3991
HIGHEDU ^{S}	203.7629	24.8953	75.9112	22.6776
	23.0745	56.1560	37.8875	21.2011
AGEREDU ^{S}	—	—	—	—
CHILD6	-35.2209	9.2197	-39.4158	-0.1610
	10.0627	10.6800	24.4074	13.5197
CHILD16	-22.0167	-19.9752	-88.9159	-52.4275
	9.1526	10.2985	16.0910	8.8725
WAGE ^{O}	1.1551	1.0186	6.6196	4.3632
	0.2666	0.1880	0.5240	0.3054
WAGE ^{S}	1.0079	-0.2290	-2.3221	-0.6683
	0.4685	0.2695	0.7745	0.4054
INTDIFF	0.4015	-0.0496	-0.4094	-0.0138
	0.1805	0.1539	0.2833	0.1591
FARMSIZE	-1.7237	-1.5237	-6.5077	-3.8603
	0.2915	0.4111	0.5196	0.2805
DAIRY	0.4780	-41.0279	-279.6921	-189.5852
	22.5233	29.5130	33.0362	18.6498
COMMUTE	9.9455	105.9558	118.7127	93.7852
	22.8023	46.9249	32.8927	18.2732
σ_ε	380.1517	242.1718	753.3594	470.9100
	2.7863		13.8719	
σ_α	550.2979	442.7911	—	—
	8.6103			
$\frac{\sigma_\alpha^2}{\sigma_\varepsilon^2+\sigma_\alpha^2}$	0.7314	0.7468	—	—
Log-likelihood	-1841.8060		-2974.8750	-2268.1937

Table 12: Off-farm labour supply functions (cont.)

B. Single-equation results for spouse

Standard errors below coefficient estimates

	Censoring Random effects Tobit	No censoring Random effects GLS	Censoring No heterogeneity Tobit	No censoring No heterogeneity OLS
Constant	-430.0999	-1842.2797	-1705.9463	-726.2963
	86.9060	249.5188	376.2452	238.3085
AGE^{O}	-105.5395	4.7428	-7.8033	-7.5171
	9.6983	21.6684	24.6587	15.5852
$AGESQ^{O}$	1.0005	0.2126	0.3758	0.2805
	0.1097	0.2341	0.2762	0.1746
AGE^{S}	178.3286	96.2045	93.3156	58.7902
	13.8132	20.4982	22.7264	14.1276
$AGESQ^{S}$	-1.8873	-1.1619	-1.3187	-0.8548
	0.1605	0.2307	0.2609	0.1616
$COMEDU^{O}$	11.1295	-46.8011	27.7154	27.0684
	48.6740	106.8202	62.4189	40.7452
$HIGHEDU^{O}$	-360.9449	-1.8376	-26.7881	-27.0407
	38.1174	10.1202	59.0139	39.0383
$AGEREDU^{O}$	-285.4763	-57.2583	-49.3385	-33.9619
	24.5243	66.9376	38.6548	25.2934
$COMEDU^{S}$	-523.8829	-219.2300	-339.3249	-171.4282
	43.5485	102.5133	62.9950	38.7355
$HIGHEDU^{S}$	162.5826	617.9859	742.7947	576.7529
	25.0946	69.2495	40.1803	26.9268
$AGEREDU^{S}$	-95.2036	35.2762	-143.8716	-106.5378
	41.1100	94.3052	56.2600	36.1981
CHILD6	-138.8173	-109.6602	-59.5795	-51.6768
	12.2173	14.6256	27.0460	17.2466
CHILD16	6.4844	-31.3289	-5.4794	-15.0972
	9.5641	13.9485	17.3379	11.2886
$WAGE^{O}$	0.0488	-0.3979	-1.6155	-1.2803
	0.3946	0.2597	0.5987	0.3879
$WAGE^{S}$	2.0932	-0.3977	4.1034	3.5765
	0.5954	0.3717	0.7571	0.5150
INTDIFF	-0.0959	-0.7177	-0.3747	-0.2401
	0.1917	0.2103	0.3121	0.2021
FARMSIZE	2.6204	0.8751	0.0631	0.1704
	0.3707	0.5482	0.5392	0.3562
DAIRY	-278.6527	-106.5610	-272.2662	-172.6536
	23.4482	39.2430	36.4449	23.6899
COMMUTE	-159.9935	19.4327	-4.4078	10.2155
	23.4068	58.1491	35.8414	23.2068
σ_ε	491.1687	342.8104	863.6223	598.0100
	4.1506		14.3727	
σ_α	789.1363	540.2009	—	—
	12.8045			
$\dfrac{\sigma_\alpha^2}{\sigma_\varepsilon^2 + \sigma_\alpha^2}$	0.6808	0.7220	—	—
Log-likelihood	- 2584.4860		-3745.2660	-3084.8719

Table 13: Off-farm labour supply functions for both farmers

Results for bivariate model. Heterogeneity not accounted for.

Standard errors below coefficient estimates

	Operator Censoring Tobit	Spouse Censoring Tobit	Operator No censoring SURE	Spouse No censoring SURE
Constant	-2059.4620 335.8631	-1706.0410 362.2500	-788.6080 184.4371	-725.2542 237.6418
AGE^{O}	112.3219 25.6088	-7.4077 22.5226	40.7538 12.2309	-7.5329 15.5418
$AGESQ^{O}$	-1.5243 0.2912	0.3716 0.2610	-0.5663 0.1370	0.2807 0.1741
AGE^{S}	-2.5758 23.1071	92.8408 21.3171	11.7404 11.0642	58.7630 14.0882
$AGESQ^{S}$	0.2398 0.2679	-1.3130 0.2543	-0.0468 0.1266	-0.8545 0.1611
$COMEDU^{O}$	-368.1451 58.4866	26.6963 67.7447	-155.4258 31.9835	27.1027 40.6319
$HIGHEDU^{O}$	251.2383 54.7681	-25.5783 70.8635	198.5105 30.6598	-27.0452 38.9297
$AGEREDU^{O}$	-232.8295 35.1517	-49.2863 39.3771	-144.2405 19.8316	-33.9996 25.2230
$COMEDU^{S}$	-203.8953 65.6101	-340.5107 59.2470	-99.6666 30.3190	-171.5102 38.6276
$HIGHEDU^{S}$	76.0874 39.6660	742.2229 50.2502	22.6776 21.1452	576.7641 26.8519
$AGEREDU^{S}$	—	—	-142.6671 54.2451	-107.4685 36.0769
CHILD6	-38.9444 23.2830	-59.2020 27.3519	-0.1610 13.4841	-51.6347 17.1985
CHILD16	-88.8064 16.6687	-5.2491 18.0979	-52.4275 8.8491	-15.0793 11.2572
$WAGE^{O}$	6.6191 0.4702	-1.6065 0.6574	4.3632 0.3046	-1.2804 0.3868
$WAGE^{S}$	-2.3315 0.8311	4.1016 0.7768	-0.6683 0.4044	3.5767 0.5135
INTDIFF	-0.4093 0.2986	-0.3751 0.3136	-0.0138 0.1587	-0.2401 0.2015
FARMSIZE	-6.5081 0.4603	0.0597 0.5656	-3.8603 0.2798	0.1703 0.3553
DAIRY	-279.5078 35.6853	-272.3239 37.3830	-189.5852 18.6007	-172.6395 23.6240
COMMUTE	118.6754 36.1283	-4.8336 37.0559	93.7852 18.2250	10.2084 23.1423
σ_ε	753.4557 14.3534	863.4875 19.7158	469.6700	596.3500
ρ	0.0431 0.0203	0.0431 0.0203	—	—
Log-likelihood	-6717.9460		-2259.1699	-3075.3457

Table 14: Distributional properties of residuals

Single equation results for off-farm supply functions

	Censoring Random effects Tobit	No censoring Random effects GLS	Censoring No heterogeneity Tobit	No censoring No heterogeneity OLS
Operator:				
Mean	0.0772	0.0000	-0.0247	0.0000
Std. dev.	0.5093	0.4938	0.4663	0.4697
Minimum	-0.5753	-0.8813	-1.6425	-1.3878
Maximum	1.8522	1.8450	1.7055	1.6635
Skewness	1.9620	1.7388	1.6695	1.5057
Kurtosis	5.7006	5.3731	5.6762	5.1430
Spouse:				
Mean	-0.2588	0.0000	0.0177	0.0000
Std. dev.	0.6495	0.6261	0.5929	0.5964
Minimum	-1.7726	-1.5325	-1.6179	-1.5771
Maximum	1.9163	2.0246	1.7094	1.6422
Skewness	0.3471	0.4226	0.5029	0.4443
Kurtosis	2.1511	2.4884	2.3592	2.3157