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Female Labour Supply and Marital Status Decisions: A Life-Cycle Model

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This paper studies the interdependence between and the determinants of life-cycle marital status and labour force participation decisions of women. A dynamic utility maximization model is presented and estimated using longitudinal data on women from the Panel Study of Income Dynamics. The MLE method employed, involves solving a dynamic programming problem. Further, a minimum distance estimator is proposed which allows for the incorporation of wage data in a computationally simple way. The estimates are used to predict changes in the life-cycle patterns of employment, marriage and divorce due to differences in education, race, the female's earnings and her (potential) husband's earnings. The estimation results indicate that the utility gains to marriage are decreasing in the female's wage rate and increasing in her (potential) husband's earnings, while the opposite is found for gains to working. Ignoring the endogeneity of marital status decisions is shown to lead to an underestimation of own and husband's wage effects on female labour supply.

1. INTRODUCTION

The American family has undergone a major transformation over the last four decades. This change was characterized by a large increase in the labour force participation rate of married women, a sharp increase in the rate of divorce, a drop in the fertility rate and an increase in the number of female-headed households and never-married men and women. These demographic trends have led to an increased recognition among labour economists of the importance of household structure in the study of individual and family labour supply. In the study of female labour supply, for example, there is growing awareness that both marital status and fertility decisions are strongly interrelated with female labour supply decisions and can therefore no longer be considered exogenous from a life-cycle perspective. The presence of children (especially when they are young) is known to have a strong negative effect on the mother's labour supply. Consequently, female wages and labour force experience could be expected to play an important role in decisions on the timing and number of births.

Female labour force participation decisions have also been found to depend strongly on the marital status of women. In addition, economic theories of marriage imply a strong correlation between a female's return in the labour market and her 'return' in the marriage market, measured in terms of utility gains from marriage. For example, according to Becker's (1973, 1974) theory of marriage, marital gains can be derived from the specialization of labour within the household, which is found to depend negatively on the ratio of the wife's to the husband's wage rate. Gains from marriage and therefore marital status decisions will thus in general depend on a female's (potential) wage rate. If gains from marriage are greater for low-wage women, this will imply higher marriage and lower divorce rates and a resulting self-selection of low-wage women into the married state. Decisions to enter or exit the married state, and the timing of entry or exit, are therefore also likely to depend on female wages and previous work experience.

As part of an expanding literature on the timing and spacing of births, several life-cycle models have been developed and estimated which have addressed the relation between life-cycle fertility and female labour supply (Heckman and Willis (1975), Hotz and Miller (1988) and Moffitt (1984)). The interaction between marital status and labour supply decisions, on the other hand, has received considerably less attention. Research on the labour supply of single- and multiple-person households has largely ignored the endogeneity of marital status decisions. First, there is a vast empirical literature that examines female labour supply *conditional* on marital status. Typically, an hours function is estimated where both the husband's wage income (sometimes as part of the female's non-labour income) and the marital status of the individual are included as explanatory variables. These studies assume both marital status and the husband's income to be exogenous, which may lead to biased estimates of the labour supply function.[1] Second, in most studies of household labour supply, both male and female labour supply decisions are determined jointly through maximization of a household utility function or as the outcome of a bargaining game. While the exogeneity assumption on the husband's labour supply and wage income is often relaxed, current static and dynamic models of household labour supply still ignore the endogeneity of the household formation process itself.[2]

Following the innovative work of Becker (1973, 1974), the economics literature on marriage and divorce behaviour has highlighted several important aspects of marital status decisions. The different potential sources of marital gains and its dependence on individual characteristics has been the main focus in models of optimal sorting or matching (Koopmans and Beckmann (1957), Becker (1981), Lam (1988)). The division of marital gains and its relationship to consumption and time allocation decisions within the household have been studied in recent game-theoretic models of household behaviour (McElroy and Horney (1981), Chiappori (1988)) and the uncertainty and dynamic aspects of marital status decisions has played the prominent role in models of marital search and divorce (Becker *et al.* (1977), Mortensen (1988), Montgomery (1992)).

Even though several studies in this literature have emphasized the strong interactions between marital status and labour supply decisions, and despite the important implications for studies of individual and household labour supply, to date relatively few studies have explicitly modelled both decisions jointly.[3] Moreover, few have made due allowance for persistent unobserved heterogeneity and none of these studies adopt and estimate the parameters of a dynamic framework capable of capturing the inherent dynamic nature of marital status and work decisions. Given the many dynamic aspects of marital status decisions, where each decision typically has long-term consequences, the interaction with

1. The same problem arises in the estimation of wage functions where a marital status indicator is included as an exogenous regressor variable (see Nakosteen and Zimmer (1987), who report a strong bias for the case of male wage equations).

2. Life-cycle models of family labour supply, for example, are typically estimated using data on couples who were continuously married throughout the survey period (for example, Heckman and MaCurdy (1980), Altug and Miller (1990)), so that estimates derived for these models are likely to reflect a sample selection bias. Given the sharp rise in the rate of divorce, where currently 44% of all marriages of the early 1970s either have ended or are predicted to end in divorce, it is clear that the need to incorporate marital status decisions into life-cycle labour supply models is becoming even greater.

3. Johnson and Skinner (1986, 1988) and Haurin (1989) analysed the response of labour supply decisions to a realized or anticipated divorce, and McElroy (1985) studied household membership and market work decisions by young men.

market work decisions cannot satisfactorily be captured in a static framework. A female might opt for a labour market career and consciously postpone marriage. On the other hand, more work experience generally implies higher wages, which in turn might affect gains from a potential marriage. Interruptions in labour market participation caused by marriages as well as the birth and presence of children can have long-term effects through lower future wages associated with less labour market experience, making the female more economically dependent on the husband. In addition, the birth of children could directly reduce the probability of a future divorce, by increasing the utility gains to marriage.

This study represents a first attempt to fill this gap in the labour supply literature by the construction and estimation of a structural dynamic model that explicitly addresses the interdependence between marital status and labour force participation choices. A simple dynamic utility maximizing framework is specified in which a female simultaneously determines her marital status and work decision in each period, while taking into account the effect of current decisions on future choices. Each female derives utility from leisure, being married, the presence of children and the consumption of a composite good. In addition to the direct utility derived from being married, marriage may provide additional utility gains through an increase in income as well as a possibly higher utility derived from having children when married. The interdependence of sequential choice decisions is captured in the model through the dependence of wages on previous work experience, through the presence of children, through a direct effect of previous choices and experiences on current preferences and through the persistence in unobserved individual traits. The model incorporates different types of uncertainty such as those associated with marital search, divorce, current and future own and husband's wage earnings and the birth of children, which is characterized in this model by an exogenous stochastic process which is conditional on the female's marital status.

The structural model enables us to examine the joint determination of labour supply and marital status decisions of women and the dependence of these decisions on the presence of children and other individual characteristics. In particular, the estimates of the model are used to predict differences in the life-cycle patterns of employment, marriage and divorce due to differences in education, race, the female's (potential) earnings and her (potential) husband's wage income.

Estimation of discrete-time discrete-state dynamic programming models such as the one in this paper has recently received considerable attention (see Eckstein and Wolpin (1989*b*) for a recent review). The maximum likelihood estimation method employed here is most similar to that in Wolpin (1984, 1987), Eckstein and Wolpin (1989*a*) and Berkovec and Stern (1991). It is based on a recursive numerical solution of "reservation values" and expected value functions, from which the choice probabilities in the likelihood function can be calculated. Our estimation procedure differs, on the other hand, in its additional use of a minimum distance estimator which allows for the incorporation of female and male earnings data in a computationally simple way that has not been achieved in prior work.

The model is estimated using longitudinal data on women from the Michigan Panel Study of Income Dynamics (PSID). The estimated model is shown to fit the data reasonably well. The results indicate that the average utility gains from marriage are decreasing in the female's wage rate and increasing in her (potential) husband's earnings. As a result, women with low wage rates and women with high expected husband's earnings are (all else equal) predicted to be more likely to marry soon after leaving school, less likely to work in the labour force and less likely to divorce. High wage women, on the other hand, are more likely to postpone marriage until after several years of market work, and are more likely on average to get a divorce. The estimates further imply that there exists considerable habit persistence in the individual choice decisions, where previous experiences strongly affect a female's current preferences. The presence of children is found to substantially increase the utility gains from marriage, thereby reducing the probability of a divorce, and to increase the disutility of working.

This paper is organized as follows. The next section presents a dynamic model of female labour force participation and marital status decisions. Section 3 discusses the data and Section 4 deals with the econometric specification and estimation of the model. The estimation results and the model's explanatory power are discussed in Section 5 and the incorporation of unobserved permanent individual effects is discussed in Section 6. Finally, Section 7 offers concluding comments and suggests some important areas for future research.

2. A STRUCTURAL MODEL OF MARITAL STATUS AND LABOUR SUPPLY DECISIONS

In addition to the need for a dynamic framework, the economics literature on marriage and divorce has identified several aspects of these decisions that our model should ideally include. The dynamic model presented here incorporates many of these aspects in an explicit way, but others only indirectly. In particular, it will focus primarily on the female's decision process and will assume that every husband always works full time in the labour market. Given that in a typical representative sample, such as the one used in this study, 95% of the male population works, this is not a very restrictive assumption. To avoid the complications associated with modelling the choice of husband as a multivariate choice problem, and given the emphasis on female labour supply decisions, each (potential) husband will be characterized solely by his wage income. Utility gains associated with marriage and work decisions are however directly modelled and the dynamic nature of both decisions will be represented through several sources of state and duration dependence. Uncertainty and search aspects will further be modelled by random arrivals of new preference evaluations of existing and potential spouses, by the random arrival of "marriage opportunities", and by the randomness of female and male earnings. Fertility is represented in the model by a simple indicator of whether any children are present in each period or not. The characterization of the stochastic movement of this stock variable over time only requires the modelling of the first birth. We will characterize the birth of the first child by an exogenous stochastic process where the probability of a birth depends on the individual's marital status, education, age and race.[4]

Starting with the period in which the individual leaves school, in each period an individual is assumed to maximize the present value of utility over a known finite horizon (T) by choosing whether or not to work, whether or not to be married and how much to consume. The objective of the individual is to maximize

$$E\sum_{t=1}^{T}\delta^{t-1}[U(p_t, m_t, c_t; n_t, p_{t-1}, m_{t-1}, mdur_{t-1}, X_{1t})] \tag{1}$$

4. Thus, in our model fertility is only indirectly endogenous through its dependence on marital status choices. It is clear that a more complete model of life-cycle female labour supply should explicitly incorporate fertility decisions as choice variables. However, to avoid the modelling and estimation complications resulting from an increase in the choice set (and dimension of the state space) in the model, the focus here will be on the interaction of marriage, divorce and labour force participation decisions conditional on the presence of children in each period, leaving explicit incorporation of fertility decisions as an important topic for future research.

where the utility function is specified as

$$\begin{aligned}U(p_t, m_t, c_t; n_t, p_{t-1}, m_{t-1}, mdur_{t-1}, X_{1t})\\ = a_{1t}m_t + (a_{2t} + a_{3t}m_t)p_t + (\beta_1 + \beta_2 p_t + \beta_3 m_t)c_t\\ + (1-p_t)(1-m_t)v_{1t} + p_t(1-m_t)v_{2t} + m_t(1-p_t)v_{3t} + p_t m_t v_{4t}\end{aligned}$$

by choosing a path $\{([p_t, m_t] \in I_t, c_t \in \Re); t=1, \ldots, T\}$, where p_t represents the labour force participation decision in period t; $p_t=1$ (participation) or $p_t=0$ (non-participation) and m_t indicates whether the individual is married at time t ($m_t=1$) or single ($m_t=0$). c_t equals the female's consumption in period t of a composite good. I_t represents the set of choice possibilities for p_t and m_t in period t, $\delta \in [0, 1]$ is the subjective discount factor and E is the expectations operator.

The v_{it}, $i=1, \ldots, 4$ capture stochastic changes in the utility of each combined work and marital status choice. They represent variations in the utility obtained from leisure, random variations in the individual's preference for working, stochastic variation in the compatibility between marriage and working, as well as changes in the utility derived from getting married or being married. The latter variation could be interpreted as the realization of new preference valuations of current or potential partners.

The marginal utility of consumption depends on both the current work and marital status of the individual. The direct utility obtained from being married (a_{1t}), the disutility of working when single (a_{2t}) and the difference in the disutility of working when married instead of single (a_{3t}) are further parameterized as functions of a set X_t of individual characteristics and previous experiences as follows:

$$\begin{aligned}a_{1t} &= X_t'\alpha_1 = X_{1t}'\alpha_{11} + \alpha_{12}n_t + \alpha_{13}m_{t-1} + \alpha_{14}mdur_{t-1}\\ a_{2t} &= X_t'\alpha_2 = X_{1t}'\alpha_{21} + \alpha_{22}n_t + \alpha_{23}p_{t-1}\\ a_{3t} &= X_t'\alpha_3 = X_{1t}'\alpha_{31} + \alpha_{32}n_t + \alpha_{33}p_{t-1} + \alpha_{34}m_{t-1} + \alpha_{35}mdur_{t-1}\end{aligned} \tag{2}$$

where the vector X_{1t} represents the female's race, age, education and region of residence, n_t is an indicator of whether children are present at the beginning of period t ($n_t=1$) or not ($n_t=0$) and $mdur_{t-1}$ refers to the duration of the current marriage until the beginning of period t and can be defined as $mdur_{t-1} = m_{t-1}[mdur_{t-2} + m_{t-1}]$ where $mdur_0 = m_0 = 0$. Thus both the disutility of working (when single and married) and the utility associated with being married are allowed to depend on the presence of children as well as several other individual characteristics, X_{1t}, capturing individual differences in tastes. The disutility of working and the utility derived from being married are likely to be much greater when children are present, that is, we expect that $\alpha_{12} > 0$ and $\alpha_{22} < 0$.

The disutility of working and the utility associated with being married may also depend on the previous period's work and marital status decisions as well as the duration of the current marriage (when married). This dependence of current preferences on previous experiences was found to be important in the empirical analyses of dynamic labour supply decisions by Johnson and Pencavel (1984) and Eckstein and Wolpin (1989*a*). In terms of our model the disutility associated with market work might increase or decrease with having worked in the previous period, that is, non-market time at adjacent points in the life cycle may be substitutes or complements. A positive effect of the previous period's work decision on the current utility of working ($\alpha_{23} > 0$) may reflect habit formation or complimentarity of leisure time in subseqent periods, while a negative effect may reflect an increasing disutility of working with previous work effort.

The utility associated with being currently married may similarly depend on previous marital status choices. A positive dependence may reflect a possible increase during a marriage in the bond between both partners and in their emotional dependence. Accordingly, we allow preferences for being married to depend on the individual's marital status at the time of each period's choice decision and, if currently married, on the duration of the marriage. In case of habit persistence we would expect α_{13} and α_{14} to be positive.

The choice decision in each period as described in (1) is made subject to the female's budget constraint, which is assumed to be satisfied period by period,[5] and is given by

$$w_t p_t + \psi(p_t) \cdot w_t^h m_t = c_t \tag{3}$$

where the wife's and husband's wage earnings are denoted by w_t and w_t^h, respectively, and $\psi(p_t)$ represents the fraction of the husband's income that is available for consumption by the female. The net transfer of income by the husband to the female, $\psi(p_t)w_t^h$, may depend on the female's work decision. In general, we would expect the net transfer to be positive, i.e. we expect that $\psi(p_t)>0$, as wives generally earn less than their husbands, and expect the transfer to be much smaller if the wife works.[6]

The female's own current and future wage earnings are stochastic and will generally depend on the female's previous work decisions. Accordingly, when the female chooses to work, she will receive wage earnings w_t that depend on her personal characteristics, X_{1t}, her previous period's work decision, p_{t-1}, her total work experience, exp_{t-1}, as well as the average manufacturing wage earnings in the local labour market during the period of observation, z, and an i.i.d. serially uncorrelated random component u_t with mean zero, representing random fluctuations in earnings over time. Thus

$$\begin{aligned} w_t &= X'_{1t}\gamma_1 + \gamma_2 p_{t-1} + \gamma_3 exp_{t-1} + \gamma_4 exp_{t-1}^2 + \gamma_5 z + u_t \\ &= X'_{2t}\gamma + u_t \end{aligned} \tag{4}$$

where work experience exp_{t-1}, represents the total number of prior years the female worked in the labour force since leaving school and therefore evolves according to the law of motion $exp_{t-1} = exp_{t-2} + p_{t-1}$ with $exp_0 = p_0 = 0$. The previous period's work decision is included as a separate variable to allow for a stronger effect of more recent work experience. At the time of each period's work decision the female knows both the current value of w_t and the wage structure in (4), but does not know the future realizations of u_t and w_t.

The earnings of each female's (potential) husband in period t are specified by the following "matching equation":

$$\begin{aligned} w_t^h &= X'_{3t}\pi_1 + \pi_2 exp_{t-1} + \pi_3 hexp_{t-1} + \pi_4 hexp_{t-1}^2 + \pi_5 z + v_t \\ &= X'_{4t}\pi + v_t \end{aligned} \tag{5}$$

where $X_{3t} \subset X_{1t}$ is a vector of characteristics of the female, consisting of her education, race and region of residence. *hexp* represents the female's potential work experience, defined as the difference between her age and years of education, which, given the very strong positive sorting on age and education in the marriage market (see Becker (1981)),

5. The introduction of savings and borrowing behaviour in dynamic choice models is not straightforward, and will generally lead to a considerable expansion of the choice set and state space which, given the associated computational burdens, is beyond the scope of this paper.

6. The net transfer is especially likely to be positive if we interpret part of this transfer to be the wife's share of the savings in expenditures resulting from the public good nature of some consumption goods shared by the husband and wife.

can be interpreted as a close proxy for her (potential) husband's work experience. z, the state's average manufacturing wage earnings, is included as an indicator of the average strength of regional demand for labour, and v_t represents a serially uncorrelated stochastic earnings component with mean zero. The vector X_{4t} represents all explanatory variables in the equation pooled together.

The dependence on the female's characteristics does not only reflect her preferences for a particular husband's wage income, but also determine her position in the "marriage market". This matching equation therefore describes for each woman the average earnings of husbands of women with similar characteristics that are most similar to hers. At the time of each period's choice decision each woman knows her (potential) husband's actual current income as well as the earnings equation above, which she is assumed to use to forecast the future earnings of her (potential) husband.

In the model outlined above each (potential) husband is characterized by a particular realization of his earnings. In addition, the random utility components v_{3t} and v_{4t} capture fluctuations in the valuation of other characteristics of the potential or current husband as well as random events that could affect the value of the marriage. The uncertainty about and variation in the value or "quality" of each match and about the realization of the husband's wage earnings in each period gives rise both to marital search and divorces. Given realizations of these variables in each period, an individual decides whether to get married, stay married, or to (temporarily) delay marriage. Once married, new (and presumably lower) preference valuations of the value of the marriage and new earnings realizations could lead to a divorce.

Another aspect of marital search, that has not yet been discussed, concerns the definition of the choice set I_t in each period. Rather than assuming the existence of a marriage opportunity in each period, we allow for the possibility that the choice set I_t in each period in (1) may not include all marital status options, i.e. that the option to get married may not materialize in each period when currently single. In addition, we permit the probability of such an event to differ for different individuals, by characterizing the arrival of a marriage opportunity in each period by the arrival rate, $\Upsilon(m_{t-1}, X_{1t})$, which depends on the vector of individual characteristics X_{1t} defined earlier.[7] We specify:

$$\begin{aligned}
&\Pr(I_t = J_0 \mid m_{t-1} = 0) = \Upsilon(0, X_{1t}) = \Phi(X'_{1t}\omega) \\
&\Pr(I_t = J_0 \mid m_{t-1} = 1) = \Upsilon(1, X_{1t}) = 1 \qquad (6) \\
&\Pr(I_t = J_1 \mid m_{t-1} = k) = 1 - \Upsilon(k, X_{1t}), \qquad k = 0, 1
\end{aligned}$$

where $J_0 = \{p_t \in (0, 1); m_t \in (0, 1)\}$, $J_1 = \{p_t \in (0, 1); m_t = 0\}$ and $\Phi(\cdot)$ is the standard normal distribution function.

A final aspect of this model concerns the modelling of life-cycle fertility. In the model it is assumed that the effect of children on marital status and work choices can be captured by the effect of a single indicator of whether any children are present in period t ($n_t = 1$) or not ($n_t = 0$).[8] As a result, $n_t = 1$ is an absorbing state and the stochastic movement of

7. It is assumed that all individuals currently married (with $m_{t-1} = 1$) will always have the option to remain married, reflecting Becker's notion that all divorces are voluntary in the sense that a divorce will only occur if both individuals (possibly through compensation of one partner by the other) will be better off when divorced than when staying married. Alternatively, we could think of a divorce initiated by the husband as large negative draws of the stochastic components v_{3t} and v_{4t}.

8. In general one would expect both the number and the ages of all children to be important determinants of work and marital status decisions (see Hotz and Miller (1988)). However, to limit the size of the state space, we assume that the fertility effect can be adequately captured by a single indicator of the presence of any children.

n_t over time can be completely characterized by the specification of the exogenous probability in each period of a first birth. We specify this yearly birth rate, or hazard rate, and with that the stochastic movement of n_t over time, as the following function of female characteristics:

$$\begin{aligned}
&\Pr(n_t=1\,|\,n_{t-1}=0)=\Phi(X'_{5t}l)\\
&\Pr(n_t=1\,|\,n_{t-1}=1)=1 \qquad\qquad (7)\\
&\Pr(n_t=0\,|\,n_{t-1}=k)=1-\Pr(n_t=1\,|\,n_{t-1}=k), \qquad k=0,1
\end{aligned}$$

where X_{5t} represents the female's marital status in the previous period (m_{t-1}), her education, race and a linear and quadratic term in age.

Before describing the solution method to the individual's dynamic optimization problem, it is important at this point to identify and discuss in some more detail the different sources of marital gains and dynamics in the proposed model. First, the direct net utility gains an individual receives from marriage could be negative or positive, depending on whether the utility derived from companionship can compensate for the loss in privacy and independence, and may increase or decrease with the duration of the marriage. If the utility derived from children is greater when married than when single, marriage will provide additional utility gains for women with children but also for women without children, through an increase in the probability of, and the subsequent utility derived from a future birth. Second, marriage may provide a means to increase the income available for the female's consumption.

The total utility gains or losses associated with being married will also depend on its effect on the disutility of working and the female's marginal utility of consumption, and will therefore vary with her own and her (potential) husband's earnings. Considering the effect of an increase in the (potential) husband's earnings on the individual's current utility gains to marriage, our model predicts it to be positive both when working and not working if $(\beta_1+\beta_2+\beta_3)\psi(1)$ and $(\beta_1+\beta_3)\psi(0)$ are positive. The model further predicts it to have a negative effect on the immediate net gains from working when currently married if $(\beta_1+\beta_2+\beta_3)\psi(1)$ is smaller than $(\beta_1+\beta_3)\psi(0)$. Similarly, the model predicts that an increase in the female's wage rate will increase the current gains from working both when single and when married as long as the marginal utilities of consumption $(\beta_1+\beta_2)$ and $(\beta_1+\beta_2+\beta_3)$ are positive. The impact on the gains from marriage when currently working will be negative as long as $\beta_3<0$.

The model incorporates various sources of dynamics. First, the dependence of wages on the individual's past work history and of the disutility of working on the previous period's work decision implies that when choosing whether or not to work in period t, the individual will not only consider the current utility difference associated with work vs. not-work choices, but also the effects of the current work decision on future utility levels and choices through an increase in work experience. Concerning the current period's utility tradeoffs, in deciding whether or not to work, the individual weighs the advantages of working this year, such as an increase in current and future wage earnings, against its disadvantages, such as the disutility associated with work and a decrease in the net transfer by the husband, when married. The actual outcome depends therefore on the relative magnitudes of her wage, her disutility of working, her husband's earnings (when married) and also on future returns to work experience and the direct effects on future utility levels.

Similarly, in the current marital status decision, the individual has to take into account its effect on future utility levels, resulting from the dependence of utility levels on previous experiences and the impact of a change in the current marital status on the probability of a subsequent birth.[9]

The dynamic programming solution

When incorporating the budget constraint (3) into the utility function in (1), the resulting model consists of the earnings equations (4) and (5) and the following dynamic utility maximization problem:

$$\max_{\{(p_t, m_t), t=1,\ldots,T\}} E\sum_{t=1}^{T} \delta^{t-1} [\mathscr{U}(p_t, m_t; X_t, w_t, w_t^h)] \tag{8}$$

where X_t is a vector with elements X_{1t}, n_t, p_{t-1}, m_{t-1} and $mdur_{t-1}$ and where the expectation is taken over all future values of I_t, n_t, w_t, w_t^h and the stochastic utility components v_{it}, $i=1, \ldots, 4$. The utility $\mathscr{U}$, corresponding to each of the four possible choice states (single and not working, married and not working, single and working, married and working) equals:[10]

$$\begin{aligned}
&\text{State 1}: \mathscr{U}(0, 0; X_t, 0, 0) = v_{1t} \\
&\text{State 2}: \mathscr{U}(0, 1; X_t, 0, w_t^h) = X_t'\bar{\alpha}_1 + (\beta_1+\beta_3)\psi(0)w_t^h + v_{2t} \\
&\text{State 3}: \mathscr{U}(1, 0; X_t, w_t, 0) = X_t'\bar{\alpha}_2 + (\beta_1+\beta_2)w_t + v_{3t} \\
&\text{State 4}: \mathscr{U}(1, 1; X_t, w_t, w_t^h) = X_t'\bar{\alpha}_3 + (\beta_1+\beta_2+\beta_3)w_t + (\beta_1+\beta_2+\beta_3)\psi(1)w_t^h + v_{4t}
\end{aligned} \tag{9}$$

where $\bar{\alpha}_1 = \alpha_1$, $\bar{\alpha}_2 = \alpha_2$ and $\bar{\alpha}_3 = \alpha_1 + \alpha_2 + \alpha_3$.

An alternative, "reduced form", representation of the maximization problem can be obtained by substituting both earnings equations into the utility function in (9). The utility levels associated with each choice alternative $i=1, \ldots, 4$ can then be defined as

$$\mathscr{U}_{it} = R_{it}(\mathscr{X}_t) + \varepsilon_{it} = \mathscr{X}_t'\lambda_i + \varepsilon_{it} \qquad i=1, \ldots, 4 \tag{10}$$

where $\lambda_1 = 0$ and $\mathscr{X}_t$ is a vector of all variables in X_t, X_{2t} and X_{4t} combined. Given our definitions of X_{2t} and X_{4t} we can thus define $\mathscr{X}_t' = [X_t'\ exp_{t-1}\ exp_{t-1}^2\ z\ hexp_{t-1}^2]$. The "reduced form" coefficients λ_i, $i=2, 3, 4$ are functions of the utility and earnings equations parameters.[11] The ε_{it} terms represent the composite error terms defined as

$$\begin{aligned}
\varepsilon_{1t} &= v_{1t} \\
\varepsilon_{2t} &= v_{2t} + (\beta_1+\beta_3)\psi(0)\upsilon_t \\
\varepsilon_{3t} &= v_{3t} + (\beta_1+\beta_2)u_t
\end{aligned}$$

9. While not introduced into the framework to limit the computational costs associated with solving and estimating the model, it is important to note that the dependence of current utility levels on the marriage and work history need not necessarily be confined to the most recent marital status decision, marriage spell and most recent work decision and total work experience. A previous divorce may affect the utility of re-marriage as well as the arrival rate of marriage opportunities, especially if children from a previous marriage are present. Besides the female's most recent work decision and total work experience, the individual work decisions made two or three periods back might be of separate importance.

10. Note that the average utility associated with the single and not-working state equals zero. Alternatively, we could have specified this utility to be a function of individual characteristics. However, because in the estimation its coefficients would not be identified, we normalized them to zero, so that the $\bar{\alpha}_i$ coefficients can be interpreted as measuring the effect on utility relative to its effect on the utility of choosing the single and not-working option.

11. For example, for an element in X_t with coefficients α_{1i}, α_{2i} and α_{3i} in the utility of alternatives 2 to 4, and with coefficient γ_j in the own earnings equation and coefficient π_k in the husband's earnings equation, the corresponding reduced-form parameter for that element in the utility associated with alternative 4 equals: $\lambda_{4i} = \bar{\alpha}_{3i} + (\beta_1+\beta_2+\beta_3)\cdot\gamma_j + (\beta_1+\beta_2+\beta_3)\psi(1)\cdot\pi_k$.

and

$$\varepsilon_{4t} = v_{4t} + (\beta_1+\beta_2+\beta_3)u_t + (\beta_1+\beta_2+\beta_3)\psi(1)v_t.$$

It is assumed that these composite random components, ε_{it}, $i=1,\ldots,4$, are independently distributed over time and individuals.[12]

Given the utility specifications above, let $d_i(t)=1$ if alternative i, $(i=1,2,3,4)$, is chosen in period t and $d_i(t)=0$ otherwise. In correspondence with (8), the maximum value of expected utility at time t, $t<T$, is then

$$V_t(\Omega(t)) = \max_{i\in I_t}\,[R_{it}(\mathscr{X}_t) + \varepsilon_{it} + \delta E[V_{t+1}(\Omega(t+1))|d_i(t)=1, \Omega(t)]] \tag{11}$$

where $\Omega(t)$ is the relevant information set at t containing the current realizations of the error terms ε_{it}, the vector of individual characteristics $\mathscr{X}_t$ in period t (which includes measures of the decision history until t), the choice set I_t and the values of the λ_i's. The expectation in (11) is taken with respect to all stochastic components in $\Omega(t+1)$, including the realization of next period's choice set (i.e. the arrival of marriage opportunities), the presence of a child by the time of next period's choice decision and the realization of the stochastic earnings and utility components.

It is possible to derive all $V_t(\Omega(t))$ functions $t=1,\ldots,T$ and to solve for the optimal policy at each t by exploiting the finite-horizon nature of the dynamic programming problem. In period T we have $V_T(\Omega(T)) = \max_{j\in I_T}[R_{jT}(\mathscr{X}_T)+\varepsilon_{jT}]$. Further, for each period $t<T$ and for each state vector $\mathscr{X}_t$, we can define three values ε^*_{kt}, $k=2,3,4$ such that[13]

$$\begin{aligned}\delta E[V_{t+1}(\Omega(t+1))|d_1(t)=1, \mathscr{X}_t] + \varepsilon^*_{kt} \\ = \mathscr{X}_t'\lambda_k + \delta E[V_{t+1}(\Omega(t+1))|d_k(t)=1, \mathscr{X}_t].\end{aligned}$$

Then the optimal policy for each information vector $\mathscr{X}_t$ and each $i\in I_t$ can be defined as:

$$\begin{cases} d_i(t)=1 \\ d_j(t)=0, \quad \forall j\neq i \end{cases} \quad \text{iff} \quad \varepsilon_{it}-\varepsilon_{jt} \geqq \varepsilon^*_{jt}(\mathscr{X}_t) - \varepsilon^*_{it}(\mathscr{X}_t) \quad \forall j\in I_t. \tag{12}$$

In each period t, the values ε^*_{kt}, $k=2,3,4$ $(\varepsilon^*_{1t}=0)$ divide the four-dimensional space up into regions in each of which one (assuming no ties) of the alternatives is optimal. Given a distributional assumption for the ε_{kt}'s, the decision rule in each period, the terminal value function V_T and equation (11), it is possible to solve, by backward recursion, for all $V_t(\Omega(t))$ functions and all ε^*_{kt} values. Note that this involves the calculation of the expectations $E[V_{t+1}(\Omega(t+1))|d_i(t)=1, \mathscr{X}_t]$ for each choice i and period t, which itself requires the calculation of the expectations $E[\max \varepsilon_{it+1}|d_i(t)=1, \mathscr{X}_t]$.

3. A DESCRIPTION OF THE DATA

The data used in this study were extracted from the 1985 family-individual tape of the Michigan Panel Study of Income Dynamics (PSID). The PSID started in 1968 with a sample of approximately five thousand households, which included a sample that was

12. Unobserved persistent individual effects will be introduced in Section 6.

13. Note that conditioning on the information set $\Omega(t)$ in the expected value function of $t+1$ is equivalent to conditioning on $\mathscr{X}_t$ as the errors are assumed to be serially uncorrelated. Allowing for non-zero serial correlation will in general greatly complicate the estimation as the relevant information set in each period will contain all past error realizations.

representative of all U.S. households in 1968 and a supplementary low-income sample. Household heads were interviewed annually to obtain fairly detailed information on socio-economic and demographic characteristics and on each member's prior year's earnings and employment. Further, the 1985 interview included a detailed retrospective marital history of the household head.

The initial sample extract included all females aged 12 to 19 in 1968 (or 29 to 36 in 1985), who were part of the national representative random section of the PSID. This age group was selected so that for each individual a complete work and marital history could be constructed. The first observation year for each female in the sample is the year in which she leaves school, the final observation year will either be 1985 or the year the female dropped out of the sample. For the resulting unbalanced panel, the average number of years available for each female is about 13 years (see Table 1).

For the construction of the marital history both the 1985 retrospective information and the year-by-year marital status information were used. The retrospective data can add extra information not directly obtainable from the yearly panel data, such as divorces and remarriages that occur within the same year, and the starting dates of marriages that started before 1968. A female is defined to be married (MARRIED = 1) when she is both legally married and is living with her husband for the majority of the year. No distinction is therefore made between divorces and separations. Also this definition of marital status does not include those who cohabit as being married. The decision to cohabit is quite different from the decision to marry. However, because the available data on cohabitation appeared not very reliable, cohabitation was not included as a separate choice.

For other variables used in the empirical analysis the following definitions apply. A person is defined to participate in the labour force (WORK = 1) in a particular year if yearly hours of work exceeded 775.[14] It therefore does not include those who work less than 15 hours a week or those who work less than 20 weeks full time. Work experience (EXP) represents the total number of prior years the person has participated in the labour force. MDUR is defined as the duration of the current marriage up to the previous year. It therefore equals zero if the person was not married in the previous period. CHILD represents a yearly indicator of whether the woman has any children (CHILD = 1) or not (CHILD=0).

Given our assumption that each female decides about full-time work or non-participation only, each female's yearly earnings (WAGE) are defined to equal 2000 (hours) times the female's average hourly wage, which was obtained by dividing annual labour income by annual hours of work.[15] Each woman is assumed to use this measure of potential annual earnings in solving her dynamic optimization problem. Earnings are further expressed in real terms and are deflated by the implicit price deflator for personal consumption expenditures, with 1983 as base year. Real husband's earnings (HWAGE) are obtained in a similar way, by multiplying his average hourly wage rate, obtained by dividing annual labour income by annual hours of work, by 2000.

Years of education (EDUC) represent the number of years spent in full-time education until the first time the person left school. It therefore does not include education obtained later in life (although in our sample very few women did return to school) and may therefore not be a precise measure of the person's human capital. RACE is defined as 0

14. In the first year, when the female leaves school, the cut-off level is defined to be 600 hours. The estimation results were found to be insensitive to changes in the cut-off points to 500 and 1000 hours instead of 775.

15. Except for the calculation of the hourly wage rate, we therefore ignore the information on actual hours and we assume that the wage rate is independent of hours worked.

if the person is white and 1 otherwise. SOUTH is an indicator equal to one if the individual lived in the South during the majority of the years the individual is included in the sample. The variable MANUFWG is the mean state manufacturing wage earnings, in thousands of 1983 dollars, averaged over the years the individual was in the sample. This variable represents a measure of "permanent" or average local labour market demand. In the individual's decision process it is assumed that only these permanent values matter for current and future wages and decisions.

After deleting individuals from the sample for whom information on any of the above variables were missing, the resulting sample contains information on 548 females with a total of 7204 person-year observations. The means and standard deviations of the variables are shown in Table 1.

TABLE 1

Descriptive statistics

Variable	Mean	Standard deviation (Frequency)	Number of observations
	Sample of 548 *individuals*		
Years in Sample	13·146	4·182	548
Age in 1st period	18·380	1·944	548
EDUC	12·971	2·178	548
MANUFWG	33·631	4·858	548
RACE	0·177	(97)	548
SOUTH	0·290	(159)	548
	Sample of 7204 *person-year observations*		
AGE	24·976	4·711	7204
CHILD	0·486	(3498)	7204
EXP	3·880	3·700	7204
MDUR	2·759	3·805	7204
WAGE	13·698	6·340	3632
HWAGE	19·800	9·764	3362
WORK	0·598	(4305)	7204
MARRIED	0·549	(3952)	7204
Working + Single	0·311	(2240)	7204
Working + Married	0·287	(2065)	7204
Not-working + Single	0·140	(1012)	7204
Not-working + Married	0·262	(1887)	7204
Part. Rate-Single	0·689		3252
Part. Rate-Married	0·523		3952
Part. Rate-Total	0·598		7204

Note: Female earnings, WAGE, are calculated for the sample of workers with non-missing wage information. Husband earnings, HWAGE, are calculated for married women who did report their husband's wage earnings. Both earnings are in thousands of 1983 dollars.

Even though the sample consists of relatively young women, Table 2 shows that most of them have already undergone one or more changes in marital status. Keeping in mind that the survey period is different for each individual, only 123 (22%) of the females remained single throughout their observation interval, 81 (15%) got married twice, 117 (21%) experienced one divorce and 31 (6%) two or more divorces.

As a first measure of the relationship between marital status and labour force participation decisions, the lower part of Table 1 reports a simple cross-tabulation. For the sample of 7204 person-year observations the participation rate for the single state person-year observations is much greater than for the married state observations (respectively

TABLE 2

Frequencies of observed marital status sequences

Marital status sequence	Number of observations	Marital status sequence	Number of observations
S	123	M	19
SM	258	MS	3
SMS	53	MSM	1
SMSM	60		
SMSMS	20		
SMSMSM	8		
SMSMSMS	3		

Note: Each letter represents a spell occurring over one or more years. M stands for Married, S for Single. Observed sequences end either at the end of the sample period (1985) or when the individual is dropped from the sample due to non-response. The first spell starts in the year the individual leaves school.

69% and 52%). Of course, these numbers conceal both differences across individuals as well as differences across time and it will therefore be more instructive to look at these differences separately.

Accordingly, out of the total sample all observations corresponding to the 1984 wave were selected to obtain a 1984 cross-section.[16] Table 3 shows fairly large differences in the average individual characteristics for the different employment and marital status groups. In particular, married women are more likely to be white, more likely to have children, less likely to work, have on average less work experience and, for those who work, lower average earnings than their single counterparts. Similarly, comparing non-working and working women, we find that women who participate in the labour force have on average more work experience, more years of education, are less likely to have children and to be married and, for those who are married, are married to husbands with average earnings which are lower than for women who do not work.

To study the patterns in marital status and work decisions over time, Figure 1 presents both the proportions of women who are married and who are working in the labour force, for the first 16 years since leaving school (for later years there are very few observations). Within the first five years more than 50% of the women get married and by the tenth year the percentage of women who are married has increased to about 70%. The percentage of women who have children shows a similar increase over time, which continues beyond the first 16 years. While the labour force participation rate initially increases to more than 60% in the third year since leaving school, it subsequently decreases to about 55% in the eighth year since leaving school, after which it slowly starts to increase again. The graph suggests that with more women getting married and with fewer women remaining childless, the initial growth in the participation rate decreases and then becomes negative. When the percentage of women who are married stabilizes, the participation rate starts to increase again, even as the percentage of women who have children continues to increase.

Figure 2 shows the labour force participation rates for single and married women. It is clear that the participation rate for married women is persistently lower than that for single women. Both rates initially increase, possibly reflecting the time it takes to find an

16. The 1984 wave was chosen instead of the 1985 wave because the yearly information on husband's earnings, which in the PSID is obtained retrospectively in each subsequent year, was missing for the year 1985, which was the last year included in our sample.

TABLE 3

Variable means for 1984 *cross-section*

Variable	Total	Marital status Single	Married	Employment status Not-working	Working
AGE	31·12	30·86	31·25	30·96	31·20
CHILD	0·73	0·41	0·89	0·93	0·63
EXP	7·51	8·06	7·24	5·04	8·75
MDUR	5·55	0·45	8·08	6·68	4·98
EDUC	13·22	13·21	13·23	12·77	13·45
RACE	0·13	0·22	0·08	0·12	0·13
SOUTH	0·28	0·28	0·28	0·28	0·28
MANUFWG	33·70	33·69	33·71	33·82	33·64
MARRIED	0·67	0·00	1·00	0·79	0·61
WORK	0·67	0·79	0·61	0·00	1·00
HWAGE	22·52	—	22·52	26·64	19·82
WAGE	15·34	17·14	14·28	—	15·34
Number of observations	437	145	292	146	291

Note: Cross-sectional data from the 1984 wave of the PSID. The sample consists of females with ages between 28 and 35 years. The average earnings are calculated using information on the women and husbands who work only.

acceptable job and persistence in the work decision through accumulation of work experience. While the increase in the participation rate for single women is persistent, however, it is not so for married women. For the latter group, the participation rate stabilizes in the third year since leaving school, then falls until year eight after which it starts to increase again. The importance of children in the explanation of these differences is shown in Figure 3. The figure shows first that the difference in the participation rate persists once we condition on the presence of children, and second, that childless women (both single and married) have a considerably higher participation rate.

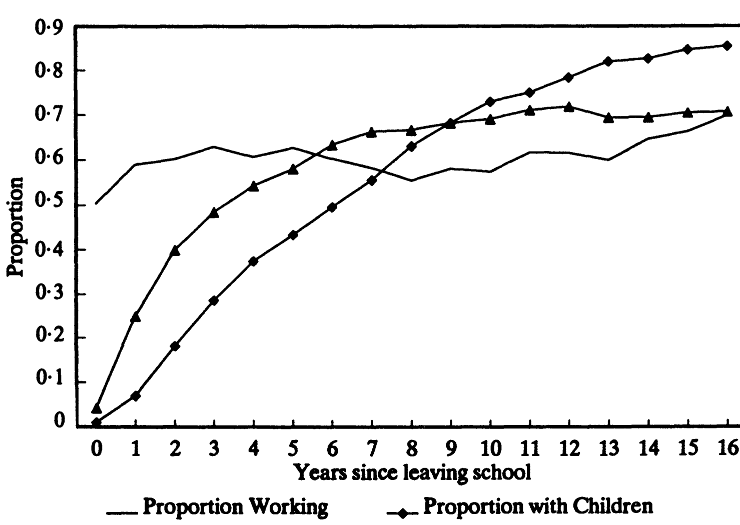

FIGURE 1

Proportions working, married and with children

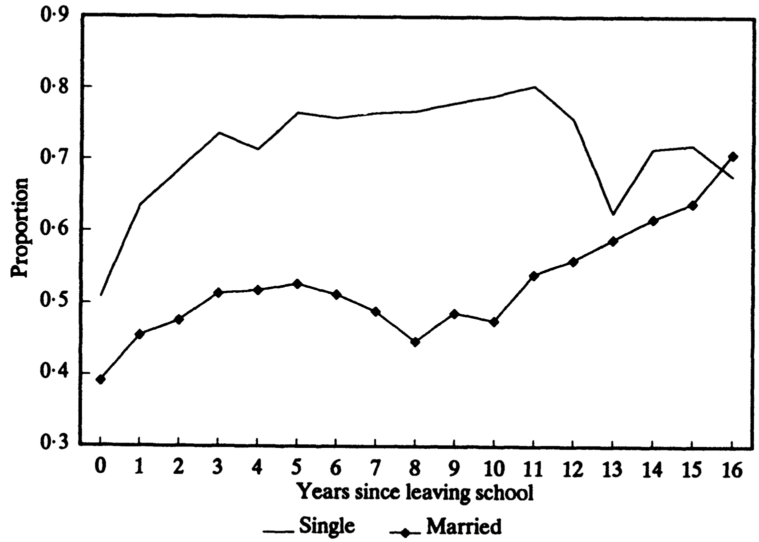

FIGURE 2
Proportion working by marital status

Of course, it is not possible to tell from Figures 2 and 3 to what extent the differences in the participation rates are merely the consequence of self-selection into both marital states and to what extent they are the result of a structural difference in decision behaviour associated with being single or married. It should also be kept in mind that the composition of each group of married and single women changes with the time elapsed since leaving school. Because these rates are averages, they conceal the individual transitions between the marital status and employment states. It is these individual transitions that are the focus of analysis in the estimation of our economic model. Estimates of this model will

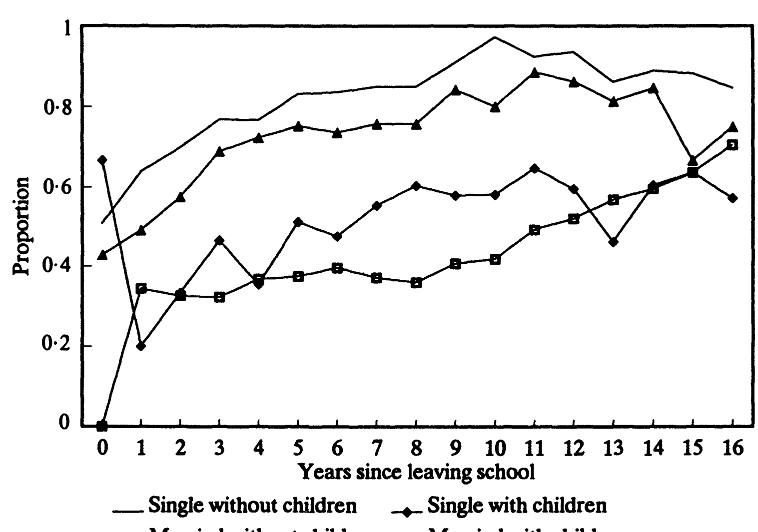

FIGURE 3
Proportion working by marital + fertility status

provide us with a better understanding of the joint determination of labour supply and marital status decisions, how these choices are related over time and how they depend on the female's education, race, (potential) earnings and other individual characteristics.

Finally, in our model fertility outcomes are characterized by the exogenous probability of a first birth, given in (7). Probit estimates of the parameters l, obtained using the data on first births in our sample, are presented in Table A1. As expected, the probability of a first birth is considerably larger if the female was married in the previous year, and while it first increases with age, after age 20 it starts to fall. The probability of a first birth at each age is further decreasing in the female's education, and is lower for whites. It is assumed that the women in our sample use this equation to evaluate the probability of a next period's birth.

4. ECONOMETRIC SPECIFICATION AND ESTIMATION

To estimate the model using the sample just described, we will first need to specify the particular distributions of the various error terms in our model. Given these specifications, the probability that a female chooses each of the four possible states (single and not working, single and working, married and not working, married and working) can be obtained from the solution to the dynamic programming problem. Estimates of the structural parameters will then be found by maximum likelihood and minimum distance estimation techniques.

Given the optimal policy in (12) it is possible to calculate for each vector $\mathscr{X}_t$ the probability that alternative i is chosen in period t as

$$\Pr(d_i(t)=1|\mathscr{X}_t)=\Upsilon\cdot\Pr(d_i(t)=1|\mathscr{X}_t, J_0)+(1-\Upsilon)\cdot\Pr(d_i(t)=1|\mathscr{X}_t, J_1) \tag{13}$$

where $\Upsilon=\Upsilon(m_{t-1}, X_{1t})$ is the arrival rate of marriage opportunities defined earlier, and

$$\Pr(d_i(t)=1\,|\mathscr{X}_t, J_k)=\Pr[\varepsilon_{it}-\varepsilon_{jt}\geqq\varepsilon^*_{jt}(\mathscr{X}_t)-\varepsilon^*_{it}(\mathscr{X}_t)\;\forall j\in J_k] \qquad k=0, 1.$$

In general only numerical solutions for these probabilities are available. However, when the ε_{it} errors are assumed to be i.i.d. extreme value distributed, these choice probabilities have a convenient analytical solution.[17] In this case

$$\begin{aligned}\Pr(d_i(t)=1|\mathscr{X}_t, J_k)&=\Pr[\varepsilon_{it}-\varepsilon_{jt}\geqq\varepsilon^*_{jt}(\mathscr{X}_t)-\varepsilon^*_{it}(\mathscr{X}_t)\;\forall j\in J_k]\\&=\frac{e^{\varepsilon^*_{it}}}{\sum_{j\in J_k}e^{\varepsilon^*_{jt}}}\\&=\frac{\exp[R_{it}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_i(t)=1, \mathscr{X}_t]]}{\sum_{j\in J_k}\exp[R_{jt}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_j(t)=1, \mathscr{X}_t]]}\end{aligned} \tag{14}$$

for all $i\in J_k$ and equals zero otherwise.

Also, the expected value functions turn out to have a convenient analytical solution in this case.[18] Using the fact that $E[\varepsilon_{it}|d_i(t)=1, \mathscr{X}_t, J_k]=\ln[\Pr(d_i(t)=1|\mathscr{X}_t, J_k)]$, it is

17. The assumption that the composite errors are i.i.d. extreme value distributed obviously implies certain restrictions on the functional form and covariance matrix of the underlying utility and earnings random components. It is important to note however, that the alternative is to impose distributional assumptions on the underlying errors, which in most cases would be just as restrictive as the ones implied here.

18. Because of this property, the extreme value error specification has been quite popular in the estimation of dynamic programming models (see, for example, Berkovec and Stern (1991), Hotz and Miller (1988) and Rust (1988)). Note that when the errors are i.i.d. normal, each probability would involve a numerical evaluation of a trivariate normal integral.

straightforward to show that

$$\begin{aligned}E[V_t(\Omega(t))|\mathscr{X}_t] &= \Upsilon E[\max_{i\in J_0}\{R_{it}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_i(t)=1,\mathscr{X}_t]+\varepsilon_{it}\}|\mathscr{X}_t]\\ &\quad +(1-\Upsilon)E[\max_{i\in J_1}\{R_{it}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_i(t)=1,\mathscr{X}_t]+\varepsilon_{it}\}|\mathscr{X}_t]\\ &= \Upsilon \ln \textstyle\sum_{j\in J_0}\exp[R_{jt}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_j(t)=1,\mathscr{X}_t]]\\ &\quad +(1-\Upsilon)\ln\textstyle\sum_{j\in J_1}\exp[R_{jt}(\mathscr{X}_t)+\delta E[V_{t+1}(\Omega(t+1))|d_j(t)=1,\mathscr{X}_t]].\end{aligned}$$

As described in the previous section, our PSID sample constitutes a panel of 548 individuals in which the choice of each alternative i is observed for each individual k for T_k periods. Let the decision set for individual k be $\underline{d}^k(t)=[d_1^k(t), d_2^k(t), d_3^k(t), d_4^k(t)]$ and $\boldsymbol{d}^k=[\underline{d}^k(1),\ldots,\underline{d}^k(T_k)]$ where $d_i^k(t)$ specifies the actual choice of alternative i for individual k at time t. Thus $\underline{d}^k(t)$ is the vector defining the alternative chosen at time t for individual k and $\boldsymbol{d}^k$ is the vector describing the choice sequence over the individual's observed sample period.

Our objective is to estimate the structural parameters, θ, given the observed data on the individuals' choices and own and husbands' earnings, where θ includes the utility function parameters (α_1, α_2, α_3 and β_1, β_2, β_3), the budget constraint parameters ($\psi(0)$ and $\psi(1)$), the parameters of the two earnings equations, (γ and π), as well as the marriage offer arrival rate parameters (ω) and the discount factor (δ).

Focusing first only on the data on the actual choices of the $K(=548)$ individuals and ignoring the available data on earnings, the (marginal) likelihood function is defined as

$$\begin{aligned}L_1(\lambda) &= \textstyle\prod_{k=1}^K \Pr(\boldsymbol{d}^k|\lambda)\\ &= \textstyle\prod_{k=1}^K \Pr[\underline{d}^k(T_k)|\underline{d}^k(T_k-1),\ldots,\underline{d}^k(2),\underline{d}(1)]\cdots\Pr[\underline{d}^k(2)|\underline{d}^k(1)]\Pr[\underline{d}^k(1)] \quad (15)\end{aligned}$$

where λ is the vector of "reduced-form" parameters in (10), the arrival rate parameters, ω, and the discount factor, i.e. $\lambda=[\lambda_1,\lambda_2,\lambda_3,\lambda_4,\omega,\delta]$.

Each of the probabilities above is equal to the probability that the chosen alternative is the optimal one, which is equal to the probability, for each possible choice set I_t, that the draw of the $(\varepsilon_{it})_{i\in I_t}$ vector falls in the region of the (ε_t) space where the chosen alternative is optimal. In the case of i.i.d. extreme value ε's, the likelihood function equals the product of weighted averages of logistic probabilities as defined by (13) and (14). Thus an algorithm for estimating the model amounts to calculating these probabilities for each individual and time period. As we saw earlier, the backward recursive solution to the dynamic programming problem provides us with these probabilities. Note that for each set of parameter values the evaluation of the corresponding likelihood function requires solving the dynamic programming problem for each individual separately. Estimation is therefore not a trivial task and necessitates fairly extensive computer run times.[19]

The other data available are the female's earnings in the years she works, and her husband's earnings in the years she is married. Incorporating this information, the sample likelihood function is

$$L_2(\theta)=\textstyle\prod_{k=1}^K \Pr(\boldsymbol{d}^k, \boldsymbol{w}^d, \boldsymbol{w}^{hk}|\theta) \quad (16)$$

19. A single (gradient-method) iteration for the model estimated and presented in Table 4 took approximately 45 minutes CPU time on an IBM 3090 mainframe.

where the likelihood function can now be expressed in terms of all the structural coefficients θ and where $w^{hk}=[w_1^{hk},\ldots,w_{T_k}^{hk}]$ and $w^k=[w_1^k,\ldots,w_{T_k}^k]$ are the sequences of the husband's and own earnings observed for individual k, elements of which will be zero (missing) if in that period the female is not married, does not work, or if either earnings are unobserved.

Maximization of the likelihood L_2, which like L_1 requires solving each individual's dynamic programming problem, is computationally much more cumbersome than the maximization of L_1, as the dimension of the parameter vector is much smaller in the latter (in our case 34 parameters) than in the former (50 parameters). Furthermore, unlike L_1 which only requires the specification of the distribution of the composite ε's errors, L_2 requires a complete specification of the joint distribution of the underlying stochastic utility components together with the error terms in the two earnings equations. We therefore propose an alternative three-stage procedure to estimate the structural parameters, which instead involves the computationally simpler maximization of L_1.

In the first stage, with the composite error distributions specified to be extreme value, the likelihood function L_1 is maximized to find consistent estimates of the reduced-form coefficients λ. In the second stage, using OLS, the earnings data are used to estimate the coefficients in the two earnings equations, γ and π, while correcting for the selection bias caused by using data on workers and on married men (husbands) only. The selectivity bias correction procedure, described in detail in the Appendix, is similar to the one adopted in Dubin and McFadden (1984) and uses the maximum likelihood estimates of the reduced-form parameters obtained in the first stage. For the estimation of these earnings equations no functional form assumptions need to be made about the distribution of the error components u_t and v_t, except that both conditional expectations $E[u_t|\varepsilon_{1t},\varepsilon_{2t},\varepsilon_{3t},\varepsilon_{4t}]$ and $E[v_t|\varepsilon_{1t},\varepsilon_{2t},\varepsilon_{3t},\varepsilon_{4t}]$ be linear in the ε_{it}, $i=1,\ldots,4$ error terms.

In the third stage, given the three sets of consistent estimates from the first two rounds, defined as $\hat{\lambda}$, $\hat{\gamma}$ and $\hat{\pi}$ with associated covariance matrices $V_{\hat{\lambda}}$, $V_{\hat{\gamma}}$ and $V_{\hat{\pi}}$, we can obtain consistent estimates of the structural parameters θ by using a minimum distance estimator (MDE) (see Chamberlain (1984)). We define the MDE as

$$\hat{\theta}=\arg_\theta \min\,[\hat{p}-g(\theta)]'V^{-1}[\hat{p}-g(\theta)]$$

where the function g imposes on the reduced-form parameters the restrictions specified by the structural model (such as those discussed in footnote 11) and $\hat{p}=[\hat{\lambda}\ \hat{\gamma}\ \hat{\pi}]'$. V represents the covariance matrix of $\hat{p}$ and can be estimated using both the estimates $V_{\hat{\lambda}}$, $V_{\hat{\gamma}}$, $V_{\hat{\pi}}$ and the outer-products of the first-order conditions, as described in the Appendix.

The resulting estimate of θ, $\hat{\theta}\xrightarrow{a.s.}\theta^0$ and

$$\sqrt{N}(\hat{\theta}-\theta^0)\xrightarrow{D} n[0,(H'V^{-1}H)^{-1}] \tag{17}$$

where $H=\partial g(\hat{\theta})/\partial\theta'$ and θ^0 is the true value of θ (see Chamberlain (1984)).

Parameter identification is best discussed by studying the three steps in the estimation procedure separately. Starting with the two earnings equations (4) and (5), the coefficients γ and π are identified by the data on wages.[20] In the estimation of the reduced-form model (10), given that $\lambda_1=0$, all reduced-form coefficients λ_i, $i=2,3,4$ are identified by the data on the individual choice decisions. As in a standard job search model, without data on all actual offers and without any exclusion restrictions, the arrival probability parameters ω are identified only on functional form. The discount factor is identified through the non-linearity of the expected value functions and the finiteness of the optimization horizon.

20. Note that in the second stage of the estimation procedure n_t, $mdur_t$ and m_{t-1} do not directly enter the earnings equations, while they do enter the choice probabilities and thus the selection-bias correction terms.

Having discussed the identification of the coefficients λ, γ and π, the identification of the structural utility parameters follows from the minimum distance estimator. In our empirical specification each earnings equation contains three variables in $\mathscr{X}_t$ that are not included in the utility function, i.e. they are not included in X_t. This implies that the structural coefficients in (9); α_1, α_2, α_3, $(\beta_1+\beta_3)\psi(0)$, $(\beta_1+\beta_2)$, $(\beta_1+\beta_2+\beta_3)$ and $(\beta_1+\beta_2+\beta_3)\psi(1)$ are over-identified. It is further clear that β_1, β_2 and $\psi(0)$ cannot be separately identified and that we can only estimate β_3, $\psi(1)$, $(\beta_1+\beta_2)$ and $(\beta_1+\beta_3)\psi(0)$.

A final note concerns the interpretation of the coefficients of the presence of children variable, n_t, in the utility function. In our model we have assumed that there are no monetary costs associated with having children. Note, however, that had we added a fixed cost of children τn_t on the right-hand side of the budget constraint (3), it would not have been possible to separately identify τ from α_{12}, α_{22} and α_{32}. Accordingly, the estimates provided for the latter coefficients can be interpreted as estimates of (what essentially are) the net utility effects of children.

5. ESTIMATES OF THE STRUCTURAL MODEL

The model was estimated with the optimization horizon, T, at the time of leaving school fixed at age 45 minus the age at leaving school, and for four values of the discount factor, $\delta=0{\cdot}00$, $0{\cdot}75$, $0{\cdot}85$ and $0{\cdot}95$.[21] The estimation results for the three positive discount factor values were qualitatively very similar both in terms of explanatory power and in their implications for individual response behaviour which will be analysed below. To limit the number of tables and results, and to focus on the difference between a "dynamic" (forward looking) vs. a "static" (myopic) model, we will therefore only report the $\delta=0{\cdot}85$ and $\delta=0$ estimation results.[22]

Table 4 presents the estimates and asymptotic standard errors of the structural parameters for the two values of the discount factor.[23] The standard errors of the estimates are obtained as in (17), using the estimate of the covariance matrix, $\hat{V}$, discussed in Section II of the Appendix. Starting with the estimates of the female earnings equation, for both discount factor values, we find the usual positive experience and education effects and slightly lower wage earnings for non-whites and for those living in the South. For a given number of years of education and work experience, the female's age captures the years the female has spent out of the labour force since leaving school. It has a negative effect on earnings, picking up the depreciation of human capital over time. The strong positive effect of the previous period's work decision further indicates that more recent work experience has a higher wage return than earlier work experience.

The estimates of the husband's earnings equation reveal the usual concave experience-earnings profile, which provides indirect evidence that the female's potential work experience is a good proxy for her husband's work experience. The estimates also indicate that women who are white and women with more education and work experience marry husbands with, on average, higher wage rates. Furthermore, husband's earnings are higher in states with high mean manufacturing wage earnings. As was the case for the female

21. Attempts to estimate the discount factor were not successful. When iterating on δ, the estimates did not converge. The discount factor becomes negative and the likelihood surface very flat. Eckstein and Wolpin (1989*a*) and Berkovec and Stern (1991) reported similar problems in estimating δ.

22. Estimation results for the $\delta=0{\cdot}75$ and $\delta=0{\cdot}95$ cases are available on request from the author (see also Van der Klaauw (1992)).

23. The corresponding estimates of the reduced form parameters λ, and the earnings equation parameters, γ and π, are presented in Tables A2 and A3 in the Appendix.

TABLE 4

Minimum distance estimates of life-cycle model

	Variable	Estimate	SDE	Estimate	SDE
Utility function parameters					
α_{111}	constant	−2·500	1·324	−3·965*	0·887
α_{112}	EDUC	0·079	0·118	−0·036	0·076
α_{113}	AGE	−0·275*	0·077	−0·140*	0·053
α_{114}	RACE	0·078	0·576	0·188	0·374
α_{115}	SOUTH	0·544	0·367	0·266	0·230
α_{12}	n_t	1·423*	0·159	0·886*	0·157
α_{13}	m_{t-1}	3·533*	0·338	3·686*	0·334
α_{14}	$mdur_{t-1}$	0·046	0·026	−0·006	0·008
α_{211}	constant	0·221	0·959	−1·829*	0·506
α_{212}	EDUC	−0·233*	0·083	−0·124*	0·047
α_{213}	AGE	−0·032	0·023	−0·004	0·013
α_{214}	RACE	−0·497*	0·219	−0·314*	0·114
α_{215}	SOUTH	0·351	0·202	0·206	0·107
α_{22}	n_t	−0·372*	0·137	−0·150	0·084
α_{23}	p_{t-1}	1·033*	0·199	1·429*	0·141
α_{311}	constant	−0·832	0·968	−0·698	0·743
α_{312}	EDUC	0·100	0·086	0·073	0·064
α_{313}	AGE	0·133*	0·049	0·106*	0·044
α_{314}	RACE	0·341	0·385	−0·057	0·323
α_{315}	SOUTH	−0·168	0·221	−0·160	0·180
α_{32}	n_t	−0·397*	0·162	−0·403*	0·108
α_{33}	p_{t-1}	1·004*	0·168	0·792*	0·132
α_{34}	m_{t-1}	−0·072	0·134	−0·067	0·136
α_{35}	$mdur_{t-1}$	0·052*	0·016	0·026*	0·008
$(\beta_1+\beta_2)$	w_t	0·376*	0·057	0·199*	0·031
β_3	w_t	−0·111*	0·043	−0·037	0·020
$(\beta_1+\beta_3)\psi(0)$	w_t^h	0·368*	0·111	0·242*	0·078
$\psi(1)$	w_t^h	0·633	0·347	0·344	0·272
Arrival rate marriage opportunities					
w_1	constant	5·216*	1·880	5·352*	2·552
ω_2	EDUC	−0·251*	0·092	−0·271*	0·133
ω_3	AGE	−0·045	0·031	−0·037	0·041
ω_4	RACE	−0·656*	0·308	−0·323	0·369
ω_5	SOUTH	−0·058	0·232	−0·092	0·299
Female earnings equation					
γ_{11}	constant	−6·020*	1·882	−5·746*	1·890
γ_{12}	EDUC	1·384*	0·099	1·379*	0·099
γ_{13}	AGE	−0·130*	0·058	−0·127*	0·057
γ_{14}	RACE	−0·113	0·500	−0·045	0·499
γ_{15}	SOUTH	−0·718	0·467	−0·766	0·467
γ_2	p_{t-1}	1·987*	0·248	2·082*	0·248
γ_3	exp_{t-1}	0·682*	0·103	0·588*	0·096
γ_4	$exp_{t-1}^2/100$	−0·283	0·537	0·498	0·514
γ_5	MANUFWG	−0·014	0·027	−0·019	0·028
Husband earnings equation					
π_{11}	constant	−11·751*	3·822	−8·231*	3·360
π_{12}	EDUC	1·297*	0·219	1·266*	0·219
π_{13}	RACE	−3·648*	1·017	−3·708*	1·013
π_{14}	SOUTH	−0·019	0·972	−0·272	0·945
π_2	exp_{t-1}	0·287*	0·095	0·331*	0·106
π_3	$hexp_{t-1}$	1·335*	0·231	1·086*	0·183
π_4	$hexp_{t-1}^2$	−0·033*	0·010	−0·023*	0·008
π_5	MANUFWG	0·084	0·046	0·033	0·029
δ	discount factor	0·000		0·850	
log likelihood	L_1	−5256·2		−5260·0	
distance		14·550		14·544	

Notes: * = significant at 5% level.

The decision horizon, T, at the time of leaving school was fixed at 45 years minus the age at leaving school. *Distance* represents the value of $[\hat{p}-g(\theta)]'\hat{V}^{-1}[\hat{p}-g(\theta)]$ evaluated at the estimated value $\hat{\theta}$.

earnings equation, the parameter estimates are insensitive to the value of the discount factor.

The estimates of the marriage opportunity arrival rate function show that the yearly probability of meeting a potential spouse is lower for women with more years of education, is decreasing in age and is much lower for non-whites. The latter finding (though not statistically significant in the dynamic version of the model) is consistent with the widely reported lower ratio of eligible males to females in the marriage market for blacks.

Turning now to the estimates of the utility function parameters in Table 4, as well as the estimates of the sum of several of these parameters presented in Table A4, the most important implications can be summarized as follows:

(1) The estimates imply that the utility gains from working are increasing in the female's earnings. The negative value of β_3, on the other hand, implies that the utility gains from marriage for those who work depend negatively on the female's earnings (although the estimate is only significant at the 10% level in the positive discount factor case).
(2) While the share parameter $\psi(0)$ is not identified, the estimates for $\psi(1)$ indicate that 63% of the husband's earnings in the zero discount factor case and 34% in the positive discount factor case will be available for consumption by the wife. Combined with the marginal utility of consumption parameter estimates, this implies that the utility gains from working are decreasing in the husband's earnings when married $((\beta_1+\beta_2+\beta_3)\psi(1)<(\beta_1+\beta_3)\psi(0))$. The utility gains from marriage, on the other hand, are increasing in the husband's earnings, both when working $((\beta_1+\beta_2+\beta_3)\psi(1)>0$, although not significantly so), and not-working $((\beta_1+\beta_3)\psi(0)>0)$.
(3) The utility gains from being married are greater when children are present, as $\alpha_{12}>0$. The presence of children also leads to an increase in the disutility of working, especially when married $((\alpha_{32}+\alpha_{22})<\alpha_{22}<0)$.
(4) All else equal, non-whites receive lower utility gains or a greater disutility from working than whites when single $(\alpha_{214}<0)$ but not when married $(\alpha_{214}+\alpha_{314}\approx 0$, see Table A4). There is no significant difference between whites and non-whites in the direct utility gains from marriage.
(5) The coefficient estimates of the lagged marital status and marriage duration variables imply strong state and duration dependence in preferences for marriage. Similarly, comparing the utility derived from working and not working the utility gains from working increase with the amount of prior work $(\alpha_{23}>0)$, reflecting positive habit persistence.
(6) The estimates for both discount factor specifications are qualitatively similar. However, as will be discussed below, both estimates do in fact imply different types of optimal response behaviour. Note that it is not possible to test one discount factor value specification against the other, as they are not nested.

Before illustrating the implications of these estimates in terms of individual differences in life-cycle patterns of labour supply and marital status choices, we first present various indicators of the model's explanatory power. Given that the static and dynamic model were found to perform equally well in fitting the data, we only focus on the $\delta=0{\cdot}85$ version. Conditional on each individual's characteristics in the year of leaving school, and given the estimated values of the parameters in Table 4 and the predicted birth probability parameters in Table A1, for each individual 1000 work and marital status choice sequences were simulated from the first period to each individual's final observation period. Yearly

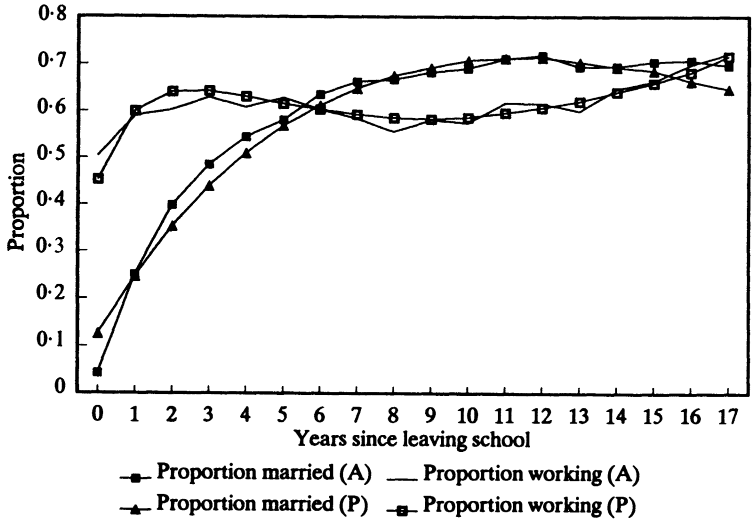

FIGURE 4

Actual + predicted proportions married and working

predicted proportions for each marital status-work state were then obtained by averaging in each period over all individuals and simulations.

Figures 4 and 5 show the corresponding predicted proportions of women working in each year since leaving school, as well as those for single and married women separately, and the percentage of women who are married in each year. The figures show that the model fits the data fairly well; in predicting the proportion of women who are married in each year, in predicting the much higher labour force participation rates in all years for single women as compared to married women and predicting the sharp rise, flattening and

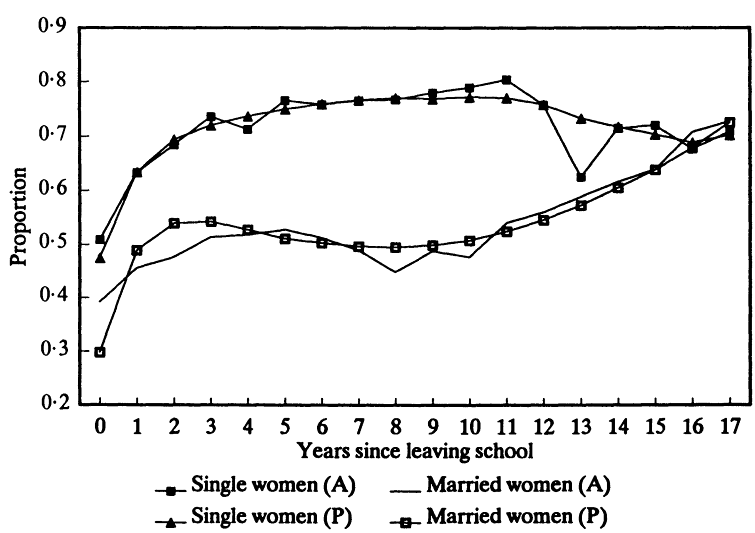

FIGURE 5

Actual and predicted proportions working by marital status eventual decline in the work rate of single women. It also captures the initial increase, the subsequent fall and at later ages the resurgence in the participation rate of married women.

Table 5 provides additional evidence of the model's ability in predicting the choice patterns and work-experience profiles in the sample. It compares the predicted to actual proportions of women in the four states for each five-year interval. The table indicates that with every subsequent five-year interval the proportion of women choosing the married-working state grows sharply, the proportion choosing the single working state falls steadily, and the percentage choosing the married not-working state first increases and then declines. The predicted patterns parallel the actual ones in all these characteristics. For each of the four choice alternatives, a chi-square test does not reject the null hypothesis that predicted and actual total proportions in all four five-year intervals are the same at the 5% level.

TABLE 5

Actual and predicted proportions in each state by year

Year	Experience	Single not-working A	Single not-working P	Married not-working A	Married not-working P	Single working A	Single working P	Married Working A	Married Working P	No. of obs. [proportions] [A]	No. of obs. [proportions] [P]
1–5	$exp_1=0$	0·243	0·245	0·172	0·163	0·417	0·423	0·168	0·169	2654	
6–10	$exp_6\in[0, 5]$	0·083	0·085	0·327	0·319	0·273	0·276	0·317	0·320	2447	
11–15	$exp_{11}\in[0, 10]$	0·075	0·071	0·318	0·322	0·223	0·219	0·384	0·389	1700	
	$exp_{11}\in[0, 5]$	0·141	0·135	0·448	0·470	0·105	0·105	0·307	0·291	[0·473]	[0·431]
	$exp_{11}\in[6, 10]$	0·017	0·023	0·202	0·210	0·329	0·305	0·452	0·463	[0·527]	[0·569]
16–20	$exp_{16}\in[0, 15]$	0·087	0·102	0·227	0·213	0·210	0·229	0·476	0·456	401	
	$exp_{16}\in[0, 5]$	0·188	0·277	0·357	0·361	0·098	0·100	0·357	0·263	[0·279]	[0·300]
	$exp_{16}\in[6, 10]$	0·050	0·041	0·266	0·229	0·173	0·188	0·511	0·542	[0·347]	[0·319]
	$exp_{16}\in[11, 15]$	0·047	0·016	0·093	0·084	0·327	0·364	0·533	0·536	[0·371]	[0·381]
	χ^2	1·517		2·251		1·050		0·567			

Note: Entries represent proportions of individuals in each marital status-work state, by intervals of number of years since leaving school. exp_t represents the work experience accumulated up to period t, A = actual and P = predicted. $\chi^2=\sum(n_p-n_a)^2/n_p$, n_p = total number predicted in each 5-year interval, n_a = actual total number, and $\chi^2(3, 0{\cdot}95)=7{\cdot}82$.

Table 5 also reports for each five-year period, the choice probabilities by different levels of work experience accumulated up to the beginning of each five-year interval, as well as the proportions of women with these different levels of work experience. As expected, the proportion of women choosing either non-working state decreases in work experience. The proportion of women choosing either married state also declines with an increase in work experience. Again the predicted proportions match the actual ones fairly well. Finally, the last column of the table indicates that the model also performs reasonably well in predicting the average experience level at the beginning of each five-year interval.

To further illustrate the model's ability in predicting the life-cycle marriage and divorce patterns, Figure 6 presents actual and predicted values of the percentage of women never married and the rate of first marriage by age. It shows that the predicted survivor function and first marriage (hazard) rate are very similar to the actual ones. In particular, the predicted marriage rate function parallels the initial increase, reaches a maximum around age 22, and captures the subsequent gradual decline with age. The predicted median age at first marriage, for those who were predicted to marry, equals the actual median age of 22 and the proportion of women in the sample who never marry was predicted to be 0·189 compared to the actual proportion of 0·225.

Figure 7, which reports the percentage still married and the rate of divorce by duration of first marriage, similarly indicates that the predicted survivor function and divorce hazard

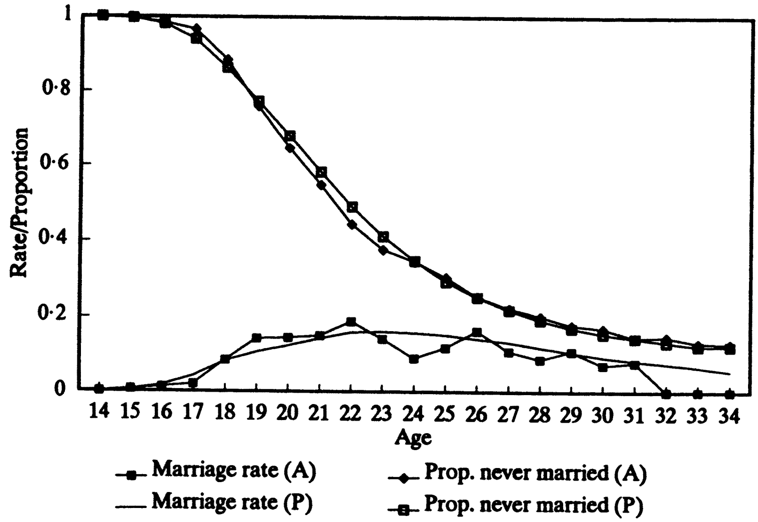

FIGURE 6

Actual and predicted rate of first marriage and proportion never married

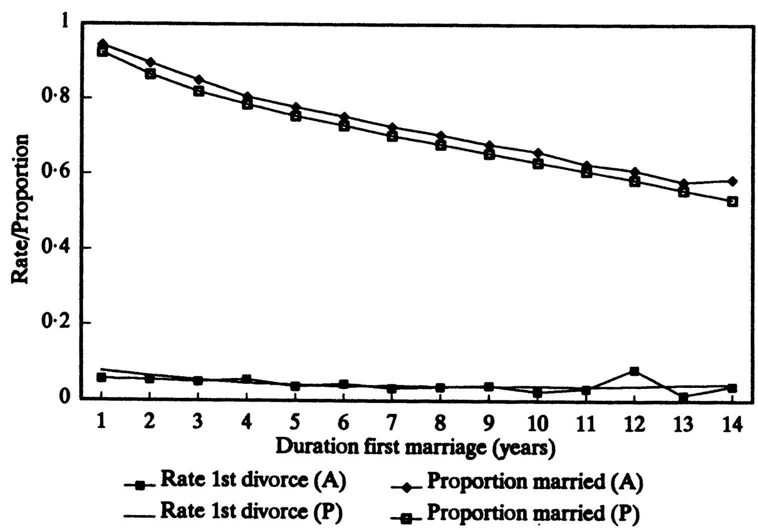

FIGURE 7

Actual and predicted rate of first divorce and proportion still married

rate function do capture the general trends in the data. The predicted median duration of the first marriage equals the actual median of 16 years, and a predicted proportion of 0·644 of married women who never divorce is close to the actual proportion of 0·652. The predicted values in these calculations and in both figures were again obtained using the Monte Carlo simulation described earlier.[24]

24. When comparing the model's ability in predicting life-cycle behaviour for different groups of women, we found the model to perform slightly better for whites and for those with more than 12 years of education.

TABLE 6

Simulated work and marital history of representative female at age 35

	At age 35 Change in probability			Change in years		Median
	Never married	Never divorced	Never remarried	Work exper.	Ever married	Age 1st marriage
Baseline prob.	0·07	0·47	0·43	9·9	10·2	21
Δ WAGE	0·05	−0·02	0·03	2·5	−1·3	1
Δ HWAGE	−0·05	0·09	−0·06	−2·6	2·3	−1
Δ EDUC	0·00	0·09	0·00	−0·2	−0·2	1
non-white	0·23	−0·17	0·18	0·1	−5·2	5
Δ return to exp	0·06	−0·06	0·06	2·7	−1·5	1
Δ arrival rate	0·05	0·05	0·10	0·4	−0·7	1

Note: Entries represent changes in simulated values corresponding to changes in different characteristics of a representative female obtained for the $\delta = 0{\cdot}85$ specification. The first two changes considered are permanent own and (potential) husband's earnings increases of $1000. The third change is a one year increase in education (which also implies that the female left school at age 19 instead of 18). The fourth change evaluates the differences in behaviour if the female were non-white instead of white. Both the education and race effects are total effects (they include the indirect effects through wages). The final two changes are a 25% increase in the wage returns to work experience (γ_3 was increased by 25%), and a 25% decrease in the marriage opportunity rate when single (Υ falls by 25%).

Simulations

To evaluate the implications of the estimates in Table 4 for individual life-cycle choice behaviour, it will be useful to analyse in more detail the influence of some of the variables and in particular the female's wage rate and the (expected) husband's wage earnings on the work and marital status decisions made over the life cycle.

Table 6 reports, for the case where $\beta = 0.85$, the effect of changes in several variables on the life-cycle marital status and work choices made up to age 35, that is, during the first 18 years after leaving school, by a female of fairly representative characteristics.[25] The predicted values in the table were obtained by simulating 10,000 choice sequences from the year of leaving school until age 35, using the parameter estimates reported in Table 4.

Reflecting the corresponding decrease in the gains from marriage, earning an extra $1000 in each year leads to an increase in the median age at first marriage, a considerable increase in the probability of never marrying before age 35, an increase in the probability of experiencing a divorce once married, and a decrease in the probability of a remarriage after a divorce. As a result, the total number of years of marriage at age 35 is much lower. At the same time, the higher earnings raise the gains from working resulting in a 26% increase in the predicted level of work experience at age 35. An increase of $1000 in the (potential) husband's earnings at all ages, on the other hand, increases the attractiveness of marriage and leads a considerable increase in the predicted number of years of marriage. The increase in husband's earnings also leads to a reduction in the gains from working, lowering the expected level of work experience at age 35 by 2·6 years.

One extra year of education, combined with its positive effect on her own and her (potential) husband's earnings, the negative effect on the marriage opportunity arrival rate, and the increase by one year in the age at leaving school, has a small positive effect on the probability of getting and staying married. It also leads to an increase in market

25. The representative female is white, does not live in the South, has 12 years of schooling, left school at age 18, and lives in a state with mean manufacturing wages equal to $336·29.

work, resulting in an average level of work experience at age 35 which is the same as that of a similar female who had left school one year earlier.

When the female is non-white rather than white, lower (potential) husband's earnings, a lower marriage opportunity arrival rate and racial differences in preferences for working and marriage, together reduce the attractiveness of marriage, but lead to no significant change in the average expected experience level at age 35. A closer look at the yearly work patterns reveals that this is primarily due to a higher probability of working in later years, following an initial period of less labour market participation just after leaving school.

To study the effect of an increase in the wage returns to work experience, the coefficient of work experience in the earnings equation, γ_3, was increased by 25%. The predicted response to this change is qualitatively very similar to that of a constant increase at all ages in the female's earnings. However, the yearly choice patterns reveal considerable differences in the timing of the response. The effect of a change in the wage equation intercept on the probability of working and being married is more immediate and relatively constant at all ages compared to the response to a change in the slope of the wage profile, which increases with the number of years since leaving school.

Finally, we also evaluated the predicted response of the representative female to a 25% decrease in the arrival rate of marriage opportunities at each age.[26] Not surprisingly, this change leads to a fall in the probability of ever marrying and a fall in the probability of a re-marriage when divorced before age 35. The probability of a divorce before age 35, however, is predicted to decrease, but this may simply be due to the increase in the median age at first marriage.

It is interesting to study whether and how the optimal response behaviour implied by the dynamic model differs from that implied by the static model. Simulations for the static model show the responses to be qualitatively similar, but also show that they can differ considerably in their magnitudes, and more importantly, in their timing. These differences were most pronounced in the case of the increase in the returns to work experience. While the static model predicts a very small effect at earlier ages, the dynamic model, with forward looking behaviour, predicts much larger immediate responses to the anticipated increase in future returns from working today. Not only does the probability of working at younger ages increase, the steeper wage profile also increases the probability that the female will remain single at all ages as higher future earnings lower expected future gains from marriage, causing both a delay of entry into marriage and a lower probability of ever marrying. In the myopic case, the response in work and marriage behaviour only increases with age once the individual has accumulated more work experience.

A notable difference in predicted response behaviour was also found in the case of a decrease in the arrival rate. While the predicted responses in work behaviour are almost identical, the responses in marriage behaviour are very different. For a myopic female, a drop in the arrival rate leads to an immediate and large reduction in the marriage and re-marriage rate, while for a forward looking individual the predicted response is much smaller. The smaller effect is caused by a corresponding fall in the "reservation value" of marriage offers, which is similar to the fall in the reservation wage caused by a drop in the offer arrival rate in the standard job search model.

A third and related difference between the static and dynamic model concerns their predicted immediate responses to current temporary and permanent changes in earnings. While the static model does not distinguish between temporary and permanent changes,

26. The baseline estimate of the probability of a marriage opportunity equals 0·95 at age 18 and declines to approximately 0·75 at age 50.

the dynamic specification predicts much bigger responses to permanent than to temporary changes. While the responses to permanent changes in own and husband's earnings were always found to be larger in the dynamic case, the opposite was true for temporary changes.

Unconditional vs. conditional labour supply elasticities

To date, most of the wage elasticities of female labour supply which have been reported in the labour supply literature, are conditional wage elasticities, obtained by treating marital status as an exogenous determinant. The model estimated here treats marital status as a choice variable, which is similarly dependent on the individual's (potential) wage earnings. It would therefore be interesting to use our estimates to study how the wage elasticities of female labour supply change when marital status is included as an endogenous rather than an exogenous regressor variable. In particular, for the model estimated here, it would be informative to compare the unconditional wage elasticities to those obtained conditional on marital status. Unfortunately, because of the discrete nature of our labour supply measure, it is not possible to derive conventional wage elasticities of labour supply. It is however possible to use the estimates to calculate the wage elasticity of the probability of labour force participation and to decompose it into two parts, as described in Section III of the Appendix. The first part measures its direct effect on the probability of working, while keeping the *probability* of choosing to be married in the current period constant. The second measures an indirect wage effect on the labour force participation probability caused by a change in the probability of choosing the married state when the wage rate increases.

To illustrate this decomposition, predicted wage elasticities were calculated for all observations in our sample that were part of the 1984 wave, forming a 1984 cross-section. For this sample, the average own wage elasticity and the husband's wage elasticity were, respectively 0·89 and −1·30. The indirect effects accounted for 4% of the total own wage elasticity and 17% of the husband's wage elasticity. When comparing the individual decompositions, we found the indirect effects to be greatest (in both percentage and absolute terms) at younger ages when many of the women have not yet married, where both indirect effects account for 7% and 54% of the total wage elasticities. For these women, a higher wage rate implies lower gains from marriage, reducing the tendency to get married which then leads to an increase in the probability of working. Higher husband's earnings, on the other hand, increase the gains from marriage and through a higher marriage rate, reduce the probability of working.

These predictions imply that the own wage elasticities of the probability of labour force participation will be underestimated by up to 4% if one ignores the endogeneity of marital status decisions. Similarly, the negative husband's wage elasticity will be underestimated by 17% if one does not take account of the fact that higher husband's wage rates reduce the probability of a divorce and increase the probability of marriage. Even though we cannot use our estimates to calculate conventional wage elasticities of hours of work, these results do suggest that the conditional wage elasticities are likely to be (slightly) smaller than the unconditional ones, especially if the sample includes a relatively large number of young single women.

6. ALTERNATIVE MODEL SPECIFICATIONS

In this section two alternative specifications of the model are considered. First, to evaluate the importance of including the individual characteristics X_{1t} (EDUC, AGE, RACE, SOUTH) as direct determinants in the utility function, measuring individual differences in preferences for working and marriage, an alternative *restricted* version of the model was estimated which did not allow for these direct effects. While the magnitude of most estimated parameters did change, qualitatively the estimates imply a similar dependence of the gains from working and of being married on the female's and husband's earnings. A chi-square test, however, rejects the null hypothesis that the direct effects are zero ($\Delta(\textit{distance}) = 78{\cdot}9 > \chi^2(12, 0.95)$), and the restricted model was found to perform somewhat less well in fitting the data.

Note that the estimation of this restricted model only involved a simple re-estimation of the third stage (MDE) of our procedure, where the new structural restrictions are now imposed on the same reduced form coefficient estimates obtained earlier for the unrestricted model. There is no need to re-do the computationally most intensive first stage of the estimation procedure, which required solving each female's dynamic programming problem. This ease of testing and estimating alternative nested models represents an additional advantage of our estimation procedure over a conventional FIML estimation of the likelihood L_2 in (16), which would have required a complete re-estimation of the restricted model.

Second, a version of the model was estimated which allows for the presence of persistent unobserved individual differences in preferences for work and marriage. In particular, we re-specified the $a_{it}\,(i=1, 2, 3)$ utility terms in (2) as:

$$a_{1t} = X_t'\alpha_1 + \mu_1, \qquad a_{2t} = X_t'\alpha_2 + \mu_2, \qquad a_{3t} = X_t'\alpha_3 + f\mu_2$$

where μ_1 and μ_2 are individual specific unobserved differences in, respectively, the direct utility obtained from being married and the disutility of working, and are assumed to be uncorrelated with the observed heterogeneity components X_t. The inclusion of $f\mu_2$, where f is a parameter, permits an individual's unobserved disutility of work to be different when married instead of single. The taste components μ_1, μ_2 and the parameter f are known to the individual, but are unobserved by the econometrician.

The corresponding "reduced form" representation of the model can again be defined as in (10), where the $R_{it}(\mathscr{X}_t)$ functions are now given by

$$R_{1t}(\mathscr{X}_t) = \mathscr{X}_t'\lambda_1, \qquad R_{2t}(\mathscr{X}_t) = \mathscr{X}_t'\lambda_2 + \mu_1$$

$$R_{3t}(\mathscr{X}_t) = \mathscr{X}_t'\lambda_3 + \mu_2, \qquad R_{4t}(\mathscr{X}_t) = \mathscr{X}_t'\lambda_4 + \mu_1 + (1+f)\mu_2.$$

In this case, the likelihood functions defined in (15) and (16) are conditional likelihoods where the conditioning (though omitted there) is on the set of errors $\mu = [\mu_1, \mu_2]'$. By integrating over the distribution of μ, we can remove the conditioning on μ to obtain the sample likelihood function $\mathscr{L}_1$ defined as

$$\mathscr{L}_1(\lambda) = \prod_{k=1}^{K} \int \Pr(\boldsymbol{d}^k | \lambda, \mu)\, dF(\mu) \tag{18}$$

where F is the distribution of μ.

Following an approach similar to that proposed by Heckman and Singer (1984), we specify F as a discrete multinomial distribution. In particular, we assume that individuals can be divided into four groups (types), with population proportions $q_1, \ldots, q_4$. The first type has a (relatively) low preference for both marriage and work, with values $\mu_1 = 0$, $\mu_2 = 0$. The second also has a low preference for work ($\mu_2 = 0$), but has a high preference for marriage, in that this type of individual receives $\mu_1 = \rho_1$ more utility units when married than type 1. The third group has a low preference for marriage ($\mu_1 = 0$), but a high preference for work with $\mu_2=\rho_2$. Finally, type 4 individuals receive higher utility both from marriage and from working ($\mu_1=\rho_1$, $\mu_2=\rho_2$). Thus the unobserved taste components μ_1 and μ_2 are specified to have the following multinomial distribution:

$$\Pr((\mu_1,\mu_2)=(0,0))=q_1, \qquad \Pr((\mu_1,\mu_2)=(\rho_1,0))=q_2$$
$$\Pr((\mu_1,\mu_2)=(0,\rho_2))=q_3, \qquad \Pr((\mu_1,\mu_2)=(\rho_1,\rho_2))=q_4$$

with $\sum_{j=1}^4 q_j=1$. Then for each type, defined by a particular value of (μ_1,μ_2), the contribution to the likelihood function $\Pr(d^k|\lambda,(\mu_1,\mu_2))$ can be calculated. The likelihood contribution of an individual k will then equal the weighted average of these terms, where the weights are the sample fractions $q_1,\ldots,q_4$. The distribution parameters ρ_1, ρ_2 and q_1, q_2, q_3, q_4 as well as the parameter f can be estimated along with the parameters λ.

TABLE 7

Minimum distance estimates of life-cycle model with unobserved permanent individual effects

	Variable	Estimate	SDE		Variable	Estimate	SDE
Utility parameters				Arrival rate parameters			
α_{111}	constant	−4·458*	0·901	ω_1	constant	3·571*	1·731
α_{112}	EDUC	−0·029	0·073	ω_2	EDUC	−0·179*	0·088
α_{113}	AGE	−0·138*	0·048	ω_3	AGE	−0·032	0·031
α_{114}	RACE	0·050	0·348	ω_4	RACE	−0·432	0·319
α_{115}	SOUTH	0·334	0·235	ω_5	SOUTH	0·264	0·301
α_{12}	n_t	1·230*	0·189	Female earnings eqn.			
α_{13}	m_{t-1}	3·319*	0·344	γ_{11}	constant	−7·549*	2·222
α_{14}	$mdur_{t-1}$	−0·017	0·009	γ_{12}	EDUC	1·365*	0·099
α_{211}	constant	−2·964*	0·478	γ_{13}	AGE	−0·122*	0·058
α_{212}	EDUC	−0·041	0·045	γ_{14}	RACE	−0·091	0·497
α_{213}	AGE	−0·016	0·013	γ_{15}	SOUTH	−0·378	0·540
α_{214}	RACE	−0·403*	0·122	γ_2	p_{t-1}	2·009*	0·252
α_{215}	SOUTH	0·183	0·113	γ_3	exp_{t-1}	0·584*	0·111
α_{22}	n_t	−0·273*	0·101	γ_4	$exp_{t-1}^2/100$	−0·536	0·656
α_{23}	p_{t-1}	1·440*	0·135	γ_5	MANUFWG	−0·014	0·027
α_{311}	constant	−1·178	0·727	Husband earnings eqn.			
α_{312}	EDUC	0·089	0·060	π_{11}	constant	−10·574*	3·532
α_{313}	AGE	0·112*	0·037	π_{12}	EDUC	1·295*	0·219
α_{314}	RACE	0·107	0·290	π_{13}	RACE	−3·690*	1·022
α_{315}	SOUTH	−0·170	0·170	π_{14}	SOUTH	−0·153	0·962
α_{32}	n_t	−0·518*	0·122	π_2	exp_{t-1}	0·381*	0·106
α_{33}	p_{t-1}	0·797*	0·146	π_3	$hexp_{t-1}$	1·231*	0·198
α_{34}	m_{t-1}	−0·053	0·140	π_4	$hexp_{t-1}^2$	−0·029*	0·008
α_{35}	$mdur_{t-1}$	0·020*	0·010	π_5	MANUFWG	0·058	0·039
$(\beta_1+\beta_2)$	w_t	0·156*	0·029	Heterogeneity parameters			
β_3	w_t	−0·074*	0·025	q_2		0·431*	0·068
$(\beta_1+\beta_3)\psi(0)$	w_t^h	0·245*	0·067	q_3		0·108*	0·048
$\psi(1)$	w_t^h	1·053	0·713	q_4		0·335*	0·065
				ρ_1		0·728*	0·129
Log-likelihood L_1			−5226·1	ρ_2		0·726*	0·127
distance		11·88		f		0·237	0·280

Notes: * = significant at 5% level. $q_1=1-\sum_{i=2}^4 q_i$.
The decision horizon, T, at the time of leaving school was fixed at 45 years minus the age at leaving school and δ was fixed at 0·85.

Estimates of the model with $\delta=0{\cdot}85$ are reported in Table 7. Most of the parameter estimates are very similar to those in Table 4. The parameter values of the EDUC and presence of children variables changed somewhat, the marginal utility of consumption parameter, β_3, has become more negative and the income share parameter, $\psi(1)$, though still insignificant, has become greater than 1. But, most importantly, the overall qualitative results have remained the same.

Looking at the heterogeneity distribution, we find that the largest groups in the population are the 43% females of type 2 (with a high preference for marriage but a low one for working) and 34% of type 4 (high preference for both). The remaining 23% have a relatively high preference to remain single. An individual's probability of having a relatively high preference for working or for marriage appear unrelated, that is, the population appears to be randomly distributed into the four categories with the probability of having a high preference for marriage being independent of the probability of having a high preference for work.[27] Further, f is positive, but insignificant, implying that those who prefer work do so to the same extent, irrespective of their marital status.

The introduction of this type of unobserved heterogeneity increases the log-likelihood value of the first-stage maximum likelihood estimation by 30·1 points. Given that six extra parameters were estimated, this improvement in the likelihood is statistically significant at the 95% level ($-2 \cdot \Delta(\text{Log } Likh) = 60{\cdot}2$ while $\chi^2(6, 0{\cdot}95) = 14{\cdot}4$).

The introduction of time-invariant unobservables represents, in an admittedly limited way, a relaxation of the earlier imposed assumption of identically independently distributed ε_{it} errors. Note that in addition to not allowing for any serial correlation over time, this assumption implies in a static (but not in a dynamic, given the presence of the expected value functions) framework the well known independence of irrelevant alternatives property. The overall significance of the unobserved heterogeneity distribution parameters therefore suggests that this i.i.d. assumption may be too restrictive. On the other hand, the estimates also show that the qualitative estimation results do not change very much when this restriction is relaxed, giving an increased confidence in the validity of the main results.

7. CONCLUSION

This paper has been concerned with the construction and estimation of a structural dynamic model of marital status and labour force participation decisions that a woman makes over her lifetime. In this model, the individual's finite-horizon optimization problem constitutes a dynamic programming problem that can be solved by backward induction. To estimate the model a three-stage procedure was proposed which allows, in addition to data on work and marital status choices, for the incorporation of both female and male earnings data in a computationally simple way. The estimates were used to predict changes in the life-cycle patterns of marriage, divorce and employment due to changes in female earnings, (potential) husband's earnings, education, as well as differences by race. The model was shown to fit the data reasonably well in terms of various measures of life-cycle work, marriage and divorce behaviour.

The results showed that a female's work and marital status decision in each period depends strongly on the individual's earnings, race, education and the presence of children. The strong interdependence between the gains to marriage and the gains from working further implies that a female's marital status cannot be considered exogenous with respect to the participation decision. Higher female earnings, for example, increase the probability that the female will work but also decrease the gains from marriage leading to both lower marriage rates and higher divorce rates among high-wage women. Higher expected

27. Random assignment implies that $q_1 \cdot q_4 = q_2 \cdot q_3$. Here we find 0·0422 amd 0·0465 for both expressions and we cannot statistically reject their equality.

husband's earnings lead to an increase in the gains and thus the probability of getting and staying married and to a decrease in the probability that a married woman works. For our sample, ignoring the endogeneity of marital status decisions causes the current work response to own and husband's earnings changes to be underestimated by 4% and 17%.

In addition to the strong own and husband's earnings effects, for women with children, we found the gains from marriage to be much greater and the gains from working smaller, resulting in a higher (re-)marriage rate and a lower divorce rate for these women. Because of a lower arrival rate of marriage opportunities and the lower average gains from marriage associated with the considerably lower earnings of potential husbands, the marriage rate of non-white women was found to be much smaller, and the divorce rate much higher, than those of otherwise identical women who are white.

The estimates also identified several important sources of duration and state dependence in individual choice behaviour. As a result, dynamics plays an important role in female labour supply and marital status decisions. The dynamic model studied here was shown to have different and more plausible implications for the response behaviour to, for example, changes in the future wage returns to work experience and a decrease in the arrival rate of marriage opportunities, than a static model of myopic choice behaviour.

The estimates of our model were shown to be robust to the incorporation of one particular form of unobserved time-invariant heterogeneity. However, more general forms of serial correlation in the error terms and less restrictive assumptions concerning the within-period correlation between choice specific errors remain to be explored. Also, more research is required to investigate the estimation problems encountered in several studies, including this one, when trying to estimate the discount factor. In the model presented here, the discount factor is identified through the non-linearity of the expected value functions and the finiteness of the optimization horizon, and is therefore, if estimable, likely to be sensitive to alternative functional form specifications of the utility function. Another important area for future research is the modelling in our framework of fertility as outcomes of choice decisions, rather than purely exogenous events.

This study's finding of a strong relationship between returns in the labour and marriage market has important policy implications. Any policy programme aimed at influencing female or male earnings or labour supply behaviour may have important effects on marriage and divorce behaviour, which could affect the ultimate outcome of the programme. Ignoring these marital status effects may therefore lead to incorrect policy evaluations. To date studies on the implications of social welfare programmes have considered either only the work (dis)incentives of welfare programmes, such as AFDC, or only their effect on marriage and divorce decisions. A study of both incentive effects together will be of considerable importance given the strong interdependence between work and marital status decisions.

Finally, the model and the estimates discussed in this paper have interesting implications for the explanation of the post-war labour force participation and marriage and divorce trends mentioned in the introduction. The steady increase in average real female earnings over the last four decades, especially when compared to that of males, has led to an increase in the gains from working and thus higher participation rates for both single and married women. The observed fall in the marriage rate and rise in the divorce rate over the same time period is consistent with our finding that the gains from marriage decrease with an increase in female (potential) earnings. The increase in the female participation rate and in the divorce rate do further reinforce each other as divorces typically lead to an increase in female labour supply and more work experience leads to higher future earnings.

APPENDIX

I. *Sample selection-bias correction in the earnings regressions*

I.1. *Estimation of the female earnings equation*

To obtain estimates of the earnings equation parameters γ, equation (4) was estimated by OLS using the non-missing earnings data of the workers in our sample. To account for the fact that workers form a non-random subset of the potential labour force population, a selection-bias correction term was included in the earnings equation to adjust for the fact that $E[u_t|d_3(t)=1$ or $d_4(t)=1]$ may not equal zero. Given the assumption that single and married women are paid according to the same earnings equation, this sample selection correction term is equivalent to an estimate of $E[u_t|d_3(t)=1]$ for single working women and $E[u_t|d_4(t)=1]$ for married working women.

As shown by Dubin and McFadden (1984), if the conditional expectation of u_t is linear in the extreme value distributed ε_{it} error terms, that is, if we can write $E[u_t|\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}, \varepsilon_{4t}]=\sum_i r_i\varepsilon_{it}$ with $\sum_i r_i=0$, then

$$E[u_t|d_j(t)=1, I_t]=\sum_{i\in I_t, i\neq j} r_i\left[\frac{P_{it}\ln P_{it}}{1-P_{it}}+\ln P_{jt}\right]$$

where each P_{it} represents the choice probability $\Pr(d_i(t)=1|I_t)$ and I_t is the choice set in period t.

Given that

$$E[u_t|d_3(t)=1]=\Upsilon E[u_t|d_3(t)=1, J_0]+(1-\Upsilon)E[u_t|d_3(t)=1, J_1]$$

$$E[u_t|d_4(t)=1]=\Upsilon E[u_t|d_4(t)=1, J_0]$$

where Υ is the marriage offer probability, it can then be shown that

$$E[w_t|d_3(t)=1 \text{ or } d_4(t)=1]=X'_{2t}\gamma+r_2R_{2t}+r_3R_{3t}+r_4R_{4t}$$

where

$$R_{2t}=\left[\Upsilon\left(\frac{P_{2t}\ln P_{2t}}{1-P_{2t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)-(1-\Upsilon)\left(\frac{P^*_{1t}\ln P^*_{1t}}{1-P^*_{1t}}\right)\right]\cdot I[d_3(t)=1]$$
$$+\Upsilon\left(\frac{P_{2t}\ln P_{2t}}{1-P_{2t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]$$

$$R_{3t}=\left[\Upsilon\left(-\ln P_{3t}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)-(1-\Upsilon)\left(\frac{P^*_{1t}\ln P^*_{1t}}{1-P^*_{1t}}+\ln P^*_{3t}\right)\right]\cdot I[d_3(t)=1]$$
$$+\Upsilon\left(\frac{P_{3t}\ln P_{3t}}{1-P_{3t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]$$

$$R_{4t}=\left[\Upsilon\left(\frac{P_{4t}\ln P_{4t}}{1-P_{4t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)-(1-\Upsilon)\left(\frac{P^*_{1t}\ln P^*_{1t}}{1-P^*_{1t}}\right)\right]\cdot I[d_3(t)=1]$$
$$+\Upsilon\left(-\ln P_{4t}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]$$

where $I[\cdot]$ is the indicator function, $P_{it}=\Pr(d_i(t)=1|J_0)$ for all $i=1, 2, 3, 4$ and $P^*_{it}=\Pr(d_i(t)=1|J_1)$ for all $i=1, 3$.

Given the first stage maximum likelihood estimates of λ_i, $i=i=1,\ldots,4$ and the parameters ω of the marriage opportunity arrival function Υ, we can obtain estimates $\hat{R}_{it}$, $i=2, 3, 4$ of the R_{it} terms, by replacing the probabilities P_{jt} and P^*_{jt} in these expressions by their predicted values. Note that these estimated probabilities have in fact already been calculated in the last iteration of the maximization of L_1 as these probabilities enter directly into the likelihood function.

The final earnings equation estimated is then

$$w_t=X'_{2t}\gamma+r_2\hat{R}_{2t}+r_3\hat{R}_{3t}+r_4\hat{R}_{4t}+\xi_{1t}$$

where ξ_1 is an error term with zero mean. Note that it is possible to obtain unbiased estimates of the standard errors of the coefficients of this equation, which are corrected for the fact that some of the regressor variables have been estimated, by deriving the corresponding submatrix of $(H'V^{-1}H)^{-1}$ in (17).

TABLE A1

Conditional probability of a first birth

	Variable	Estimate	SDE
l_1	constant	-1.439	0.870
l_2	EDUC	-0.098*	0.016
l_3	AGE	0.091	0.076
l_4	$\text{AGE}^2/100$	-0.223	0.154
l_5	RACE	0.258*	0.085
l_6	SOUTH	0.013	0.069
l_7	m_{t-1}	1.175*	0.069
Log likelihood		-1062.36	

Notes: * = significant at the 5% level.
The sample consists of 4083 person-year observations, including 377 first births.

I.2. *Estimation of the husband's earnings equation*

To obtain estimates of the husband's earnings equation parameters π, equation (5) was estimated by OLS using the non-missing earnings data of husbands. To account for the fact that the husbands in our sample form a non-random subset of the total population of potential husbands, a selection bias correction term was included in the earnings equation to adjust for the fact that $E[u_t|d_2(t)=1 \text{ or } d_4(t)=1]$ may not equal zero.

If the conditional expectation of v_t is linear in the ε_{it} error terms, that is, if we can write $E[v_t|\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}, \varepsilon_{4t}]=\sum_i s_i \varepsilon_{it}$ with $\sum_i s_i=0$, then

$$E[v_t|d_j(t)=1, I_t]=\textstyle\sum_{i\in I_t, i\neq j} s_i\left[\dfrac{P_{it}\ln P_{it}}{1-P_{it}}+\ln P_{jt}\right].$$

Given that

$E[v_t|d_2(t)=1]=\Upsilon E[v_t|d_2(t)=1, J_0]$ and $E[v_t|d_4(t)=1]=\Upsilon E[v_t|d_4(t)=1, J_0]$ it can be shown that

$$E[w_t^h|d_2(t)=1 \text{ or } d_4(t)=1]=X'_{4t}\pi+s_2S_{2t}+s_3S_{3t}+s_4S_{4t}$$

where

$$S_{2t}=\Upsilon\left[\left(-\ln P_{2t}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_2(t)=1]+\left(\frac{P_{2t}\ln P_{2t}}{1-P_{2t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]\right]$$

$$S_{3t}=\Upsilon\left[\left(\frac{P_{3t}\ln P_{3t}}{1-P_{3t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_2(t)=1]+\left(\frac{P_{3t}\ln P_{3t}}{1-P_{3t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]\right]$$

$$S_{4t}=\Upsilon\left[\left(\frac{P_{4t}\ln P_{4t}}{1-P_{4t}}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_2(t)=1]+\left(-\ln P_{4t}-\frac{P_{1t}\ln P_{1t}}{1-P_{1t}}\right)\cdot I[d_4(t)=1]\right].$$

Given the first stage maximum likelihood estimates of λ_i, $i=1,\ldots,4$ and the parameters ω of the marriage opportunity arrival function Υ, we can again obtain estimates $\hat{S}_{it}$, $i=2, 3, 4$ of the S_{it} terms, by replacing the probabilities P_{jt} and P^*_{jt} in these expressions by their predicted values.

The husband's earnings equation estimated is then

$$w_t^h=X'_{4t}\pi+s_2\hat{S}_{2t}+s_3\hat{S}_{3t}+s_4\hat{S}_{4t}+\xi_{2t}$$

where ξ_2 is an error term with mean zero.

II. *The estimation of the covariance matrix V (the MDE weighting matrix)*

Consider three estimators ψ_1, ψ_2 and ψ_3 that each solve a set of first-order conditions:

$$1/N\textstyle\sum f_1(\psi_1)=0$$

$$1/N\textstyle\sum f_2(\psi_1, \psi_2)=0$$

$$1/N\textstyle\sum f_3(\psi_1, \psi_3)=0$$

TABLE A2

Maximum likelihood estimates reduced form model

	Variable	Estimate	SDE	Estimate	SDE
Utility function parameters					
λ_{21}	constant	-6.623^*	0.903	-5.686^*	0.444
λ_{22}	EDUC	0.035	0.086	0.007	0.041
λ_{23}	AGE	0.242^*	0.080	0.124^*	0.039
λ_{24}	RACE	-1.243^*	0.170	-0.688^*	0.066
λ_{25}	SOUTH	0.460^*	0.189	0.128	0.084
λ_{26}	n_t	1.347^*	0.162	0.833^*	0.160
λ_{27}	m_{t-1}	3.499^*	0.339	3.655^*	0.337
λ_{28}	$mdur_{t-1}$	0.045	0.026	-0.006	0.008
λ_{29}	exp_{t-1}	0.116^*	0.027	0.087^*	0.014
λ_{210}	MANUFWG	0.025	0.015	0.002	0.007
λ_{211}	$hexp^2_{t-1}$	-0.013^*	0.003	-0.006^*	0.001
λ_{31}	constant	-1.570^*	0.577	-2.663^*	0.323
λ_{32}	EDUC	0.288^*	0.026	0.151^*	0.014
λ_{33}	AGE	-0.085^*	0.019	-0.031^*	0.009
λ_{34}	RACE	-0.504^*	0.114	-0.301^*	0.060
λ_{35}	SOUTH	-0.036	0.156	-0.042	0.087
λ_{36}	n_t	-0.439^*	0.141	-0.173^*	0.086
λ_{37}	p_{t-1}	1.692^*	0.108	1.793^*	0.104
λ_{38}	exp_{t-1}	0.337^*	0.049	0.148^*	0.034
λ_{39}	$exp^2_{t-1}/100$	-0.690^*	0.330	-0.035	0.156
λ_{310}	MANUFWG	-0.017	0.012	-0.013^*	0.007
λ_{41}	constant	-6.379^*	0.964	-7.626^*	0.437
λ_{42}	EDUC	0.288^*	0.084	0.146^*	0.035
λ_{43}	AGE	0.026	0.080	0.003	0.033
λ_{44}	RACE	-0.688^*	0.194	-0.370^*	0.059
λ_{45}	SOUTH	0.472^*	0.203	0.102	0.083
λ_{46}	n_t	0.600^*	0.172	0.290	0.159
λ_{47}	p_{t-1}	2.541^*	0.083	3.580^*	0.331
λ_{48}	m_{t-1}	3.425^*	0.339	2.569^*	0.082
λ_{49}	$mdur_{t-1}$	0.097^*	0.026	0.021^*	0.006
λ_{410}	exp_{t-1}	0.246^*	0.046	0.109^*	0.028
λ_{411}	$exp^2_{t-1}/100$	-0.119	0.293	0.146	0.132
λ_{412}	MANUFWG	0.005	0.016	-0.007	0.006
λ_{413}	$hexp^2_{t-1}$	-0.006^*	0.003	-0.001	0.001
Arrival rate marriage opportunities					
ω_1	constant	4.847^*	1.900	4.880^*	2.592
ω_2	EDUC	-0.237^*	0.093	-0.272^*	0.135
ω_3	AGE	-0.043	0.031	-0.022	0.042
ω_4	RACE	-0.567	0.310	-0.295	0.373
ω_5	SOUTH	-0.062	0.233	-0.071	0.299
δ	discount factor	0.000		0.850	
Log likelihood L_1		$-5256.2.$		-5360.0	

Notes: * = significant at 5% level.
The decision horizon, T, at the time of leaving school was fixed at 45 years minus the age at leaving school. In the estimation MANUFWG was divided by 100.

where N is the number of observations. In terms of $\psi = [\psi_1\ \psi_2\ \psi_3]'$ we can also write this as

$$1/N \sum f(\psi) = 0.$$

In our case, ψ_1 represents the vector of estimators of the reduced form utility parameters, ψ_2 represents the estimators of the female's earnings equation parameters and ψ_3 the estimators of the husband's earnings equation parameters. The dependence of f_2 and f_3 on ψ_1 is due to the inclusion of the sample-selection bias-correction terms, which are functions of the parameter vector ψ_1. Following Hansen (1982), ψ has asymptotic distribution

$$\sqrt{N}(\psi - \psi^0) \xrightarrow{D} n[0, (J'D^{-1}J)^{-1}]$$

where $n(\cdot, \cdot)$ represents the normal distribution, ψ^0 is the "true" value of ψ, $J = E[\partial f(\psi^0)/\partial\psi]$ and $D = E[ff']$.

TABLE A3

Wage equation estimates (OLS)

	Variable	$\delta=0\cdot0$ Estimate	SDE	$\delta=0\cdot85$ Estimate	SDE
Female earnings equation					
γ_{11}	constant	$-10\cdot966^*$	$2\cdot789$	$-10\cdot910^*$	$2\cdot789$
γ_{12}	EDUC	$1\cdot327^*$	$0\cdot101$	$1\cdot325^*$	$0\cdot101$
γ_{13}	AGE	$-0\cdot127^*$	$0\cdot059$	$-0\cdot126^*$	$0\cdot059$
γ_{14}	RACE	$-0\cdot037$	$0\cdot502$	$-0\cdot046$	$0\cdot501$
γ_{15}	SOUTH	$0\cdot379$	$0\cdot649$	$0\cdot373$	$0\cdot649$
γ_2	p_{t-1}	$2\cdot274^*$	$0\cdot272$	$2\cdot240^*$	$0\cdot272$
γ_3	exp_{t-1}	$0\cdot532^*$	$0\cdot132$	$0\cdot528^*$	$0\cdot131$
γ_4	$exp^2_{t-1}/100$	$0\cdot868$	$0\cdot784$	$0\cdot888$	$0\cdot784$
γ_5	MANUFWG	$0\cdot144^*$	$0\cdot069$	$0\cdot145^*$	$0\cdot069$
r_2	$\hat{R}_{2t}$	$-0\cdot607$	$0\cdot324$	$-0\cdot602$	$0\cdot323$
r_3	$\hat{R}_{3t}$	$0\cdot174$	$0\cdot189$	$0\cdot152$	$0\cdot186$
r_4	$\hat{R}_{4t}$	$0\cdot334$	$0\cdot255$	$0\cdot303$	$0\cdot235$
	Adj. R^2	$0\cdot318$		$0\cdot318$	
Husband earnings equation					
π_{11}	constant	$-14\cdot723^*$	$4\cdot994$	$-14\cdot712^*$	$4\cdot994$
π_{12}	EDUC	$1\cdot265^*$	$0\cdot227$	$1\cdot263^*$	$0\cdot227$
π_{13}	RACE	$-3\cdot380^*$	$1\cdot027$	$-3\cdot392^*$	$1\cdot027$
π_{14}	SOUTH	$0\cdot091$	$1\cdot112$	$0\cdot096$	$1\cdot111$
π_2	exp_{t-1}	$0\cdot208$	$0\cdot132$	$0\cdot216$	$0\cdot132$
π_3	$hexp_{t-1}$	$1\cdot499^*$	$0\cdot313$	$1\cdot511^*$	$0\cdot313$
π_4	$hexp^2_{t-1}$	$-0\cdot037^*$	$0\cdot012$	$-0\cdot037^*$	$0\cdot012$
π_5	MANUFWG	$0\cdot152$	$0\cdot100$	$0\cdot150$	$0\cdot100$
s_2	$\hat{S}_{2t}$	$0\cdot910^*$	$0\cdot251$	$0\cdot931^*$	$0\cdot243$
s_3	S_{3t}	$2\cdot128$	$1\cdot284$	$2\cdot323$	$1\cdot221$
s_4	S_{4t}	$-0\cdot528^*$	$0\cdot260$	$-0\cdot473$	$0\cdot248$
	Adj. R^2	$0\cdot150$		$0\cdot150$	

Notes: * = significant at 5% level.
The terms, $\hat{R}_{2t}$, $\hat{R}_{3t}$, $\hat{R}_{4t}$ and $\hat{S}_{2t}$, $\hat{S}_{3t}$, $\hat{S}_{4t}$, were calculated using the reduced form maximum likelihood estimates reported in Table A2, and are defined in the Appendix. The standard errors were corrected for the fact that these selection-bias correction terms were estimated. In the estimation MANUFWG was divided by 100.

TABLE A4

Estimates of combined structural parameters

Parameters	$\delta=0$ Estimate	SDE	$\delta=0\cdot85$ Estimate	SDE
$\alpha_{212}+\alpha_{312}$	$-0\cdot133$	$0\cdot077$	$-0\cdot050$	$0\cdot062$
$\alpha_{213}+\alpha_{313}$	$0\cdot101^*$	$0\cdot044$	$0\cdot102^*$	$0\cdot042$
$\alpha_{214}+\alpha_{314}$	$-0\cdot155$	$0\cdot356$	$-0\cdot371$	$0\cdot307$
$\alpha_{22}+\alpha_{32}$	$-0\cdot769^*$	$0\cdot109$	$-0\cdot553^*$	$0\cdot071$
$\alpha_{23}+\alpha_{33}$	$2\cdot037^*$	$0\cdot150$	$2\cdot221^*$	$0\cdot116$
$(\beta_1+\beta_2+\beta_3)$	$0\cdot265^*$	$0\cdot045$	$0\cdot162^*$	$0\cdot030$
$(\beta_1+\beta_2+\beta_3)\phi(1)$	$0\cdot167$	$0\cdot156$	$0\cdot056$	$0\cdot085$

Note: * = significant at 5% level.

In our case ψ_2 and ψ_3 do not enter f_1 but ψ_1 does enter f_2 and f_3. Therefore, J and D can be estimated by

$$\hat{J}=1/N\begin{pmatrix} \sum \partial f_1(\hat{\psi}_1)/\partial\psi_1 & 0 & 0 \\ \sum \partial f_2(\hat{\psi}_1,\hat{\psi}_2)/\partial\psi_1 & \sum \partial f_2(\hat{\psi}_1,\hat{\psi}_2)/\partial\psi_2 & 0 \\ \sum \partial f_3(\hat{\psi}_1,\hat{\psi}_3)/\partial\psi_1 & 0 & \sum \partial f_3(\hat{\psi}_1,\hat{\psi}_3)/\partial\psi_3 \end{pmatrix}$$

and

$$\hat{D}=1/N\begin{pmatrix}\sum f_1f_1' & \sum f_1f_2' & \sum f_1f_3'\\ \sum f_2f_1' & \sum f_2f_2' & \sum f_2f_3'\\ \sum f_3f_1' & \sum f_3f_2' & \sum f_3f_3'\end{pmatrix}.$$

As the estimator $\hat{\psi}_1$ defined by the first set of first-order conditions above is a maximum likelihood estimator, the information matrix equality property implies that we can replace $1/N\sum \partial f_1(\hat{\psi}_1)/\partial\psi_1$ by $-1/N\sum f_1f_1'$ so that there is no need to calculate the second derivatives of the log-likelihood function. The estimators of the earnings equation parameters however, are not maximum likelihood estimators, so that we do need to calculate the derivatives of the second and third sets of first-order conditions.

III. *Decompositions of the wage elasticities*

In Section 5 the following formula was applied to decompose the total change in the probability of working for each female who was part of the 1984 wave, resulting from a one dollar increase in her wage rate (a \$2000 increase in earnings):

$$\begin{aligned}\Delta \operatorname{Prob}(p_t=1) = {} & \Delta \operatorname{Prob}(p_t=1\mid m_t=0)\\ & +\operatorname{Prob}(m_t=1)[\Delta \operatorname{Prob}(p_t=1\mid m_t=1)-\Delta \operatorname{Prob}(p_t=1\mid m_t=0)]\\ & +\Delta \operatorname{Prob}(m_t=1)[\Delta \operatorname{Prob}(p_t=1\mid m_t=1)-\Delta \operatorname{Prob}(p_t=1\mid m_t=0)\\ & +\operatorname{Prob}(p_t=1\mid m_t=1)-\operatorname{Prob}(p_t=1\mid m_t=0)]\end{aligned}$$

where the difference operator Δ refers to the change resulting from a one dollar increase in the wage rate. The sum of the first two terms on the right-hand side gives the change in the participation probability when keeping the probability of choosing the married state constant. The third term represents the indirect effect caused by a change in the marital status probability.

The total, direct and indirect effects thus obtained were subsequently converted into elasticities to obtain the estimates in Section 5.

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