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JOB SEARCH THEORY, LABOUR SUPPLY AND UNEMPLOYMENT DURATION

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Abstract

This paper presents structural models of sequential job search in which individuals take into account their supply of labour in the job acceptance decision. Two approaches are followed. First the neo-classical assumption is made that, given the wage rate, individuals can choose their working hours optimally by maximising utility subject to the budget constraint. Under this condition, the assumption from standard job search theory that the wage rate is the only job characteristic on which the job acceptance decision is based can be justified. Data on labour supply can be used as additional information in the estimation of the parameters of the utility function. The second approach is to assume that weekly working hours is a job characteristic which, just like the wage rate, arrives from an offer distribution. Both models are used to construct a stationary structural model of unemployment duration which includes unobserved heterogeneity. The level of the social security benefit payments will influence the job acceptance decision and the social security system as a whole is modelled as a state dependent source of income. The models can be estimated with the maximum likelihood estimator, but this will require a substantial amount of C.P.U. time, due to the fact that the unobserved heterogeneity has to be integrated out. Therefore, various simulation estimators are discussed.

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1 Introduction

This paper presents models in which elements of job search theory and the labour supply literature are combined. A functional form for the models will be specified and the functional form will be estimated structurally. Flinn and Heckman (1982a) present an overview of the estimation of structural job search models. Applications can be found in Narendranathan and Nickell (1985) and Van den Berg (1990a). In order to find closed form solutions for the model restrictive assumptions have to be made and this is the reason why the estimation of structural job search models has not become as popular as the reduced form duration models, see Flinn and Heckman (1982b) and Kiefer (1988) for an overview.

Nevertheless, there is still room for extension in the specification of structural job search models as compared with the models which have been estimated up till now. Notably the assumption that the wage rate is the only component in the objective function of the individual decision maker can be relaxed. The standard job search framework is only concerned with the choice of a job on the basis of the wage rate. On the other hand, there exists an extensive literature on labour supply models. In these models the availability of a job is given and the emphasis is on the participation decision and the choice of the number of hours. Until now few attempts have been made to integrate these two types of models. The aim of the present paper is to extend the standard job search framework with elements of labour supply theory.

Basically two routes can be followed. The first one is to make the neo-classical assumption that individuals can choose their labour supply optimally given the level of their wage rate. In this case the assumption from standard job search theory that the wage rate is the only job component on which the job acceptance decision is based remains valid. The neo-classical assumption is usually not supported by empirical evidence on the distribution of hours worked, where we typically see peaks at various levels of hours, e.g. at 40 hours a week. Therefore, the second possibility is to assume that hours are, just like the wage rate, a component of the job offer. The first attempt to introduce hours in a job search context was made by Kider (1984). In the labour supply literature restrictions on hours were introduced in a static model by Dickens and Lundberg (1985). Their model was further developed by Timmers and Woittiez (1991) and Van Soest, Woittiez and Kapteyn (1990). A different route to handle hours restrictions was followed by Rettore (1990). Bloemen (1991) formulated a static model with hours restrictions which can be interpreted as a static version of a dynamic job search model in which the rate of time preference is infinite.

In this paper, specific attention is paid to the stochastic specification. A random preference term is included in the utility function. As a result, the reservation wage rate will be random as well, as opposed to earlier work, e.g. Van den Berg (1990a) and Narendranathan and Nickell (1985), in which the reservation wage rate could only be changed by a change in the model parameters. Both the model with neo-classical labour supply and the model with hours restrictions will be considered in this paper. Data on unemployment duration and post unemployment job characteristics are used to estimate the parameters of the utility function, the parameters of the job offer distribution and the job offer arrival rate. The likelihood function can be formulated, conditional on the
random preferences, after which the random preferences can be integrated out. This integration procedure can be costly if it has to be performed numerically, which is definitely the case here, because the integrand contains the reservation wage rate which is the solution of a fixed point problem. To save computing time we can make use of simulation estimators. McFadden (1989) introduced a simulation estimator which is consistent for a fixed number of simulation replications in the context of a multinomial choice model. Bloemen and Kapteyn (1992) adapt it to the limited dependent variables model and apply it to the neo-classical labour supply model. In their application they also use simulation methods to integrate out an unobserved random preference variable. Various simulation estimators in the context of models with unobserved random variables and the specific problems which actually arise in this context will be discussed.

In section 2 the model without hours restrictions will be set up. First, attention will be paid to the assumptions that have to be made in order to be able to estimate the model. After that the reservation wage equation will be derived which specifies the strategy followed by the individual. The likelihood function is specified after which it is indicated how the likelihood estimator can be replaced by a simulation estimator. Thirdly, specific functional forms for the model will be chosen. Fourth, the available dataset is discussed. Finally, the model will be estimated and estimation results will be presented. In section 3 the neo-classical assumption of no hours restrictions is dropped and a job offer is supposed to consist of two characteristics, i.e. the number of hours and the wage rate. Instead of a single reservation wage rate there now exists a unique reservation utility level. All job offers which yield a higher utility value than this reservation utility value are acceptable. Again, the model will be estimated and estimation results will be presented. Section 4 presents residual analysis and the final section concludes.

2 Job search without hours restrictions

2.1 The model

In this section a job search model is presented in which an unemployed individual maximizes the discounted sum of expected future utility flows, under the assumption that he knows the search process according to which job offers arrive. The utility flow is a function of income and labour supply and it is assumed that once the wage rate is known, hours can be chosen optimally by maximizing the utility function subject to the budget constraint. Implicitly, the assumption of no hours restrictions is also made in the standard job search model in which the individual just maximizes the discounted sum of expected future utility flows. Therefore, the value of work function in the standard job search framework can be interpreted as the discounted sum of indirect utility flows. In the next section the neo-classical assumptions that individuals can choose hours optimally will be dropped. Because the neo-classical assumption elucidates the relation between the present model and the standard job search framework and uncovers some of its implicit assumptions it is a good point of departure.

In order to be able to find closed form solutions for the model, some possibly restrictive assumptions have to be made. Most of these assumptions are standard assumptions which are usually made in structural models of job search. They can be found
in Mortensen (1986). We deviate from the standard framework in Mortensen (1986) by including labour supply in the utility function. A different approach of incorporating labour supply in the context of a job search model can be found in Burdett and Mortensen (1978).

The assumptions are the following:

1. The individual maximizes a discounted sum of future expected utility flows, subject to the budget constraint and the job offer process:

   \[ \max_{\alpha, h_t} E \int_t^{\infty} u(y_t, h_t; \epsilon) e^{-\rho(s-t)} ds \]  

   where \( y_t \) is income in period \( t \), \( h_t \) is labour supply in period \( t \), \( \rho \) is the discount rate, \( \epsilon \) is an individual specific, time independent unobserved random taste parameter, known to the individual. The appearance of the expectation sign refers to the uncertainty about the future state, i.e. the uncertain job possibilities and the associated wage rates. The job offer arrival and wage processes are specified below. By the inclusion of labour supply in the utility function we deviate from the standard job search framework, in which the utility function contains income only.

2. The income consists of a state dependent component and a state independent component (non-labour income). If employed, income equals the sum of labour income and non-labour income:

   \[ y_t = w h_t + \mu \]  

   where \( w \) is the wage rate and \( \mu \) is non-labour income. If unemployed, income equals the sum of the unemployment benefit payments \( b \) and the state independent income:

   \[ y_t = b + \mu \]  

   As a consequence, the level of the benefit payments will influence the job acceptance decision.

3. A job offer consists of a wage rate \( w \). Job offers arrive randomly according to a Poisson process with parameter \( \lambda \) from a distribution function \( F(.; \psi, \tau) \) with accompanying density function \( f(.; \psi, \tau) \), with \( \psi \) the location parameter and \( \tau \) the scale parameter. The distribution function is known to the individual. The domain of \( F(.; \psi, \tau) \) is \((0, \infty)\).

4. The model is stationary, i.e. the job offer arrival rate \( \lambda \), the unemployment benefit level \( b \), the wage distribution \( F(w; \psi, \tau) \) and the non-labour income \( \mu \) are independent of both calendar time and elapsed duration.

5. Once the unemployed has accepted a job it will be kept until forever.
6. The utility function has the properties:

\[ \frac{\partial u}{\partial y} > 0 \]  
\[ k(h) := u(wh + \mu, h; e) \]  
\[ k''(h) < 0 \text{ for all } h > 0 \]

Under these assumptions it can be derived that there exists a unique reservation wage \( \xi(e) \). All wage offers above the reservation wage rate are acceptable, whereas those below will be rejected.

Assumption 3 is a standard assumption in the job search framework. Assumption 4 is an assumption which we need to arrive at a closed form solution. Without this assumption the reservation wage rate can only be defined implicitly in term of a differential equation, which can only be solved if not too complicated assumptions for the process of exogenous variables are specified. Van den Berg (1990b) relaxes the stationarity assumptions by introducing general forms of non-stationarity. His empirical application, however, remains restricted to non-stationarity in the benefit level \( b \), in which, after the unemployment spell has reached a specified length, a discrete jump takes place whereafter it remains constant. In the duration model literature, in which reduced form models are estimated, it turns out to be difficult to distinguish empirically between negative duration dependence and unobserved heterogeneity, i.e. once unobserved heterogeneity is introduced, the presence or absence of duration dependence is hard to establish. As we have included a random preference parameter in the utility function we hope to be able to catch the heterogeneity in the model.

Assumption 5 is made to be able to find a closed form expression for the value of a job, which then can be compared with the value of search. This assumption is of course restrictive if a job is taken on for a short period only, but if a fixed job is taken on it is not unreasonable to assume that the individuals acts as if he will hold the job forever. Moreover, the general form of the reservation wage equation remains valid if it is assumed that there is a constant layoff rate (see e.g. Flinn and Heckman (1982a)). In that case we have to be careful in the interpretation of the rate of time preference \( \rho \).

The final assumption on the form of the utility function is made to ensure that a higher wage level is always preferred to a lower, and to ensure that, once a wage level is chosen, within period utility will reach a maximum if it is maximized with respect to labour supply, subject to the linear budget constraint. Note that no restrictions are placed on the sign of the derivative of the utility function with respect to labour supply. This is done because results of Narendranathan and Nickell (1985) and Van den Berg (1990c) indicate that individuals might value unemployment, i.e. total leisure, lower than having a job. However, their specification of the objective function was very straightforward in the sense that there is a discrete jump between the utility values of unemployment and having a job. The size of this jump was estimated by them with the result mentioned before. The restrictiveness of their specification and the fact that their estimated utility parameters were not based on the after spell income data directly, because the parameters of the wage equation were estimated separately using some ad hoc truncation rule, imply that care must be taken in the interpretation of the results. Any acceptance of a job
which cannot be fully explained by the individual characteristics in their model, can
only be explained by the jump in the utility value, so the negative valuation of total
leisure may have been only be the result of their restrictive specification. Nevertheless,
their results induce us not to restrict our utility function by the requirement that it is
decreasing in labour supply everywhere. This implies that the reservation wage rate may
become negative in which case any job offer is acceptable to the individual.

The reservation wage $\xi(e)$ is implicitly defined by the following equation, the deriv-
ation of which can be found in appendix A:

$$
\nu(\xi(e), \mu; e) = u(b + \mu, 0; e) + \frac{\lambda}{\rho} \int_{\xi(e)}^{\infty} [\nu(w, \mu; e) - \nu(\xi(e), \mu; e)] dF(w; \psi, \tau)
$$

(2.7)
in which $\nu(w, \mu; e)$ is the indirect utility function which is the result of substituting the
labour supply function into the direct utility function. The indirect utility function is
well-defined whenever the labour supply function is positive, i.e. whenever the wage rate
$w$ exceeds $w_0(e)$ which is defined by

$$
\nu(w_0(e), \mu; e) = u(\mu, 0; e)
$$

(2.8)

$w_0(e)$ is the reservation wage rate of the static model without unemployment benefits
($\rho \to \infty, \ b = 0$). It can easily be shown that the dynamic reservation wage rate $\xi(e)$
defined by (2.6) always exceeds the static model reservation wage rate $w_0(e)$. This ensures
that labour supply is positive whenever $w > \xi(e)$.

In words, the reservation wage rate is the wage rate which equates the value of the
indirect utility function to the sum of the direct utility value of being unemployed and
the expected gain of receiving wage offers in the future.

Under the above assumptions it is a general result that the distribution of completed
spells of unemployment, conditional on $e$, is exponential with escape rate $\theta(e)$, which
loosely speaking equals the probability of getting an acceptable job offer.

$$
\theta(e) = \lambda F(\xi(e))
$$

(2.9)
The density function of a completed spell of unemployment, conditional on $e$, is

$$
k(t|e) = \theta(e) \exp\{-\theta(e)t\}, 0 < t < \infty
$$

(2.10)

In the formulation of the likelihood function the sampling scheme has to be taken into
account. In practice, usually two sampling methods are distinguished, i.e. sampling the
flow and sampling the stock. In the flow sample the observation period starts at a certain
point in time whereafter all individuals who become unemployed after the beginning of
the observation period are drawn into the sample and their completed spells are observed.
There may be right hand censoring because the unemployment spell has not ended before
the end of the observation period. This type of sampling is most straightforward because
we can directly use the distribution of completed spells. In the stock sampling scheme
we take a given point in time and sample individuals who are unemployed at that point
in time from the stock of unemployed. We assume that we can observe both how long
they have already been unemployed (i.e. the backward recurrence times) and how long
they will be unemployed from the point of sampling on (the forward recurrence times),
again with possible right hand censoring. Suppose that the backward recurrence time is
indicated by $p$ and the forward recurrence time by $r$ which implies that the total spell
of unemployment $t$ is the sum of $p$ and $r$. Now different routes in the formulation of the
likelihood function can be followed. We can formulate the joint distribution of forward
and backward recurrence times, in which case we either have to model the process of
inflow in the state of unemployment, or have to make the assumption that the inflow
rate is constant. The second possibility is to condition on the backward recurrence time
in which case we do not have to make assumptions about the inflow rate. The latter
procedure will be followed in this paper. In the case without unobserved heterogeneity
the backward recurrence times simply drop out because of the stationarity assumption.

For ease of exposition the likelihood contribution for the flow sample will be derived
first and it is supposed that the observation period, which starts with the beginning of
the unemployment spell for individuals in the flow sample is of length $M$.

During the observation period the individual can be observed to accept a job or not.
If no job is accepted during the observation period, the only information we have is that
the duration of the unemployment spell lasts longer than the observation period. Then
the likelihood contribution of such an individual is given by

$$
I_u(\eta|\epsilon) = \exp\{-\theta(\epsilon)M\} \tag{2.11}
$$

where $\eta$ is the vector of parameters. If $\epsilon$ has a density function $g(.; \sigma^2)$ then the conditioning on $\epsilon$ can be removed by simply integrating out $\epsilon$. The unconditional likelihood contribution becomes

$$
I_u(\eta) = \int_{-\infty}^{\infty} \exp\{-\theta(\epsilon)M\} g(\epsilon; \sigma^2) d\epsilon \tag{2.12}
$$

For individuals who accept a job during the observation period we can distinguish
between individuals whose after unemployment spell wage rate and hours are observed
and individuals whose job characteristics are unobserved. The optimal labour supply
$h^*$ for an individual with wage rate $w$ and non-labour income $\mu$ is given by the labour
supply function

$$
h^* = \bar{h}(w, \mu; \epsilon) \tag{2.13}
$$

Recall that optimal labour supply is always positive for wage rates exceeding the reservation wage rate. If we assume that observed labour supply $h$ is measured with a
multiplicative measurement error $\exp(v), -\infty < v < \infty$, the density of observed labour
supply, conditional on the wage rate and the random taste parameter can be derived
from the density of measurement error $v$, by making the transformation

$$
h = \bar{h}(w, \mu; \epsilon) \exp(v) \tag{2.14}
$$

Let the resulting density function be denoted by $r(h|w, \epsilon)$. If an individual is observed
to be working at a wage $w$ and hours $h$ this means that the observed wage rate must
exceed the reservation wage rate $\xi(\epsilon)$ which means that the density of observed wages,
conditional on $\epsilon$, is truncated. The likelihood contribution of individuals who accepted
a job and whose after spell wages and hours are observed and are equal to $w$ and $h$
respectively, and whose unemployment duration equals $t$, conditional on $\epsilon$, is given by
\begin{equation}
I_{\eta}(\eta|\epsilon) = \theta(\epsilon) \exp\{-\theta(\epsilon)t\}r(h|w,\epsilon)\frac{f(w)}{T(\epsilon)}, 0 < t < M, h > 0, w > T(\epsilon) \tag{2.15}
\end{equation}
\begin{equation}
= 0 \text{ otherwise} \tag{2.16}
\end{equation}
where $T(\epsilon)$ is the truncation probability which is defined by:
\begin{equation}
T(\epsilon) = \bar{F}(\xi(\epsilon)) \text{ if } \xi(\epsilon) > 0 \tag{2.17}
\end{equation}
\begin{equation}
= 1 \text{ if } \xi(\epsilon) \leq 0 \tag{2.18}
\end{equation}
To remove the conditioning on $\epsilon$ we have to integrate over all values of $\epsilon$ for which $w_1(\epsilon)$. The unconditional likelihood contribution becomes:
\begin{equation}
I_{\eta}(\eta) = \int_{I_\omega} \theta(\epsilon) \exp\{-\theta(\epsilon)t\}r(h|w,\epsilon)\frac{f(w)}{T(\epsilon)} g(\epsilon, \sigma^2_\epsilon) d\epsilon, t > 0, h > 0, w > 0 \tag{2.19}
\end{equation}
where
\begin{equation}
I_\omega = \{\epsilon|\xi(\epsilon) < w\} \tag{2.20}
\end{equation}
For some of the individuals who are observed to accept a job during the observation period the after spell job characteristics may be unobserved. In that case the unobserved taste parameter will be integrated out and the likelihood contribution becomes
\begin{equation}
I_{\eta u}(\eta) = \int_{-\infty}^{\infty} \theta(\epsilon) \exp\{-\theta(\epsilon)t\}g(\epsilon, \sigma^2_\epsilon) d\epsilon, 0 < t < M \tag{2.21}
\end{equation}
Now we return to the formulation of the likelihood contributions of the individuals in the stock sample. The point of right hand censoring $M$ now is the length of the period which starts at the point of sampling and ends at the end of the observation period. As said before, we condition on the backward recurrence time $p$, which implies that we condition on duration $t$ being longer than $p$. As a result, we simply have to divide the likelihood contribution derived above by the probability that $t$ exceeds $p$, see e.g Ridder (1984). The implicit assumption on the inflow rate which is made in following this procedure is that the inflow rate into the state of unemployment does not depend on the unobserved random variable $\epsilon$.
\begin{equation}
P(t > p) = \int_{-\infty}^{\infty} \exp\{-\theta(\epsilon)p\}g(\epsilon, \sigma^2_\epsilon) d\epsilon \tag{2.22}
\end{equation}
where in (2.11) and (2.12) $M$ has to be replaced by $p + M$ and the region for $t$ in (2.15) and (2.21) becomes $p < t < p + M$.

### 2.2 Simulation estimators for models with unobserved heterogeneity

In this section two simulation estimators for models with unobserved random variables which need to be integrated out are discussed. The first method simulates the
vector of scores of the log-likelihood function in such a way that the resulting simulated score vector has expectation zero at the true parameter vector. A drawback of the method is that random variables need to be drawn from the distribution of the unobserved random variable, conditional on the observed random variable. The denominator of the expression for the conditional density function of the unobserved random variable, conditional on the observed random variable, is the marginal density function of the observed variable and this density contains the integral whose evaluation we want to avoid by making use of simulation techniques. Drawing from e.g. the marginal distribution introduces a bias in the simulation of the vector of scores and as a consequence the resulting estimator will be inconsistent. The second method, to be considered below, is called smooth simulated maximum likelihood estimation (SSML) as described by Börsch-Supan and Hajivassiliou (1991).

The likelihood function presented in the previous section is of the type in which an unobserved random variable is integrated out. Let the unknown random variable be denoted by \( x \) with marginal density \( f(x|\eta) \) and let the observed random variable, or vector of random variables, be denoted by \( y \), with density function conditional on \( x \) given by \( f(y|x;\eta) \), in which \( \eta \) is the vector of parameters. The log-likelihood contribution of a single individual is given by

\[
L(\eta|y) = \ln \left[ \int_{-\infty}^{\infty} f(y|x;\eta) f(x;\eta) dx \right]
\]

Suppose that by transformation the integral can be written as

\[
L(\eta|y) = \ln \left[ \int_{-\infty}^{\infty} f(y|u;\eta) \phi(u) du \right]
\]

where \( \phi(\cdot) \) is a density function which does not depend on the parameters of interest. In the context of the previous section \( \ln L_u(\eta) \) has the form of \( L(\eta|y) \), where \( d \) is a dummy variable taking on the value 1 for uncompleted spells and the value 0 for completed spells. Adding over all individuals the log-likelihood function becomes

\[
L(\eta;y_1,\ldots,y_N) = \frac{1}{N} \sum_{i=1}^{N} \ln \left( \int_{-\infty}^{\infty} f(y_i|u;\eta) \phi(u) du \right)
\]

assuming that the \( y_i \) are i.i.d. It is a well known property of the log-likelihood function that the expectation of the vector of scores equals zero at the true parameter vector \( \eta_0 \). It is this property that is exploited in the derivation of moment conditions. The vector of scores is:

\[
\frac{1}{N} \frac{\partial L(\eta;y_1,\ldots,y_N)}{\partial \eta} = \frac{1}{N} \sum_{i=1}^{N} \int_{-\infty}^{\infty} \frac{\partial f(y_i|u;\eta)}{\partial \eta} \phi(u) du
\]

The problem is that the integral appears in both the numerator and the denominator and if we want to exploit the possibility of keeping the number of drawings \( R \), used in the simulation, small, the simulator has to enter the moment conditions linearly, see, e.g. Gouriéroux and Montfort (1989). A simulator can be constructed in the following way. Draw \( R \) i.i.d. random numbers \( u_i \), from \( f(\cdot|y_i) \), the density of \( u \) conditional on
the observed value $y_i$, for every individual $i$, $i = 1, ..., N$, and use the moment functions $S(\eta; y_i, u_{i1}, ..., u_{ir}, i = 1, ..., N)$:

$$S(\eta; y_i, u_{i1}, ..., u_{ir}, i = 1, ..., N) = \frac{1}{N} \sum_{i=1}^{N} \sum_{r=1}^{R} \frac{\partial f(y_i|u_{ir}; \eta)}{f(y_i|u_{ir}; \eta)} \frac{\partial f(y_i|u_{ir}; \eta)}{f(y_i|u_{ir}; \eta)}$$

(2.27)

To show that $S(.)$ has the same expectation properties as the true vector of scores, we take the expectation with respect to the drawings $u_{ir}$, thereby conditioning on the $y_i, i = 1, ..., N$. The conditional distribution of $u_{ir}$ given $y_i$ is

$$f(u_{ir}|y_i) = \frac{f(y_i|u_{ir}; \eta)}{\int_{-\infty}^{\infty} f(y_i|\tilde{u}; \eta) \phi(\tilde{u}) d\tilde{u}}$$

(2.28)

Taking expectations yields

$$E(S(.)|y_i, i = 1, ..., N) = \frac{1}{N} \sum_{i=1}^{N} \sum_{r=1}^{R} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{\partial f(y_i|u_{ir}; \eta)}{f(y_i|\tilde{u}; \eta) \phi(\tilde{u})} d\tilde{u} = \frac{1}{N} \sum_{i=1}^{N} \int_{-\infty}^{\infty} f(y_i|\tilde{u}; \eta) \phi(\tilde{u}) d\tilde{u}$$

(2.29)

which equals the true vector of scores. As a consequence, at the true parameter vector $\eta_0$ the simulated moments conditions have expectations zero. In (2.12) we simulate of course only one term of the score vector, i.e. the derivative of

$$\frac{1}{N} \sum_{i=1}^{N} d_i \ln \left( \int_{-\infty}^{\infty} \exp(-\theta(\epsilon) M) g(\epsilon, \sigma^2) d\epsilon \right)$$

(2.30)

In the simulator of this expression, when taking the expectation w.r.t. the drawings $\epsilon_{ir}$, we have to condition on $d_i, i = 1, ..., N$.

The problem is that in general there is no rule of drawing random numbers from the conditional density (2.28) without having to evaluate the integral in the denominator of (2.28), which we do want to avoid by using simulation methods. In practice the only thing one can do is to approximate the procedure of drawing random numbers from (2.28) by using an approximate distribution. The most straightforward choice of approximation is to draw the random numbers from the conditional distribution $\phi(.)$ of $u$. At the same time this is also the most naive way of approximating the drawing of random numbers from the conditional distribution because any information about the observed values $y_i$ is ignored. We now investigate the bias which is introduced if the moments (2.27) are used with draws $u_{ir}$ from the marginal density $\phi(.)$. First of all note that the bias, i.e. the difference between of the expectation of (2.27) at the true parameter vector and zero, could be avoided by introducing a weight factor $w(u_{ir})$, like in importance sampling, which is the ratio of the true density function (2.28) and the density one actually draws from, in this case the marginal density function $\phi(.)$.

$$w(u_{ir}) = \frac{f(u_{ir}|y_i)}{\phi(u_{ir})} = \frac{f(y_i|u_{ir}; \eta)}{\int_{-\infty}^{\infty} f(y_i|\tilde{u}; \eta) \phi(\tilde{u}) d\tilde{u}}$$

(2.31)
which again contains the integral to be simulated. So in order to investigate the bias, we
have to look at the consequences of ignoring the weight function. Note that the expectation
of the weight function equals one by construction. As a consequence, the size of the
bias is closely related to the variance of the weight function. The smaller the variance
of the weight function, the smaller will be the bias in the simulated score equations, see
e.g. Kloek and Van Dijk (1978). (Note that the weight function is identically equal to
one if the \( u_{i,r} \) are drawn from the conditional density function \( f(.|y_i) \). The expectation
of the square of the weight function is given by:

\[
E_u \{ (w(u))^2 \} = \int_{-\infty}^{\infty} [w(u)]^2 \phi(u) du = \int_{-\infty}^{\infty} w(u)f(u|y_i) du
\]  

(2.32)

The addition to the score vector of individuals who accepted a job but whose after
spell job characteristics are unobserved can be simulated in exactly the same way. If
however, the bounds of the integral are a function of the parameters, like in (2.19), an
additional complication arises, i.e. we have to take the derivatives with respect to the
bounds. Suppose we have a likelihood addition given by

\[
L_i = \ln \left[ \int_{a_i(\eta)}^{b_i(\eta)} f(y_i|u;\eta)\phi(u)du \right]
\]  

(2.33)

Then the derivatives are:

\[
\frac{\partial L_i}{\partial a_i(\eta)} = \frac{\partial h_i(\eta)}{\partial a_i(\eta)} \frac{\partial f(y_i|u;\eta)}{\partial h_i(\eta)} \frac{\partial h_i(\eta)}{\partial a_i(\eta)} + \frac{\partial h_i(\eta)}{\partial a_i(\eta)} \frac{\partial f(y_i|u;\eta)}{\partial a_i(\eta)} \frac{\partial h_i(\eta)}{\partial a_i(\eta)}
\]  

(2.34)

The second part can be simulated in exactly the same way as described before, presuming
that it is possible to draw random numbers \( u_{ir} \) from \( (a_i(\eta), b_i(\eta)) \), without having to use
an acceptance/rejection scheme. The first part represents the derivatives of the probability
of being inside the region \( (a_i(\eta), b_i(\eta)) \), leaving the density unaffected, which can
straightforwardly be calculated provided that the bounds are known explicitly. However,
this is not the case in the previous section. Therefore, it is proposed to integrate out \( t, w \) and \( h \) and replace the derivative with respect to the bounds by

\[
- \int_{-\infty}^{\infty} \frac{\partial \xi(\epsilon)}{\partial \eta} \left[ 1 - \exp\{-\theta(\epsilon)M\} \right] \frac{f(\xi(\epsilon))}{T(\xi(\epsilon))}\xi(\epsilon)g(\epsilon, \sigma^2) d\epsilon
\]  

(2.35)

The motivation behind this expression can be found in appendix C. In executing this
procedure we have to incur an efficiency loss. However, the expression can still be seen
as a good representative for the derivative of the probability of being in the required
region. Simulation of the expression is straightforward.

A second simulation estimator can be obtained by simulating the likelihood function
rather than looking at the vector of scores. The integrals which appear in (2.25) are
replaced by a simulator. Unbiased simulators for the integrals can be obtained by drawing
random numbers \( u_{ir} \) from the marginal density \( \phi(.) \) and calculating

\[
\frac{1}{R} \sum_{r=1}^{R} f(y_i|u_{ir};\eta)
\]  

(2.36)
Because of the logarithmic transformation in (2.25) the resulting estimator will be inconsistent for a fixed and small value of $R$, which actually is the reason why we considered simulation estimators based on the vector of scores before. However, if the simulator is a smooth function of the parameters, which is the case here, the method functions satisfactory even for smaller values of $R$. This is shown in Börsch-Supan and Hajivassiliou (1991) in which they call this method smooth simulated maximum likelihood estimation, where they have added the word "smooth" in order to stress the fact that one needs a simulator which is a smooth function of the parameters rather than a frequency type of simulator in order to get a satisfactory performance.

### 2.3 Specification

In this subsection a specific functional form for the direct utility function is chosen, from which the labour supply function and the indirect utility function can be derived. We use the direct utility function of Hausman (1980).

\begin{equation}
\begin{aligned}
\ln(v, h; \mu) &= -\ln(\gamma - \beta h) - \frac{\beta(h - X\delta - \epsilon - \beta y)}{\gamma - \beta h}, \beta < 0, \gamma > 0 \\
\end{aligned}
\end{equation}

where $\epsilon$ is assumed to be normally distributed with mean zero and variance $\sigma_\epsilon^2$ and $X$ is a vector of individual characteristics. Note that utility is increasing in income as required by assumption 6. It can easily be verified that the second condition of assumption 6 is also satisfied.

Maximizing utility subject to the income equation for the employed yields a linear labour supply function in which the disturbance term equals the unobserved random taste parameter:

\begin{equation}
\begin{aligned}
h(w; \mu; \epsilon) &= \beta \mu + \gamma w + X\delta + \epsilon \\
\end{aligned}
\end{equation}

The virtual wage rate $w_0(\epsilon)$, for which optimal labour supply is exactly equal to zero, defined in (2.8), is given by

\begin{equation}
\begin{aligned}
w_0(\epsilon) &= -\frac{\beta \mu + X\delta + \epsilon}{\gamma} \\
\end{aligned}
\end{equation}

Note that there are no positivity constraints on this value. The dynamic reservation wage $\xi(\epsilon)$ will always be higher than this value. Inserting the labour supply function (2.38) into the direct utility function (2.37) yields the expression for the indirect utility function:

\begin{equation}
\begin{aligned}
\nu(w, \mu; \epsilon) &= -\ln(\gamma - \beta X\delta - \beta \epsilon - \beta \gamma w - \beta^2 \mu) - \beta w \\
\end{aligned}
\end{equation}

which is well defined for all $w \geq w_0(\epsilon)$ and therefore for all $w \geq \xi(\epsilon)$.

The wage offer distribution is taken to be log-normal with log-mean $\zeta'z$ and log-variance $\tau$ respectively, where $z$ is a vector of individual characteristics. Measurement error $v$ is assumed to be normally distributed with mean zero and variance $\sigma_v^2$. The error $v$ allows for difference between optimal labour supply, generated by the labour supply function (2.38), and observed labour supply. The job offer arrival rate can also be made dependent on a vector of characteristics $z$ by specifying

\begin{equation}
\begin{aligned}
\lambda &= \exp(\kappa'z) \\
\end{aligned}
\end{equation}
Characteristics which may influence the arrival rate of job offers are individual characteristics like age and sector of education, as well as characteristics of the environment of the individual like the geographical situation.

2.4 The data

The data are obtained from the Socio-Economic Panel (SEP), which is a survey carried out in the Netherlands every half a year in April and October by the Central Bureau of Statistics (CBS). In the survey the participating individuals are asked to report their occupational status for every month in the past half year. The data which are used are those of the wave of the survey in October 1985 up to the wave in October 1987, which implies that the observation period is two and a half years. Selected are male individuals who reported to be unemployed in any month during the observation period, which means that the sample partly has a stock character and partly a flow character. It has been determined how many months they remained unemployed, and for the individuals in the stock sample the backward recurrence times are gathered as well. For most of the individuals whose unemployment spell ended during the observation period, data on their after spell hourly wage rate and the weekly number of hours are available. The sample consists of 516 individuals. The number of complete unemployment spells is 272. The remaining 244 spells are truncated. For 211 of the 272 individuals whose unemployment spells are completed the after spell job characteristics, i.e. the hourly wage rate and the weekly number of working hours, are observed.

Looking at the data on the completed unemployment spells we see that peaks in the frequencies of unemployment durations can be found every half a year in the months where the survey on the preceding half year is conducted. In figure 2.1 the frequencies of the completed unemployment spells of the flow sample and the forward recurrence times of the stock sample are plotted and the peaks are at duration levels of 6, 12, 18 and 24 months. The peak observations are apparently the result of misreporting and as a result the data on unemployment durations in units of one month are unreliable. Therefore, the durations in units of one month are divided into groups of half a year. The likelihood contribution then becomes the probability that the unemployment spell ends somewhere in the observed interval of half a year.

In table 2.1 some sample statistics are given. In the survey there are five levels of education where level 1 is the lowest and level 5 the highest. The mode of the level of education is 2. We have divided the Netherlands into four regions. Region 1 is the most strongly industrialized part of the Netherlands which includes the larger cities. Region 4 is the least industrialized part of the Netherlands with a relatively low population density and a sizeable agricultural sector. Region 3 is the south of the Netherlands which contains some large companies and agricultural industry. In region 2 (the east) there is a mix of industry and agriculture. Apart from having information about the level of education we have information available about the type or sector of education. Sector 1 is the technical sector which includes chemics, physics, mathematics and biology, sector 2 includes the economic and administrative directions, sector 3 is general education and sector 4 includes services.

In table 2.2 estimates obtained with simulated maximum likelihood, using $R = 10$
drawings are presented. According to the estimates of the utility parameters, optimal labour supply is not very sensitive with respect to non-labour income and the wage rate. The wage elasticity of labour supply is 0.0996. Family size has a positive effect on the optimal amount of labour supply. Age has a negative effect on the job offer arrival rate, i.e. the older one is, the fewer job offers can be expected. The nationality dummy, which is one for those who do not have the Dutch nationality, is negative, indicating that having the Dutch nationality influences the job offer arrival rate positively. The regional dummies have a positive sign, which means a higher job offer arrival rate for people living outside the agricultural region 4. Only the dummies for region 1 and region 3 are significant. Living in the industrial west is associated with a higher job offer arrival rate than living in the rest of the country. Only the sectoral dummy for sector 3 which includes those individuals who only had a general type of education, i.e. no specialisation in a certain profession, is significant. The highest wages are offered to the individuals with the highest level of education.

The parameter estimate of $\rho$ is 0.00492. As unemployment duration is measured in months, this means that the monthly discount rate is 0.49%, or equivalently, the discount rate is 5.9% per year.

As noted before, estimates obtained by Narendranathan and Nickell (1985) and Van den Berg (1990c) showed that unemployment, i.e. total leisure, was assigned a lower utility value than employment. Their reservation wage equation is of the form

$$u(\xi + \mu) - \omega u(b + \mu) = \frac{1}{\rho} \int_{\xi}^{\infty} (u(x) - u(\xi)) \, dF(x)$$

(2.42)

in which $\omega$ is the utility parameter whose estimates have been found to be less than one. Now note that the right hand side of (2.42) is always positive from which we can derive that

$$u(\xi + \mu) > \omega u(b + \mu)$$

(2.43)

Now $\omega \geq 1$ implies that the reservation wage rate $\xi$ is always higher than the benefit rate $b$. However, if $\omega < 1$, the reservation wage rate is allowed to be lower than the benefit rate. Of course, a value of the reservation wage rate which is actually below the benefit rate indicates that unemployment must have a lower utility value than employment. Our specification has enough flexibility for the labour income at the reservation wage rate to be below the income from benefits, but at the same time it cannot be checked directly by looking at a single parameter whether unemployment is valued lower than employment. Therefore, it makes sense to run a simulation by drawing random preferences $\epsilon$ for each individual, calculating the reservation wage rate $\xi(\epsilon)$, computing the optimal labour income at the reservation wage rate if $\xi(\epsilon) > 0$, i.e. $\xi(\epsilon) \bar{h}(\xi(\epsilon), \mu; \epsilon)$ and comparing it with the benefit income $b$. This procedure was repeated 100 times and the result is that for 87% of the sample the reservation income is lower than the benefit income. The reason for this high percentage is the fact that 70% of the individuals in the sample is working about 40 hours a week. In the context of this model, in which individuals are assumed to choose their amount of labour supply optimally, this means that these individuals are working 40 hours a week because they like to work 40 hours a week. As a consequence, the virtual wage rate $w_0(\epsilon)$, given in (2.39), is relatively low. Although the reservation wage rate $\xi(\epsilon)$ always exceeds the virtual wage rate, these individual
preferences with respect to labour supply result in a low reservation wage rate as well. This result is consistent with the findings of Narendranathan and Nickell (1985) and Van den Berg (1990c) who have estimated a value of $\omega$ in (2.42) that is smaller than 1, i.e. unemployment lowers utility.

<table>
<thead>
<tr>
<th>variable</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>working hours (hours/week)</td>
<td>39.0</td>
<td>9.1</td>
</tr>
<tr>
<td>after tax hourly wage rate (guilders/hour)</td>
<td>10.1</td>
<td>4.5</td>
</tr>
<tr>
<td>benefits (guilders/week)</td>
<td>289.6</td>
<td>108.2</td>
</tr>
<tr>
<td>non-labour income (guilders/week)</td>
<td>80.4</td>
<td>188.8</td>
</tr>
<tr>
<td>age</td>
<td>31.2</td>
<td>11.8</td>
</tr>
<tr>
<td>family size (persons)</td>
<td>3.2</td>
<td>1.7</td>
</tr>
<tr>
<td>education level</td>
<td>mode 2</td>
<td></td>
</tr>
<tr>
<td>Dutch nationality</td>
<td>93.6%</td>
<td></td>
</tr>
<tr>
<td>region 1 (industrialized west)</td>
<td>31.6%</td>
<td></td>
</tr>
<tr>
<td>region 2 (east)</td>
<td>29.3%</td>
<td></td>
</tr>
<tr>
<td>region 3 (south)</td>
<td>26.6%</td>
<td></td>
</tr>
<tr>
<td>region 4 (agricultural)</td>
<td>12.6%</td>
<td></td>
</tr>
<tr>
<td>sector of education 1 (technical)</td>
<td>30.4%</td>
<td></td>
</tr>
<tr>
<td>sector of education 2 (economic/administrative)</td>
<td>8.7%</td>
<td></td>
</tr>
<tr>
<td>sector of education 3 (no specialization)</td>
<td>48.8%</td>
<td></td>
</tr>
<tr>
<td>sector of education 4 (services)</td>
<td>12.0%</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2.1: Unemployment duration in months, completed spells and forward recurrence times

duration in months

Figure 2.2: Unemployment duration 0.5 years, completed spells and forward recurrence times

duration in half years
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate 1</th>
<th>Estimate 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>-2.479 x 10^{-5}</td>
<td>1.301 x 10^{-5}</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.378</td>
<td>0.251</td>
</tr>
<tr>
<td>( \delta_1 ), Constant</td>
<td>32.076</td>
<td>2.454</td>
</tr>
<tr>
<td>( \delta_2 ), Log family size</td>
<td>2.064</td>
<td>1.790</td>
</tr>
<tr>
<td>( \sigma_v )</td>
<td>1.488</td>
<td>0.0286</td>
</tr>
<tr>
<td>( \kappa_1 ), Constant</td>
<td>0.462</td>
<td>0.320</td>
</tr>
<tr>
<td>( \kappa_2 ), Log age</td>
<td>-0.215</td>
<td>0.478</td>
</tr>
<tr>
<td>( \kappa_3 ), Nationality</td>
<td>-0.958</td>
<td>0.351</td>
</tr>
<tr>
<td>( \kappa_4 ), Region 1</td>
<td>0.676</td>
<td>0.202</td>
</tr>
<tr>
<td>( \kappa_5 ), Region 2</td>
<td>0.312</td>
<td>0.195</td>
</tr>
<tr>
<td>( \kappa_6 ), Region 3</td>
<td>0.470</td>
<td>0.204</td>
</tr>
<tr>
<td>( \kappa_7 ), Sector 1</td>
<td>-0.0748</td>
<td>0.218</td>
</tr>
<tr>
<td>( \kappa_8 ), Sector 2</td>
<td>-0.293</td>
<td>0.304</td>
</tr>
<tr>
<td>( \kappa_9 ), Sector 3</td>
<td>-0.546</td>
<td>0.214</td>
</tr>
<tr>
<td>( \kappa_{10} ), Square of log age</td>
<td>-0.235</td>
<td>0.604</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0.00492</td>
<td>1.008</td>
</tr>
<tr>
<td>( \zeta_1 ), Constant</td>
<td>-12.084</td>
<td>3.135</td>
</tr>
<tr>
<td>( \zeta_2 ), Log age</td>
<td>8.088</td>
<td>1.874</td>
</tr>
<tr>
<td>( \zeta_3 ), Square of log age</td>
<td>-1.104</td>
<td>0.279</td>
</tr>
<tr>
<td>( \zeta_4 ), educ1</td>
<td>-0.329</td>
<td>0.0856</td>
</tr>
<tr>
<td>( \zeta_5 ), educ2</td>
<td>-0.289</td>
<td>0.0789</td>
</tr>
<tr>
<td>( \zeta_6 ), educ3</td>
<td>-0.165</td>
<td>0.0797</td>
</tr>
<tr>
<td>( \tau )</td>
<td>0.293</td>
<td>0.0104</td>
</tr>
<tr>
<td>( \sigma_v )</td>
<td>0.312</td>
<td>0.0909</td>
</tr>
</tbody>
</table>

**TABLE 2.2 ESTIMATION RESULTS WITH SIMULATED MAXIMUM LIKELIHOOD, \( R = 10 \)**
3 Job search with hours restrictions

3.1 The model

In general when looking at pictures of frequency distributions of labour supply data one can hardly maintain the assumption that these data can be described by a standard neo-classical micro-econometric labour supply model. Spikes can be observed in the empirical probability mass functions at weekly numbers of hours like 40. In the literature there exist different explanations for the presence of this concentration of labour supply at certain amounts of hours, but all these explanations have in common that they, in one way or another, refer to the demand side of the labour market. The theory of compensating wage differentials, see for example Abowd and Ashenfelter (1981), assumes that employers offer hours quantities like 40 and that employers are compensated by means of a higher wage rate for the loss in utility they experience by being over- or underemployed. Because of this compensation the individual is not constrained in the sense that the same utility level is acquired as in the case in which the individual could determine hours by utility maximization without wage compensation. The emphasis is on the wage function, which describes wages as a function of hours, rather than on a labour supply function. Although it is plausible that individuals within their job are compensated for working overtime hours, over and above the amount of hours agreed to in the labour contract, it is doubtful whether wage rates at spike levels are systematically higher. Especially in an economy with unemployment the employers need not to raise wages in order to satisfy their demand for labour.

The second point of view, then, is that individuals are not compensated for being under- or overemployed. Moffitt (1982) recognizes that there exist relatively few jobs with hours in the part time range. He models this by adapting the standard Tobit model. Dickens and Lundberg (1985) assume that individuals are constrained by the hours that are offered to them by the employers. Their framework is static and assumes that at a point in time the individuals receives a random amount of job offers (possibly zero) from which they choose the offer which yields the highest level of utility. This utility level is compared with the utility of not working, after which it is decided whether or not to accept the job. All job offers have the same gross wage rate but may differ in the number of hours. The hours offer distribution is modelled by means of a discrete probability distribution. The idea was applied by Tummers and Woittiez (1991), Van Soest, Woitzies and Kapteyn (1990). Bloemen (1991) dropped the assumption of having the same wage rate for every job offer. In fact, his model can be interpreted as a static version of the model presented here.

Instead of jobs arriving at a given point in time, we now assume that job offers arrive sequentially, like in the previous section. But in contrast, a job offer now consists of both a wage rate and an amount of weekly working hours. Individuals will evaluate the utility level of jobs, comparing them with the value of not accepting the job taking into account possible future job offers. Individuals are constrained in hours offered to them and therefore, unlike the standard job search framework, the wage rate is not the only job characteristic which is needed to decide whether or not to accept a job. Instead of having a reservation wage it can be derived that there exists a unique reservation
utility level. Jobs, i.e. wage-hours combinations, which generate a utility level which is higher than the reservation utility level are accepted, those with a utility level below are rejected.

More formally, assumption 1 in section 2.1, which states that individuals are utility maximizers in the neo-classical sense, is replaced by the assumption that hours arrive from an hours offer distribution, just like the wage rate. The equation for the reservation utility level is derived in appendix B. It is given by

\[ \bar{u}(\epsilon) = u(b + \mu, 0; \epsilon) + \frac{\lambda}{\rho} \int_{0}^{\infty} \int_{\xi(\bar{u}(\epsilon); \epsilon)}^{\infty} \left[ u(wh + \mu, h; \epsilon) - \bar{u}(\epsilon) \right] f(w, h) dwdh \] (3.1)

where \( \bar{u}(\epsilon) \) is the reservation utility level at random taste parameter \( \epsilon \), \( f(w, h) \) is the joint wage-hours offer distribution and \( \xi(h, \bar{u}(\epsilon); \epsilon) \) is the wage rate which generates utility level \( \bar{u}(\epsilon) \) at hours \( h \). The wage rate \( \xi(h, \bar{u}(\epsilon); \epsilon) \) can be interpreted as an hours dependent reservation wage rate. The sign of the derivative of \( \xi(h, \bar{u}(\epsilon); \epsilon) \) with respect to hours \( h \) depends on whether the individual is over- or underemployed at wage level \( \xi(h, \bar{u}(\epsilon); \epsilon) \) and the given value of hours. If an individual is overemployed an increase in hours moves utility further away from its unconstrained value and consequently the hours dependent reservation wage rate rises, thereby increasing the reluctance to accept a job. And vice versa for underemployment. As a result the reservation wage rate does not depend on hours if the individual is not constrained in the choice of hours, which leads back to the model in section 2.

In case of a discrete hours offer distribution the outer integral is replaced by summation.

The resulting expression for the escape rate becomes

\[ \theta(\epsilon) = \lambda \int_{0}^{\infty} \int_{\xi(\bar{u}(\epsilon); \epsilon)}^{\infty} f(w, h) dwdh \] (3.2)

Taking into account the different functional form of the escape rate, the likelihood contributions of individuals who did not accept a job during the observation period and those who did, but whose after spell wage rate and hours are not observed, are the same as in the previous section in (2.12) and (2.21) respectively. For the individuals whose after spell wage-hours pair is observed to be \( (w, h) \), and, again, the observed wage rate is truncated, conditional on hours and on \( \epsilon \), which leads to the likelihood contribution, conditional on \( \epsilon \):

\[ l_{\infty}(\eta|\epsilon) = \theta(\epsilon) \exp\{-\theta(\epsilon)t\} f(w, h)/Q(\epsilon), \]
\[ 0 < t < M, h > 0, w > \max\{0, \xi(h, \bar{u}(\epsilon); \epsilon)\} \]
\[ 0 \text{ otherwise} \] (3.4)

where \( Q(\epsilon) \) is the truncation probability, given by

\[ Q(\epsilon) = \int_{0}^{\infty} \int_{\xi(\bar{u}(\epsilon); \epsilon)}^{\infty} f(w, h) dwdh \] (3.5)
The unconditional likelihood function is obtained by integrating over those values of \( \epsilon \) for which the utility level evaluated in \((w, h)\) exceeds the reservation utility level.

\[
I_{\text{unconditional}}(\eta) = \int_{I_{\text{wh}}} \theta(\epsilon) \exp\{-\theta(\epsilon)t\} \frac{f(w, h)}{Q(\epsilon)} g(\epsilon, \sigma^2) d\epsilon, \quad t > 0, \ h > 0, \ w > 0
\]  

(3.6)

where the set \( I_{\text{wh}} \) is given by

\[
I_{\text{wh}} = \{\epsilon | u(w + \mu, h | \epsilon) > \bar{u}(\epsilon)\}
\]  

(3.7)

The set \( I(w, h) \) has to be non-empty for every \((w, h)\) with \( w > 0, h > 0 \).

For the individuals in the stock sample the expression (2.22) for the probability of \( t \) exceeding \( p \) can be used, taking into account that \( \theta(\epsilon) \) is now determined by (3.2).

### 3.2 Specification

For the utility function we take the specification of section 2.3 given in (2.34). The spikes in the empirical hours distribution suggest the use of a discrete hours offer distribution of the Dickens and Lundberg (1985) type. However, we are hampered by the fact that 68% of the observed labour supply is at values of 38 or 40 hours a week, making it impossible to identify probabilities of low or high levels of labour supply. Therefore, only a rough distinction is made between part time jobs (32 hours or less), full time jobs of normal levels (33 to 44 hours a week) and full time jobs of high levels (more than 44). The hours are categorized in classes of four, which yields 20 classes of hours from 1 to 80. The probability of getting a job offer from class \( l \) is given by

\[
P(h = h_l) = p_l, \ l = 1, ..., m, m = 20
\]  

(3.8)

The probabilities can parametrized by

\[
p_l = \frac{\mu_l}{\sum_{j=1}^{m} \mu_j}, \ l = 1, ..., m, m = 20
\]  

(3.9)

where the normalization

\[
\mu_m = 1
\]  

(3.10)

is made. The distinction made between part time and full time jobs can be expressed in the following restrictions:

\[
\mu_1 = \ldots = \mu_8 : \text{part time jobs}
\]  

(3.11)

\[
\mu_9 = \mu_{10} = \mu_{11} : \text{normal full time jobs}
\]  

(3.12)

\[
\mu_{12} = \ldots = \mu_{20} : \text{high level jobs}
\]  

(3.13)

Again, it is assumed that wages arise from a log-normal wage offer distribution with log-variance \( \tau \) and log-mean \( \zeta'x \). The wage offer density function is

\[
f(w) = \frac{1}{\sqrt{2\pi \tau} w} \exp\left\{-\frac{1}{2\tau^2} (\ln w - \zeta'x)^2\right\}, \ 0 < w < \infty
\]  

(3.14)
Using the discrete hours offer distribution and the wage offer distribution the reservation utility equation becomes

$$\tilde{u}(e) = u(b + \mu, 0; e) + \frac{\lambda}{\rho} \sum_{i=1}^{m} p_i \int_{\xi(h_i, \tilde{u}(e); e)}^{\infty} \left[ u(wh_i + \mu, h_i; e) - \tilde{u}(e) \right] f(w) dw$$

(3.15)

A similar expression can be found for the escape rate $\theta(e)$:

$$\theta(e) = \sum_{i=1}^{m} p_i \int_{\xi(h_i, \tilde{u}(e); e)}^{\infty} f(w) dw = \lambda \sum_{i=1}^{m} p_i \tilde{F}(\xi(h_i, \tilde{u}(e); e))$$

(3.16)

In the previous section the assumption has been made that only preferences depend on unobserved individual characteristics $e$. Now we will assume that the job offer arrival rate also depends on an unobserved random variable $q$, known to the individual, which is independent of $e$ and which is normally distributed with mean zero and variance $\sigma_q^2$. Inclusion of $q$ in the job offer arrival rate at the same time ensures that the set $I_{wh}$ defined in (3.7) is non-empty, i.e. for every observed job offer $(w, h)$ there exists an $e$ such that $u(wh + \mu, h; e) > \tilde{u}(e)$ which is consistent with the fact that we do observe $(w, h)$. The job offer arrival rate becomes

$$\lambda(q) = \exp(\kappa'z + q)$$

(3.17)

In table 3.1 estimates obtained with simulated maximum likelihood (SSML) using $R = 10$ drawings are presented. This model generates estimates of $\beta$ and $\gamma$ which are clearly different from the estimates of the model in the previous section. The reason for this is that in the neo-classical model in section 2 the parameter estimates of the utility function are mainly determined by the labour supply data, because of the assumption that hours are chosen by the individuals according to their preferences. In the neo-classical model the presence of a spike at 40 hours a week in the labour supply data can only be explained by inelastic labour supply, whereas in the present model with hours restrictions the alternative explanation for the spike is given by the presence of demand side restrictions.

Again we see a positive effect of family size. The variance $\sigma_\lambda$ of the unobserved heterogeneity in the job offer arrival rate is not very large. From the regional dummies, only the dummy variable for region 1, the industrialized western part of the Netherlands, is significant. The only significant sectoral dummy is that for sector 3, which is the sector of individuals who are not specialized in a certain profession. The sign of the estimate is negative.

The estimate of $\rho$ is 0.688 which is equivalent to a monthly discount rate of almost 70\%, which is rather high. In section 2.1, however, it was recognized that one should be careful in interpreting the estimate of $\rho$. For example, if assumption 5 in section 2.1 is replaced by the assumption that there is an exogenous layoff rate, the estimate of $\rho$ should be interpreted as the sum of this layoff rate and the discount rate. Equivalently, the ignorance of other possibly relevant labour market states changes the interpretation of the estimate of $\rho$ in a similar way, see e.g. Van den Berg (1990c).

To compare the labour income evaluated at the reservation wage rate, we run the same kind of simulation procedure as in the previous section. We compare the expected
reservation income with the benefit level $b$. The expected reservation income has been defined by:

$$
\sum_{i=1}^{m} p_i \xi(h_t, \bar{u}(e); \epsilon) \mathbb{I}(\xi(h_t, \bar{u}(e); \epsilon) > 0)
$$

in which $\mathbb{I}(\cdot)$ is the indicator function. The number of replications is 100. For 98.7% of the number of individuals in the sample, the expected reservation income in the sample is higher than the benefit level. This result is not consistent with a disutility of unemployment ($\omega < 1$ in (2.42)). An explanation for the low reservation income in the neo-classical model has already been given in section 2.4. Apart from that explanation, there is an additional explanation why the reservation income defined in (3.19) may be higher than the reservation income in section 2.4. In section 3.1 it has been explained that the larger is the deviation of offered hours from optimal labour supply, the higher will be the hours dependent reservation wage rate $\xi(h, \bar{u}(e); \epsilon)$. The hours dependent reservation wages are higher because the individual gets hours offers that do not coincide with optimal labour supply. So even if the reservation wages were evaluated in the same parameter values for both models, the reservation wage of the model with hours restrictions will be higher than the reservation wage of the neo-classical model. As the hours offer probabilities are large in the full time range, the reservation income in (3.19) is likely to be higher than the neo-classical reservation income as well.
TABLE 3.1 ESTIMATION RESULTS WITH SIMULATED MAXIMUM LIKELIHOOD, R = 10

<table>
<thead>
<tr>
<th>THE UTILITY PARAMETERS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>-0.0123</td>
<td>0.0107</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.726</td>
<td>0.968</td>
</tr>
<tr>
<td>$\delta_1$, Constant</td>
<td>27.478</td>
<td>10.523</td>
</tr>
<tr>
<td>$\delta_2$, Log family size</td>
<td>8.576</td>
<td>4.386</td>
</tr>
<tr>
<td>$\sigma_e$</td>
<td>21.334</td>
<td>14.945</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THE JOB OFFER ARRIVAL RATE PARAMETERS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_\lambda$</td>
<td>0.000963</td>
<td>0.228</td>
</tr>
<tr>
<td>$\kappa_1$, Constant</td>
<td>1.239</td>
<td>0.818</td>
</tr>
<tr>
<td>$\kappa_2$, Log age</td>
<td>-0.327</td>
<td>0.585</td>
</tr>
<tr>
<td>$\kappa_3$, Nationality</td>
<td>-0.872</td>
<td>0.378</td>
</tr>
<tr>
<td>$\kappa_4$, Region 1</td>
<td>0.720</td>
<td>0.257</td>
</tr>
<tr>
<td>$\kappa_5$, Region 2</td>
<td>0.182</td>
<td>0.247</td>
</tr>
<tr>
<td>$\kappa_6$, Region 3</td>
<td>0.232</td>
<td>0.256</td>
</tr>
<tr>
<td>$\kappa_7$, Sector 1</td>
<td>-0.00988</td>
<td>0.250</td>
</tr>
<tr>
<td>$\kappa_8$, Sector 2</td>
<td>-0.574</td>
<td>0.342</td>
</tr>
<tr>
<td>$\kappa_9$, Sector 3</td>
<td>-0.572</td>
<td>0.248</td>
</tr>
<tr>
<td>$\kappa_{10}$, Square of log age</td>
<td>-0.230</td>
<td>0.114</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RATE OF TIME PREFERENCE</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>0.688</td>
<td>3.576</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THE WAGE DISTRIBUTION</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\zeta_1$, Constant</td>
<td>-12.502</td>
<td>3.181</td>
</tr>
<tr>
<td>$\zeta_2$, Log age</td>
<td>8.287</td>
<td>1.903</td>
</tr>
<tr>
<td>$\zeta_3$, Square of log age</td>
<td>-1.129</td>
<td>0.284</td>
</tr>
<tr>
<td>$\zeta_4$, educ1</td>
<td>-0.320</td>
<td>0.0823</td>
</tr>
<tr>
<td>$\zeta_5$, educ2</td>
<td>-0.276</td>
<td>0.0776</td>
</tr>
<tr>
<td>$\zeta_6$, educ3</td>
<td>-0.144</td>
<td>0.0111</td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.288</td>
<td>0.0111</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROBABILITIES OF HOURS DISTRIBUTION</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_1 = \ldots = p_8$ part time</td>
<td>0.0204</td>
<td>0.00373</td>
</tr>
<tr>
<td>$p_9 = \ldots = p_{11}$ full time</td>
<td>0.251</td>
<td>0.0114</td>
</tr>
<tr>
<td>$p_{12} = \ldots = p_{20}$ high level jobs</td>
<td>0.00944</td>
<td>0.00217</td>
</tr>
</tbody>
</table>
4 Residual analysis and simulated frequencies

In order to be able to say something about the performance of the two models we will do some residual analysis. An overview of residual analysis of duration models can be found in Lancaster (1990) and Cox and Oakes (1984). There are two points according to which the standard residual analysis in duration models cannot be applied directly to our models. The first point is that this analysis is usually performed in the context of a flow sample, whereas we have a sample which consists of a flow subsample as well as a stock subsample. Therefore, in the analysis of the residuals we restrict ourselves to the individuals who are in the flow subsample. The second point is that residual analysis is usually performed on models which do not contain a random unobserved heterogeneity component. This problem is solved in the following way. The marginal density of observed duration $t$ is given by $f(t)$.

$$f(t) = \int_{-\infty}^{\infty} \theta(\tilde{e}) \exp\{-\theta(\tilde{e})t\} g(\tilde{e}, \sigma^2) d\tilde{e}, 0 < t < \infty$$ (4.1)

The density of the unobserved heterogeneity variable $\epsilon$, conditional on observed duration $t$ is given by

$$g(\epsilon|t) = \frac{\theta(\epsilon) \exp\{-\theta(\epsilon)t\} g(\epsilon, \sigma^2)}{\int_{-\infty}^{\infty} \theta(\tilde{e}) \exp\{-\theta(\tilde{e})t\} g(\tilde{e}, \sigma^2) d\tilde{e}, -\infty < \epsilon < \infty$$ (4.2)

Now draw a random number $\epsilon$ from $g(.|t)$. This can be done by using the inversion method, see e.g. Devroye (1986). Then the pair $(t, \epsilon)$ can be seen as a joint draw from

$$f(t)g(\epsilon|t) = \theta(\epsilon) \exp\{-\theta(\epsilon)t\} g(\epsilon, \sigma^2), 0 < t < \infty, -\infty < \epsilon < \infty$$ (4.3)

Consider the following transformation:

$$\vartheta = \theta(\epsilon)t$$
$$\epsilon = \epsilon$$ (4.4)

The jacobian of the transformation is $1/\theta(\epsilon)$. The joint density of $\vartheta$ and $\epsilon$ becomes

$$f \left( \begin{array}{c} \vartheta \\ \epsilon \end{array} \right) g \left( \epsilon | \vartheta \right) = \exp\{-\vartheta\} g(\epsilon, \sigma^2), 0 < \vartheta < \infty, -\infty < \epsilon < \infty$$ (4.5)

which implies that $\vartheta$ is exponentially distributed with parameter 1, which enables us to apply the standard residual analysis. Summarizing, the procedure is:

- Draw $\epsilon$ from $g(.|t)$, where $g(.|t)$ is evaluated in the parameter estimates and $t$ is observed duration

- Calculate $\hat{\vartheta}_r = \hat{\theta}(\epsilon_r)t = \theta(\epsilon_r, \hat{\eta})t$ in which $\hat{\theta}(\epsilon_r)$ is the hazard rate evaluated in the parameter estimate $\hat{\eta}$. $\hat{\vartheta}_r$ is the simulated residual. For every individual, several residuals can be calculated by drawing several random numbers.

- Calculate the Kaplan-Meier estimate of the survivor function in the residuals $\hat{\vartheta}_r, i = 1, ..., N, r = 1, ..., R$, in which the subindex $i$ is over individuals and the subindex $r$ is over different draws from the conditional density.
The residuals can be plotted against minus the logarithm of the Kaplan-Meier estimate. If the parametric model is correctly specified, the plot would be approximately a 45 degree line. Various forms of misspecification of the hazard rate can cause the residual plot to deviate from the 45 degree line. Lancaster (1990) shows that omitting an unobserved heterogeneity factor in the hazard rate leads to underdispersion, i.e. the plot will be below the 45 degree line. In particular interesting for our application are the deviations which are caused by wrongly assuming that the hazard rate is constant, i.e. the stationarity assumption. Ridder (1987) shows that when the data inhibit positive duration dependence, whereas a constant hazard model is estimated, the residual plot will be above the 45 degree line. In case of negative duration dependence of the hazard rate the reverse holds.

For every individual, five residuals have been simulated. Figure 4.1 shows the plot of minus the logarithm of the Kaplan-Meier estimate versus the residuals for model 1, whose estimates were presented in table 2.2. Figure 4.2 shows the same plot for model 2, based on the estimates in table 3.1. For both models the plot is above the 45 degree line, indicating that there could be positive duration dependence. However, for model 2 the deviations are much less severe than for model 1. In the figures 4.3 and 4.4 the Kaplan-Meier survivor functions and the exponential survivor functions are plotted. The plots reveal that even though the parameter estimates of the job offer arrival rate show similar effects for both models, the misspecification of model 2, in which individuals are faced by hours restrictions on the labour market, is much less severe than in model 1.

Figure 4.5 shows the frequency distribution of simulated hours, conditional on observed wages, for model 1, the model without hours restrictions, and the sample frequencies of observed hours. In this figure hours are divided in three categories, i.e. part time jobs, full time jobs and high level jobs, and the frequencies shown in the figure are the frequencies of these categories. The distinction between the categories has been described in section 3.2. The density of hours, conditional on wages can be derived from (2.19). It is given by

\[ r(h|w) = \frac{\int_{\epsilon} r(h|w, \epsilon) \frac{1}{T(\epsilon)} g(\epsilon, \sigma^2) d\epsilon}{\int_{\epsilon} \frac{1}{T(\epsilon)} g(\epsilon, \sigma^2) d\epsilon}, 0 < h < \infty \]  

(4.6)

To simulate labour supply, conditional on the observed wage rate, \( \epsilon \) is drawn from \( g(\epsilon, \sigma^2) \) restricted to the region \( I_\omega \). Optimal labour supply can then be calculated from (2.13) or, more specific, from (2.38), after which a measurement error \( v \) is drawn to simulated observed labour supply by (2.14).

Figure 4.6 shows the frequency distribution of simulated hours for model 2, the model with hours restrictions, and the sample distribution of observed hours. The distribution of hours for the second model can be derived from (3.6). It is given by

\[ p_l \int_{-\infty}^{\infty} \frac{\bar{F}(\xi(h_l, \bar{u}(\epsilon); \epsilon))}{Q(\epsilon)} g(\epsilon, \sigma^2) d\epsilon, l = 1, ..., m \]  

(4.7)

These are the probabilities of observing \( h_l, l = 1, ..., m \). A value for \( \epsilon \) is drawn from \( g(\epsilon, \sigma^2) \), which makes it possible to calculate \( \bar{u}(\epsilon) \). Then

\[ \frac{\bar{F}(\xi(h_l, \bar{u}(\epsilon); \epsilon))}{Q(\epsilon)} p_l \]  

(4.8)
is calculated for \( l = 1, \ldots, m \). Uniform random variates on the interval \((0,1)\), together with the probabilities in (4.8), are used to determine a simulated value for \( h_l \). Comparing figure 4.5 with figure 4.6, we see that for the model with hours restrictions the sample distribution of observed hours is fitted much better than for the model without hours restrictions.

Figure 4.7 shows the frequencies of simulated wages and the sample frequencies of wages for model 1. Again, the density of observed wages for model 1 can be determined from (2.19). It is given by

\[
\int_{I_w} \frac{f(w)}{T(e)} g(\varepsilon, \sigma^2_e) d\varepsilon, 0 < w < \infty
\]  \hspace{1cm} (4.9)

A wage rate is simulated by first drawing a value for \( e \) from \( g(\varepsilon, \sigma^2_e) \) and calculating \( \xi(e) \), after which a wage rate is drawn from \( f(w) \), restricted to the region \((\xi(e), \infty)\). For model 2 the frequencies of simulated wages can be found in figure 4.8. The marginal distribution of wages, derived from (3.6) is

\[
\sum_{l=1}^{m} p_l \int_{I_{w_h_l}} \frac{f(w)}{Q(\varepsilon)} g(\varepsilon, \sigma^2_e) d\varepsilon, 0 < w < \infty
\]  \hspace{1cm} (4.10)

A value for \( h_l \) is drawn from the hours offer distribution, \( e \) is drawn from \( g(\varepsilon, \sigma^2_e) \) after which a wage rate is drawn from \( f(w) \) restricted to the region \((\xi(h_l, \bar{u}(e); e), \infty)\). Comparing the figures (4.7) and (4.8), we see that there is not much difference between the two models.
Figure 4.1 Model 1: $-\log(\text{Kaplan-Meier})$ vs. residuals

Figure 4.2 Model 2: $-\log(\text{Kaplan-Meier})$ vs. residuals
Figure 4.3 Model 1: Kaplan-Meier survivor function

Figure 4.4 Model 2: Kaplan-Meier survivor function
Figure 4.5 Frequencies of working hours per week: Model 1

Figure 4.6 Frequencies of working hours per week: Model 2
Figure 4.7 Frequencies of after tax wage rates: Model 1

Figure 4.8 Frequencies of after tax wage rates: Model 2
5 Conclusions

Two models of job search have been presented. In the first model individuals can determine their labour supply optimally, given the wage rate. The second model assumes that the individual is faced by hours restrictions on the labour market. It has been shown that these two different model assumptions have different implications for the job acceptance decision of individuals. Parameter estimates of the job offer arrival rate show similar effects for both models. Age has a negative effect on the job offer arrival rate. People who live in the industrialized western part of the Netherlands have a larger probability of getting a job offer. Individuals who are not specialized in a certain profession have a lower chance of getting a job offer than other individuals. For individuals who have the Dutch nationality the job offer arrival rate is larger than for those who do not have the Dutch nationality.

For both models the reservation income for every individual has been simulated and compared with the benefit income. For the model without hours restrictions a large percentage of the simulated reservation incomes were below the benefit incomes. This is consistent with results of Van den Berg (1990c) who finds evidence in favour of "disutility of unemployment". For the model with hours restrictions however, most of the reservation incomes are above the benefit incomes. Two explanations for the different results of the two models have been given. The first is that a constrained individual always has a higher (hours dependent) reservation wage than an unconstrained individual, because he has to choose from hours offers that do not coincide with optimal labour supply. The second explanation is that the spike in the sample distribution of weekly working hours at a level of 40 hours a week, together with the assumption of free choice in model 1, lead to low estimates of the virtual wage rate and consequently lowers the lowerbound of the reservation wage rate.

Residual analysis shows that the hazard rate is possibly positive duration dependent, i.e. the longer someone is unemployed, the larger is the escape rate. Positive duration dependence of the hazard rate can be caused by negative duration dependence of the reservation wage rate, possibly due to negative duration dependence of benefit payments or positive business cycle movements. Furthermore, the residual analysis reveals substantial differences between the two model specifications. The model in which the individual can freely choose his working hours seems to be seriously misspecified, whereas the model with hours restrictions is doing reasonable, in spite of the heavy stationarity assumption.

The simulated frequencies of part time jobs, full time jobs and high level jobs reveal that the poor performance of the model without hours restrictions is mainly caused by the assumption made about labour supply.
A Derivation of reservation wage equation 2.6

Let \( V(\varepsilon) \) denote the value of search of an individual with unobserved taste shifter \( \varepsilon \). Due to the stationarity assumption (assumption 4 in section 2.1), \( V(\varepsilon) \) is independent of time. At time \( t \), the individual is not working, is looking for a job and receives weekly non-labour income \( \mu \) and weekly benefits \( b \), which are time independent due to assumption 4 in section 2.1. In a short time interval of length \( \Delta t \) the utility flow derived from \( \mu \) and \( b \) equals

\[
\int_{t}^{t+\Delta t} u(b + \mu, 0; \varepsilon)e^{-\rho(s-t)} \, ds = \frac{u(b + \mu, 0; \varepsilon)}{\rho} (1 - e^{-\rho \Delta t})
\]

(A.1)

In the time interval of length \( \Delta t \) there is a probability of \( e^{-\lambda \Delta t} \lambda \Delta t + o(\Delta t) \) of receiving a job offer, consisting of a wage rate \( \bar{w} \). The value of the job, denoted by \( W(\bar{w}; \varepsilon) \) will be compared with the value of continuing searching, which is \( V(\varepsilon) \). The job offer \( \bar{w} \) will be accepted if \( W(\bar{w}; \varepsilon) \) exceeds \( V(\varepsilon) \). Due to the assumption 5 in section 2.1, the value will remain \( W(\bar{w}; \varepsilon) \) once a job \( \bar{w} \) is accepted. With probability \( 1 - e^{-\lambda \Delta t} \lambda \Delta t + o(\Delta t) \) the individual does not get a job offer in the time interval of length \( \Delta t \), in which case the value remains at \( V(\varepsilon) \). Summarizing, the value \( V(\varepsilon) \) is

\[
V(\varepsilon) = u(b + \mu, 0; \varepsilon)(1 - e^{-\rho \Delta t})/\rho + e^{-\rho \Delta t}(1 - e^{-\lambda \Delta t} \lambda \Delta t) V(\varepsilon) + e^{-\lambda \Delta t} \lambda \Delta t E_\theta \max[V(\varepsilon), W(\bar{w}; \varepsilon)] + o(\Delta t)
\]

(A.2)

Rearranging terms yields

\[
\frac{1 - e^{-\rho \Delta t}}{\Delta t} V(\varepsilon) = \frac{u(b + \mu, 0; \varepsilon)}{\rho} (1 - e^{-\rho \Delta t}) + e^{-(\lambda + \rho) \Delta t} \lambda E_\theta \max[0, W(\bar{w}; \varepsilon) - V(\varepsilon)] + \frac{o(\Delta t)}{\Delta t}
\]

(A.3)

Letting \( \Delta t \to 0 \) we obtain

\[
\rho V(\varepsilon) = u(b + \mu, 0; \varepsilon) + \lambda E_\theta \max[0, W(\bar{w}; \varepsilon) - V(\varepsilon)]
\]

(A.4)

Using the assumptions 1, 2, 4, 5 and 6 the value of the job with wage rate \( \bar{w} \) can be obtained by solving the maximization problem

\[
\max_{y, h} \frac{u(y, h; \varepsilon)}{\rho}, \text{ subject to } y = \bar{w} h + \mu
\]

(A.5)

The solution for \( h \) is \( h^* = \bar{h}(w, \mu; \varepsilon) \) which is the neo-classical labour supply function. Inserting the solution for \( y \) and \( h \) in the direct utility function yields the indirect utility function which is \( \nu(\bar{w}, \mu; \varepsilon) \) and therefore

\[
W(\bar{w}; \varepsilon) = \frac{\nu(\bar{w}, \mu; \varepsilon)}{\rho}
\]

(A.6)

Inserting (A.6) into (A.4) gives

\[
\rho V(\varepsilon) = u(b + \mu, 0; \varepsilon) + \frac{\lambda E_\theta}{\rho} \max[0, \nu(\bar{w}, \mu; \varepsilon) - \rho V(\varepsilon)]
\]

(A.7)
A job offer \( \hat{w} \) will be accepted if \( \nu(\hat{w}, \mu; \epsilon) > \rho V(\epsilon) \). If the reverse holds, it will be rejected. As the indirect utility function is increasing in the wage rate, there exists a unique reservation wage rate \( \xi(\epsilon) \) such that all wages above it are acceptable and those below will be rejected. The value of search is equal to the value of accepting a job if

\[
\rho V(\epsilon) = \nu(\xi(\epsilon), \mu; \epsilon) \tag{A.8}
\]

Inserting (A.8) in (A.7) and using the distributional assumptions on \( \hat{w} \) results in the reservation wage equation:

\[
\nu(\xi(\epsilon), \mu; \epsilon) = u(b + \mu, 0; \epsilon) + \frac{\lambda}{\rho} \int_0^\infty [\nu(\hat{w}, \mu; \epsilon) - \nu(\xi(\epsilon), \mu; \epsilon)] dF(\hat{w}; \psi, \tau) \tag{A.9}
\]

**B Derivation of the reservation utility equation 3.1**

Let \( V(\epsilon) \) denote the value of search for an individual with unobserved characteristics \( \epsilon \). While unemployed the individual receives weekly benefits \( b \). The amount of non-labour income is \( \mu \). The flow of utility, derived from benefit level \( b \) and non-labour income \( \mu \) in a short interval of length \( \Delta t \) is, like in (A.1), given by:

\[
\frac{u(b + \mu, 0; \epsilon)}{\rho} (1 - e^{-\rho \Delta t}) \tag{B.1}
\]

The probability of receiving a job offer in a short interval with length \( \Delta t \) is \( e^{-\rho \Delta t} + o(\Delta t) \). A job offer consists of two characteristics i.e. wages and hours which arrive randomly from a joint wage-hours offer distribution. The value of a job with hourly wage rate \( \hat{w} \) and weekly working hours \( \hat{h} \) is denoted by \( W(\hat{w}, \hat{h}; \epsilon) \) for an individual with unobserved characteristics \( \epsilon \). The value of a job will be compared with the value of search \( V(\epsilon) \) in order to make the job acceptance decision. The equivalent of equation (A.2) becomes

\[
V(\epsilon) = u(b + \mu, 0; \epsilon)(1 - e^{-\rho \Delta t})/\rho + e^{-\rho \Delta t} \{ (1 - e^{-\lambda \Delta t} \lambda \Delta t) V(\epsilon) + e^{-\lambda \Delta t} \lambda \Delta t E(\hat{w}, \hat{h}) \max[V(\epsilon), W(\hat{w}, \hat{h}; \epsilon)] \} + o(\Delta t) \tag{B.2}
\]

After rearranging terms and taking the limit \( \Delta t \to 0 \) we get

\[
\rho V(\epsilon) = u(b + \mu, 0; \epsilon) + \lambda E(\hat{w}, \hat{h}) \max[0, W(\hat{w}, \hat{h}; \epsilon) - V(\epsilon)] \tag{B.3}
\]

The assumptions 2 and 5 are used to determine the value of the job with wage rate \( \hat{w} \) and hours \( \hat{h} \):

\[
W(\hat{w}, \hat{h}; \epsilon) = \frac{u(\hat{w} \hat{h} + \mu, \hat{h}; \epsilon)}{\rho} \tag{B.4}
\]

Inserting this expression in (B.3) yields

\[
\rho V(\epsilon) = u(b + \mu, 0; \epsilon) + \frac{\lambda}{\rho} E(\hat{w}, \hat{h}) \max[0, u(\hat{w} \hat{h} + \mu, \hat{h}; \epsilon) - \rho V(\epsilon)] \tag{B.5}
\]

A job offer \( (\hat{w}, \hat{h}) \) is accepted if the utility value \( u(\hat{w} \hat{h} + \mu, \hat{h}; \epsilon) \) exceeds \( \rho V(\epsilon) \). In other words, there exists an unique reservation utility level \( \bar{u}(\epsilon) \) with

\[
\bar{u}(\epsilon) = \rho V(\epsilon) \tag{B.6}
\]
All job offers which generate a utility level above \( u(\varepsilon) \) are acceptable, those below will be rejected. According to assumption 6, \( u(\omega_h + \mu, \hat{\varepsilon}) \) is increasing in \( \omega \), and therefore, for a given level of \( h \), a wage rate \( \xi(h, u(\varepsilon); \varepsilon) \) can be found such that

\[
u(\xi(h, u(\varepsilon); \varepsilon)h + \mu, \hat{\varepsilon}) = u(\varepsilon)
\]  

This \( \xi(h, u(\varepsilon); \varepsilon) \) can be interpreted as an hours dependent reservation wage rate. Using the assumption that wage and hours arrive simultaneously from a joint wage-hours offer distribution \( f(\omega, h) \), equation (B.5) can be rewritten such that the reservation utility equation (3.1) is obtained:

\[
tilde{u}(\varepsilon) = u(b + \mu, 0; \varepsilon) + \frac{\lambda}{\rho} \int_{0}^{\infty} \int_{\xi(h,u(\varepsilon);\varepsilon)}^{\infty} [u(\omega_h + \mu, h; \varepsilon) - \tilde{u}(\varepsilon)] f(h, \omega) d\omega dh 
\]  

\[
(C.8)
\]

### C Derivation of (2.35)

In this appendix we show that if the derivatives of the vector of scores with respect to the implicitly defined integration bounds are replaced by (2.35) the expectation of the resulting sum is equal to the expectation of the complete density function some dummy variables are introduced.

\[
d = 1 \quad \text{for incomplete spells (} t > M \text{)} \\
= 0 \quad \text{for completed spells (} t \leq M \text{)} \\
e = 1 \quad \text{if} \quad d = 0 \quad \text{and} \quad (w, h) \text{ is observed} \\
e = 0 \quad \text{if} \quad d = 0 \quad \text{and} \quad (w, h) \text{ is unobserved}
\]

The density function consists of the following parts:

\[
l_u(\eta) \quad \text{if} \quad d = 1 \quad \text{(C.5)} \\
(1 - \pi)l_{eu}(\eta) \quad \text{if} \quad d = 0, e = 0 \quad \text{(C.6)} \\
\pi l_{co}(\eta) \quad \text{if} \quad d = 0, e = 1 \quad \text{(C.7)}
\]

where \( \pi = E(e) \), the probability that the post unemployment job characteristics are observed which has been assumed to be independent of the parameters of interest and therefore has been neglected before. \( l_u(\eta), l_{eu}(\eta) \) and \( l_{co}(\eta) \) have been defined in (2.12), (2.21) and (2.19) respectively. To show that the density integrates to 1 we look at each contribution separately.

\[
\int_{0}^{M} l_{eu}(\eta) dt = 1 - \int_{-\infty}^{\infty} \exp\{-\theta(e)M\} g(e, \sigma^2_e) de = 1 - l_u(\eta) \quad \text{(C.8)}
\]

\[
\int_{0}^{M} \int_{0}^{\infty} \int_{0}^{\infty} l_{co}(\eta) d\omega dh dt = \quad \text{(C.9)}
\]

\[
\int_{0}^{M} \int_{0}^{\infty} \int_{0}^{\infty} \int_{0}^{\infty} \theta(e) \exp\{-\theta(e)t\} r(h|w, e) \frac{f(w)}{T(e)} g(e, \sigma^2_e) de d\omega dh dt = \quad \text{(C.10)}
\]
\[ \int_0^\infty \int_0^\infty \int_{-\infty}^\infty \int_{-\infty}^\infty \theta(e) \exp\{-\theta(e)t\} \tau(h,w,e) \frac{f(w)}{T(e)} g(e,\sigma_e^2) \, dw \, dh \, dt = 1 - l_a(\eta) \] (C.11)

From these results it can be derived that

\[ l_a(\eta) + (1 - \pi) \int_0^M l_{ca}(\eta) \, dt + \pi \int_0^M \int_0^\infty \int_0^\infty l_{ca}(\eta) \, dw \, dh \, dt = 1 \] (C.13)

As a consequence

\[ \frac{\partial l_a(\eta)}{\partial \eta} + (1 - \pi) \int_0^M \frac{\partial l_{ca}(\eta)}{\partial \eta} \, dt + \pi \int_0^M \int_0^\infty \int_0^\infty \frac{\partial l_{ca}(\eta)}{\partial \eta} \, dw \, dh \, dt = 0 \] (C.14)

or, equivalently,

\[ \frac{\partial l_a(\eta)}{\partial \eta} + (1 - \pi) \int_0^M \frac{\partial l_{ca}(\eta)}{\partial \eta} \, dt + \pi \left[ \frac{\partial \int_0^M \int_0^\infty \int_0^\infty l_{ca}(\eta) \, dw \, dh \, dt}{\partial \eta} \right] = 0 \] (C.15)

as

\[ \int_0^M \int_0^\infty \int_0^\infty \frac{\partial l_{ca}(\eta)}{\partial \eta} \, dw \, dh \, dt = \frac{\partial \left[ \int_0^M \int_0^\infty \int_0^\infty l_{ca}(\eta) \, dw \, dh \, dt \right]}{\partial \eta} \] (C.16)

Now note that the left hand side of (C.16) is equal to the expectation of \( e \theta \ln l_{ca}(\eta) / \partial \eta \), the score contribution which we want to simulate. The derivatives of (C.16) consist of two major terms, i.e. the derivatives with respect to the bounds and the derivatives with respect to the integrand. As the derivatives with respect to the integrand of the right hand side are equal to the derivatives with respect to the bounds on the left hand side, it follows that the derivatives with respect to the bounds are equal on both sides as well. Using the right hand side of (C.16) and the fact that (C.9) equals (C.11) the derivatives with respect to the bounds can be written as

\[ - \int_{-\infty}^\infty \frac{\partial \xi(e)}{\partial \eta} \left[ 1 - \exp\{-\theta(e)M\} \right] \frac{f(\xi(e))}{T(\xi(e))} g(e,\sigma_e^2) \, de \] (C.17)

which is expression (2.35). To handle the problem with the implicitly defined bounds, the original derivatives are replaced by their expectation.
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