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Abstract

In this paper the labour supply for Danish married men and women are estimated, using the piecewise linear Hausman model approach to account for non-linearities in taxes. The model takes the joint decision of participation and hours into account as well as measurement errors and unobserved heterogeneity of preferences. A linear and a non-linear labour supply function are estimated. Since the present paper is the first Danish contribution using the piecewise linear estimation technique, the results are compared with and found very similar to earlier Swedish results. We find no evidence of a backward bending labour supply curve. The inclusion of nonparticipants in the estimations increases the labour supply elasticities considerably. Finally, we simulate the labour supply responses of a few recently proposed tax reforms, among these an earned-income-tax-credit (EITC).

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1. Introduction.

Since the seminal paper by Burtless & Hausman[1] (1978) the piecewise linear approach has been widely used to estimate labour supply functions and measure work incentives. The appealing step from linearized to piecewise linear budget constraints has created a method to deal with the endogeneity from taxes and has improved the economic model's ability to fit reality. Taxes and transfers such as the progressive income tax, the deduction for certain work related expenses, welfare programs, and fixed costs of work all create non-linearities in most budget constraints. However, the existence of piecewise linear constraints raises several estimation problems, as surveyed in Moffitt (1986), Hausman (1985), Blomquist (1996), Megdal (1987) or McCurdy (1992). Although MaCurdy, Green & Paarsch (1990) and Flood & MaCurdy (1992) criticise the piecewise linear method, it is still used and defended by for instance Blomquist (1995)[2]. Several foreign studies have used the "Hausman" approach, but this paper is the first Danish study which uses this approach on Danish empirical data.

In the paper several complications are taken into account. Like in Arrufat & Zabalza (1986) we account for the joint participation and hours decision. It is especially important when we look at female labour supply where some individuals are nonparticipants. For comparability reasons, we also estimate the model on the subsample of working individuals. We take measurement errors in the labour supply into account as well as unobserved heterogeneity in preferences. The measurement error tends to spread observations out evenly over the budget constraint, while heterogeneity of preferences tends to generate clusters of observations around the kink points of a convex constraint[3]. Hence, we get a model which may be able to explain the pattern of observed hours. We estimate the model using two different empirical specifications. Firstly, we estimate a widely used linear specification which is linear in both the wage rates and non-labour income. Secondly, we estimate a non-linear specification suggested by Duncan (1990). It is based on a

[1] At the same time similar methods which dealt with the endogeneity bias were developed by Wales & Woodland (1979) and by Ashworth & Ulph (1981).

[2] For the Scandinavian countries recent studies based on the Hausman approach are Blomquist (1983), Blomquist and Hansson-Brusewitz (1990), Aronsson (1991), Flood & MaCurdy (1992), Aronsson & Karlsson (1993) and Sacklén (1996).

[3] Heterogeneity tends to disperse observations away from kink points of a non-convex constraint, cf. Moffitt (1986). We convexify the budget constraint for all individuals in the present paper.

variant of the Stone-Geary utility function and it is non-linear in wage rates but linear in non-labour income. Hence, it allows some of the individuals to be on the backward bending part of their labour supply curve or to have a non-linear forward bending labour supply curve.

In Section 2 the theoretical labour supply model is set up in the case of piecewise linear convex budget constraints following mainly Flood & MaCurdy (1992). Section 3 deals with the empirical specification and the likelihood function to maximize. Section 4 describes the data set while Section 5 refers the estimation results for married men and women, separately. In Section 5 we compare these results with the results from the model estimated on participants only. We also compare the results with earlier Swedish results where the same econometric method is used. In Section 6 an experiment which uses the estimated model is performed. We calculate the labour supply response from three non-financed and two budget neutral tax reforms. Section 7 concludes the paper.

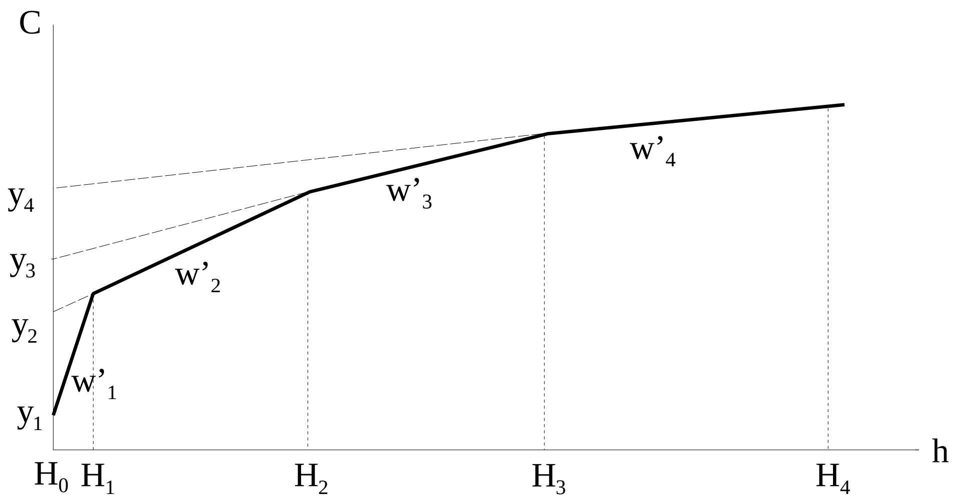
2. The piecewise linear model approach.

The statistical use of discrete-continuous variable techniques offers a natural frame work for labour supply investigations when we have to deal with piecewise linear budget constraints caused by linear progressive income taxes. In this Section, we specify the economic model following Flood & MaCurdy (1992). In Section 3, we present the empirical specification resulting from this model following Moffitt (1986) and Arrufat & Zabalza (1986).

In the piecewise linear approach it is assumed that individuals know their entire budget constraint. It is determined as C=wh+Y+V-t(I), where C is annual consumption, w is the hourly gross wage rate, h is annual labour supply, Y is annual taxable non-labour income, V is the annual non-taxable non-labour income, inclusive the spouse's after tax income, and t is the tax amount determined by the tax function, t(.), I is annual assessed income, I=wh+Y-D, where D is annual deduction in income. In a static model the individuals are assumed to choose pairs of (C,h), which maximize their utility function, U(C,h), given the piecewise linear budget constraint. The first order conditions to the maximization problem determine the labour supply function, f(w(h),Y(h)). Hence the labour supply depends on the after tax wage rate and income which again depend on the labour supply function via the tax function t(.).

In the piecewise linear case all the kinks and the after tax wage rates and virtual incomes on each segment can be found using a simple iterative procedure, as long as the non-labour income, the gross wage rate, the labour supply and the tax system are known factors. Figure 1 illustrates this for the Danish tax system which had four segments and five kinks[4] in 1990. The number of annual hours at the j'th kink point is denoted H_j. The after tax wage rate on each segment is given as $w'_j = w(1-t'_j)$ where t'_j is the marginal tax rate on segment j. The non-labour income at zero hours is given as $y_1 = V+Y-t(Y-D)$. Given after tax non-labour income, y_1, the virtual income corresponding to segment j can be found iteratively as $y_j = y_{j-1}+(w'_{j-1}-w'_j)H_{j-1}, \forall\, j \geq 2$.

Figure 1. *The piecewise linear budget constraint with four linear segments and three internal kinks. H_4 is the upper time limit for labour supply.*



Given the definition of y_j, w'_j and H_j above, the individual's optimization problem consists of three parts. The zero hours labour supply, an internal solution and the upper limit labour supply. Hence, it becomes the following

$$\begin{aligned} &\text{Max } U(C,h) \\ &\quad \text{s.t.} \\ &C = \begin{cases} y_1 & \text{if } h = H_0 \\ w'_j h + y_j & \text{if } H_{j-1} < h \leq H_j \qquad j=1,\ldots,4 \end{cases} \end{aligned} \qquad \textbf{(1)}$$

[4] Naturally, there always exists a lower bound (zero) and an upper bound (maximum time allocation). Hence, we have three internal kinks and two external or limit kinks.

The solution decomposes into two parts. First, we have to calculate the hours of labour supply, conditional on which linear segment or kink point we use to evaluate the function, $f(w'_j,y_j)$. This step yields the solutions

$$h = \begin{cases} H_j & \text{if } h = H_j & \text{Kink } j,\ j=0,\dots,4 \\ f(w'_j,y_j) & \text{if } H_{j-1} < h < H_j & \text{Segment } j,\ j=1,\dots,4 \end{cases} \quad \textbf{(2)}$$

Secondly, we have to determine the specific segment or kink on which an individual locates. Hence, the segment or kink with the maximum utility, given the solution is feasible, gives us the maximum maximorum of utility for the individual.

$$\begin{array}{llll} \text{Choose} & H_0 & \text{if } f(w'_1,y_1) \le H_0 & \\ & \text{Segment } j & \text{if } H_{j-1} < f(w'_j,y_j) < H_j & j=1,\dots,4 \\ & \text{Kink } j & \text{if } f(w'_{j+1},y_{j+1}) \le H_j < f(w'_j,y_j) & j=1,2,3 \\ & \text{Upper limit} & \text{if } f(w'_4,y_4) \ge H_4 & \end{array} \quad \textbf{(3)}$$

The combination of Equation 2 and Equation 3 gives the utility maximizing solutions for labour supply and consumption in Equation 1, cf. Blomquist (1983). In the special case where the budget constraint is convex in all parts, a simple algorithm over the linear budget segments can be used to find the optimal solution. The algorithm evaluates Equation 3 for j=0,1,... and it stops when a criterion holds. The algorithm defines uniquely the maximum solution to Equation 1.

3. The empirical specification.

Before we can specify the empirical model which we want to estimate, we have to introduce an empirical functional form for the labour supply function and a stochastic structure for the error term. We choose two functional forms in order to see whether our results are sensitive to the specification of the labour supply function. Recent discussion reveals a large variation in results from the choice of specification[5]. We choose the popular linear specification in Blomquist (1983) for comparability reasons and the non-linear specification in Duncan (1990) which allows for a backward bending or a non-linear forward bending labour supply function.

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[5] See Sacklén (1996) for an excellent overview of the dispute about the original results in Hausman (1981) and the sensitivity of the estimation results to data definitions in this study.

Consider the specification

$$h = f(w'_j, y_j) = x_j\theta + \nu \equiv \hat{h}_j + \nu, \qquad j = 1,...,4 \tag{4}$$

The unobserved error component, ν, represents heterogeneity in preferences with $\nu \sim N(\mu_\nu, \sigma^2_\nu)$. x_j is a matrix of explanatory variables, representing a constant, background characteristics, and the after tax wage rate and virtual income corresponding to segment j. In the **linear** specification, the after tax wage rate w'_j and the virtual income y_j are added linearly by the term $(\beta w'_j + \gamma y_j)$. In the **non-linear** specification they are added as $(\beta \ln(w'_j) + \gamma(y_j/w'_j))$. The latter specification allows for backward bending labour supply curves for some or all individuals if $\beta<0$ and $\gamma<0$.

The solution to the maximization problem described in Section 2 will cause a bunching of individuals at kink points on their budget constraints. However, the empirical data normally shows no bunching of individuals at the kink points and often even not in an interval around the kink points. We introduce a random error in the measured hours to explain this fact. We assume that there is an additive measurement error which can be interpreted as reporting errors. Hence, we have the double-error specification surveyed in Moffitt (1986). The larger the degree of clustering in the data, the larger the estimated variance of the heterogeneity error will become compared to the estimated variance of the measurement error. Let the measured labour supply, h^*, be a function of actual hours, h, and an error component, ϵ, so $h^* = h + \epsilon$, where $\epsilon \sim N(0,\sigma^2_\epsilon)$ and $E(\nu,\epsilon) = 0$.

Knowledge of h^* is neither sufficient to allocate individuals to their correct budget segment nor sufficient to identify their marginal tax rate, except at zero hours of work. Only information on the actual hours, h, reveals this. Since the individuals' choice of a segment is not directly observable, one has a discrete data version of an errors-in-variables problem. The resulting stochastic model specification then becomes the following: the measured labour supply equals $f(w_j,y_j)$ if a certain segment criterion holds, i.e.

$$h^* = \begin{cases} H_0 + \epsilon & \text{if } \hat{h}_1 + \nu \le H_0 & \text{Lower limit} \\ \hat{h}_j + \nu + \epsilon & \text{if } H_{j-1} < \hat{h}_j + \nu \le H_j & \text{Segment j, j=1,...,4} \\ H_j + \epsilon & \text{if } \hat{h}_{j+1} + \nu < H_j < \hat{h}_j + \nu & \text{Kink j, j=1,2,3} \\ H_4 + \epsilon & \text{if } \hat{h}_4 + \nu > H_4 & \text{Upper limit} \end{cases} \qquad \textbf{(5)}$$

This combines the discrete and continuous parts of the choice in an estimable econometric model. The likelihood function for the model is

$$\mathcal{L} = \prod_{i=I} G(h_i^* = 0) \prod_{i=J} g(h_i^*) \prod_{i=K} G(h_i^* = H_4) \qquad \textbf{(6)}$$

G(.) is the cumulative density function, g(.) is the derivative of G(.) with respect to x, $\delta G(.)/\delta x$. The subscript i measures individuals and $i \in N$, where N is the set of individuals. I is the index set for the nonparticipants ($h^*=0$), J is the index set for the individuals with a positive labour supply less than H_4 ($0<h^*<H_4$), and K measures the individuals who work more than H_4 ($h^* \ge H_4$). Let $\underline{U}_{ji} = H_{(j-1)i} - \hat{h}_{ji}$ and $\bar{U}_{ji} = H_{ji} - \hat{h}_{ji}$. Then the density $g(h_i^*)$ can be written as

$$\begin{aligned} g(h_i^*) = & \int_{-\infty}^{\underline{U}_{1i}} \phi_1[h_i^* - H_0, \nu_i]\, d\nu_i & \text{Lower limit} \\ & + \sum_{j=1}^{4} \int_{\underline{U}_{ji}}^{\bar{U}_{ji}} \phi_2[h_i^* - \hat{h}_{ji}, \nu_i]\, d\nu_i & \text{Segment j, j=1,...,4} \\ & + \sum_{j=1}^{3} \int_{\bar{U}_{ji}}^{\underline{U}_{(j+1)i}} \phi_1[h_i^* - H_{ji}, \nu_i]\, d\nu_i & \text{Kink j, j=1,2,3} \\ & + \int_{\bar{U}_{4i}}^{\infty} \phi_1[h_i^* - H_4, \nu_i]\, d\nu_i & \text{Upper limit} \end{aligned} \qquad \textbf{(7)}$$

Arrufat & Zabalza (1986) give the expression for both G(.) and g(.), and Moffitt (1986) and Flood & MaCurdy (1992) give the expression for g(.) in a specification for non-limit workers. ϕ_1(.,.) and ϕ_2 (.,.) are bivariate normal density functions of (ϵ,ν) and $(\epsilon+\nu,\nu)$ with means, variances, and covariance $(0,0,\sigma^2_\epsilon,\sigma^2_\nu,0)$ and $(0,0,\sigma^2_\epsilon+\sigma^2_\nu,\sigma^2_\nu,\sigma^2_\nu)$, respectively. A priori, there is only little reason to expect the heterogeneity and measurement errors to be correlated. Hence, we assume no correlation as is the case in all other studies with both heterogeneity and measurement errors, cf. Moffitt (1986).

Maximization of the likelihood function, $\mathfrak{L}$, provides us with the coefficients of the labour supply function f(.,.). We have both the substitution and income response so we can calculate the work disincentive effect of income taxes or labour taxes, among others. However, the calculated elasticities are only valid for small changes and only for individuals away from kink points on their budget constraints. When the tax rates or allowances are changed an individual can end up on another budget segment or get stuck at a kink or even be totally unaffected if the individual is situated on an unaffected part of the budget constraint, cf. Hausman (1985). Hence, simulations of the supply effect from tax and transfer changes have to take both participation change, hours change, kink points and shift of budget segments into account. A simple algorithm over the linear budget segments can be used to evaluate desired hours of work, cf Blomquist (1983,1988).

4. Data description.

We use data from the register data in the CLS database which covers 5% of the Danish population[6]. A representative subsample of married couples is extracted for the estimations. Self-employed, assisting spouses, individuals in education and on pensions, as well as individuals with a censored income[7] are excluded from the subsample. We end up with 1,584 married men and 1,893 married women. The data includes information on labour supply, labour and non-labour income, and background characteristics for the year 1990. Some descriptive statistics are referred in Table 1.

[6] A more recent 0.5% panel sample is documented online at CLS on the World Wide Web address www.cls.dk (1997). It contains the same variables and covers the period 1980-91, but it includes fewer individuals per year than the sample used in this study. Hence, we use register data from 1990 since we do not have access to more recent information of the same quality.

[7] The labour income information in the register data is upward censored at 1 M. DKK in 1990. The taxable income is downward censored at 0 DKK and upward censored at 1 M. DKK while the capital income is downward censored at -220,000 DKK and upward censored at 1 M. DKK.

The nonparticipants have no observed gross wage rates. Hence, we estimate a wage equation using Heckmans' two-step estimator and predict a wage rate for these individuals. The predicted wage rates substitute the missing gross wage rates in the labour supply model[8]. The wage rate estimation results are given in Appendix 1. The after tax wage rates are calculated as the gross wage rates net of the marginal tax rate as described in Section 2.

Table 1. *Descriptive statistics for the married men and women in 1990.*

Variable	Men		Women	
	Mean	Std. deviation	Mean	Std. deviation
Annual labour supply	1569.03	363.33	1237.44	593.76
Hourly gross wage rates	150.00	55.51	112.41	35.89
Annual non-labour income if zero work hours.	56629	49571	100671	52999
Age	43.41	9.18	42.58	9.67
House ownership	0.7626		0.2911	
Province	0.6824		0.6994	
Youngest child 0-2 years	0.1629		0.1389	
Youngest child 3-6 years	0.1130		0.1062	
# of children	1.0631	1.0190	0.9614	1.0016
Nonparticipant	0.0600		0.1638	
No. of observations	1584		1893	

Note: No standard deviation is given for the dummy variables. The large difference in house ownership proportion between men and women is due to a male chauvinistic tradition where the male normally is registered as the house owner even though the ownership in practice is common.

The non-labour income is calculated as the spouse's after tax income plus the individual's capital income, housing and child benefits evaluated and taxed at zero working hours, i.e. no labour income. The labour supply is the desired number of working hours, i.e. actual annual working hours plus actual annual unemployment hours. Implicitly this way of treating unemployment implies that unemployment is assumed to be involuntary, see Smith (1995). An individual is categorized as unemployed if he or she is not working and, at the same time, is a member of the unemployment insurance system[9]. The background characteristics included in the model are the age of the individuals, whether they are house owners or not, whether they live outside the Greater Copenhagen Area or not, a dummy for the presence of children aged below three years,

[8] Alternatively the unobserved wage rates may be integrated out, see MaCurdy et al. (1990).

[9] See Einerhand, Erikson & Hansen (1993) for a comprehensive description of the unemployment insurance system in Denmark

a dummy for the presence of having the youngest child aged between three and six years and finally the total number of children aged below 17.

5. Empirical results.

The linear as well as the non-linear specification from Section 3 are estimated for married men and married women. The results are presented in Table 2 and Table 3. In the estimations we have substituted all missing gross wage rates (for nonparticipants) by their predicted wage rates from a self-selectivity corrected wage estimation. The results are shown in Table A1 in Appendix 1. Although an errors-in-variable inconsistency will arise because the kink points of the constraint might be misspecified, as Moffitt (1986) points out, we maintain this way of modelling[10].

Several earlier studies, which use the Hausman method, estimate only the model on working individuals (men), see Blomquist (1983), Flood & MaCurdy (1992), Sacklén (1996) among others. The participation incentives may however be larger than the hours incentives given positive participation. We could either estimate the participation decision and the number of working hours separately, see for instance Graversen (1996b), or estimate both in the same equation. We do the latter and estimate a model where both nonparticipants and the working hours for the participants are included in the estimations. The results from these estimations are presented in table 2. The results from a model where the nonparticipants are excluded in the estimation are presented in Table 3.

The results in Table 2 vary between the linear and the non-linear specification. However, none of the specifications dominate the other. It does not seem to be an important improvement of the model to allow for backward bending labour supply curves compared with the usual linear specification. The estimates from the linear as well as the non-linear specification imply a positive sloped labour supply curve for all individuals in the sample. The compensated wage elasticity is calculated for each individual for both specifications. Since none of these compensated wage elasticities are negative, the results are consistent with neo-classical economic

[10] Blomquist and Hansson-Brusewitz (1990) handles the unobserved wage rates for nonparticipants by a joint modelling of hours and wage rates in some of their estimations, but not in all of them. Blomquist (1996) shows in a Monte Carlo simulation that the bias from misspecified wage rates can be considerable. We use a large number of explanatory variables in the wage rate equation in order to avoid misspecified predicted wage rates.

theory, i.e. we have a coherent model in both the linear and non-linear specification.

In general we find the expected nonlinear effect from age. Both specifications give very similar coefficients. As expected we also find that house ownership significantly increases the labour supply. However, as with the age parameters, it is difficult to compare the size of the effect between men and women since they have different participation probabilities. Only in the non-linear specification for men, we observe a significant influence from the Greater Copenhagen Area dummy. In general the coefficient to the province dummy variable is positive for men, while it changes sign between the two specifications for women. Neither the presence of children aged 0-6 years nor the total number of children in the household have a significant impact on the male labour supply. For women, the presence of young children has not by itself any significant impact on labour supply. The total number of children has however a significant negative impact. The fact that the presence of young children does not affect the labour supply is found in earlier Danish labour supply studies, cf. Smith (1995), Pedersen & Smith (1995), Graversen (1996a, 1996b). It is probably explained by high participation rates and relatively easy and cheap access to the public child care system in Denmark, see Dex & Smith (1990).

Both variance coefficients are highly significant in all specifications. For men, the variance of the measurement error and of the heterogeneity in preference error are of almost equal size. Hence, the variation in the distribution of hours caused by the measurement error is as important as the clustering around kink points from the heterogeneity error. For women, both variance coefficients are larger than the corresponding coefficients for men. The variance in the heterogeneity error is around one-third larger in size than the variance in the measurement error.

Table 2. *Annual labour supply for married men and women in 1990. Linear and non-linear specification*[11]*.*

Parameter	Men				Women			
	Linear		Non-linear		Linear		Non-linear	
	Estim.	S.dev	Estim.	S.dev	Estim.	S.dev	Estim.	S.dev
β								
$\ln(w_{net})/10$	-	-	2.3527	0.4260	-	-	11.0523	0.8216
$w_{net}/100$	0.3618	0.0486	-	-	1.8423	0.1290	-	-
γ								
$(y/w_{net})/10{,}000$	-	-	-0.6542	0.1338	-	-	-0.2951	0.1430
$y/100{,}000$	-0.0845	0.0240	-	-	-0.0771	0.0265	-	-
Constant	0.9003	0.2214	0.1713	0.2745	0.4395	0.3437	-2.8567	0.4408
Age/100	2.8052	1.0522	3.1620	1.0723	2.5631	1.5357	2.1965	1.5959
$Age^2/1{,}000$	-0.3950	0.1203	-0.4438	0.1220	-0.5367	0.1662	-0.5131	0.1711
House owners	0.1246	0.0234	0.0800	0.0182	0.1780	0.0392	0.1900	0.0382
Province	0.0240	0.0219	0.0457	0.0218	-0.0174	0.0360	0.0055	0.0362
Child 0-2 years	-0.0141	0.0361	-0.0273	0.0378	-0.0810	0.0661	-0.0869	0.0662
Child 3-6 years	0.0315	0.0345	0.0192	0.0360	-0.0332	0.0655	-0.0926	0.0662
# of children	0.0060	0.0127	0.0078	0.0134	-0.0737	0.0208	-0.0515	0.0192
σ_ϵ(measurement)	0.2708	0.0226	0.2417	0.0126	0.4376	0.0181	0.4162	0.0177
σ_υ(heterogeneity)	0.2643	0.0262	0.3097	0.0131	0.5862	0.0204	0.6364	0.0212
Mean $\log(\mathcal{L})$	-0.5068		-0.4807		-1.0799		-1.1091	
Av. elasticities[*]								
ϵ_{ucw_net}	0.1300	0.0282	0.2294	0.0431	0.6853	0.1066	0.9075	0.2571
ϵ_{cw_net}	0.1778	0.0397	0.2948	0.0431	0.7227	0.1110	0.9361	0.2557
ϵ_y	-0.0570	0.0254	-0.0799	0.0358	-0.0718	0.0297	-0.2295	0.1091

Note: Predicted wage rates are used when wage rates are missing. The reference person is a house renter, who lives in the Capital area and has no children. [*] Average of calculated elasticities. The standard deviations of the elasticities are the standard deviations on the empirical mean and are not corrected for the fact that the elasticities are calculated from estimated parameters.

The empirical labour supply elasticities with respect to wage rates and income[12] are calculated for each individual in the sample using the observed explanatory variables and the estimated parameters presented in Table 2. The empirical average and the standard deviation on these numbers are given in Table 2 while the distribution of the elasticities for the non-linear specification is shown in Figures 2-4. The empirical distribution of the (un)compensated wage elasticity and the income elasticity are non-symmetric which means that the presented calculated average values in Table 2 will differ from the corresponding elasticities evaluated at the median

[11] In the **linear** specification, the after tax wage rate, w, and the virtual income, y, are added linearly by the term $\beta w + \gamma y$. In the **non-linear** specification they are added as $\beta \ln(w) + \gamma(y/w)$.

[12] They are called uncompensated and compensated wage elasticity and income elasticity, respectively, in the rest of the paper.

values of the explanatory variables.

Figure 2. *The smoothened distribution of the uncompensated and compensated wage elasticity for married men. Results from both linear and non-linear specifications. (Smoothened by a moving average).*

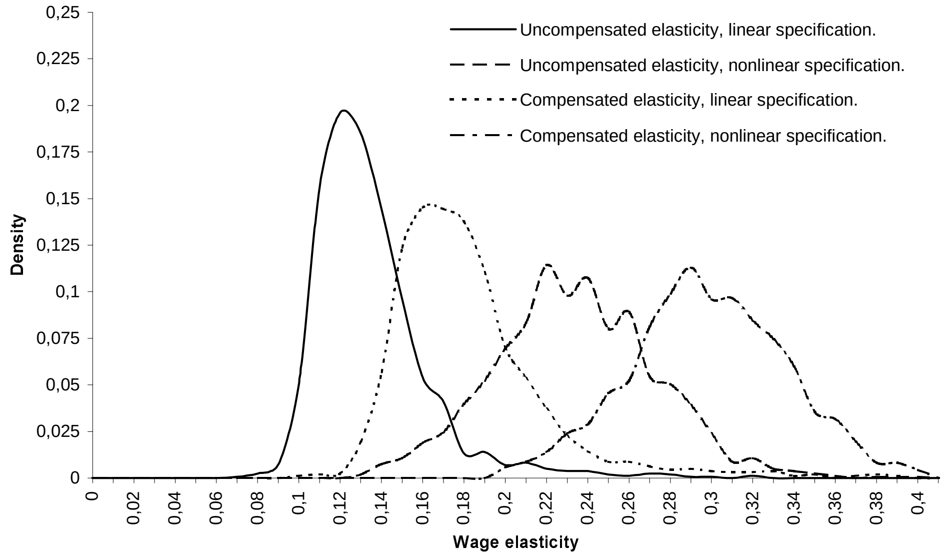


Figure 3. *The smoothened distribution of the uncompensated and compensated wage elasticity for married women. Results from both linear and non-linear specifications. (Smoothened by a moving average).*

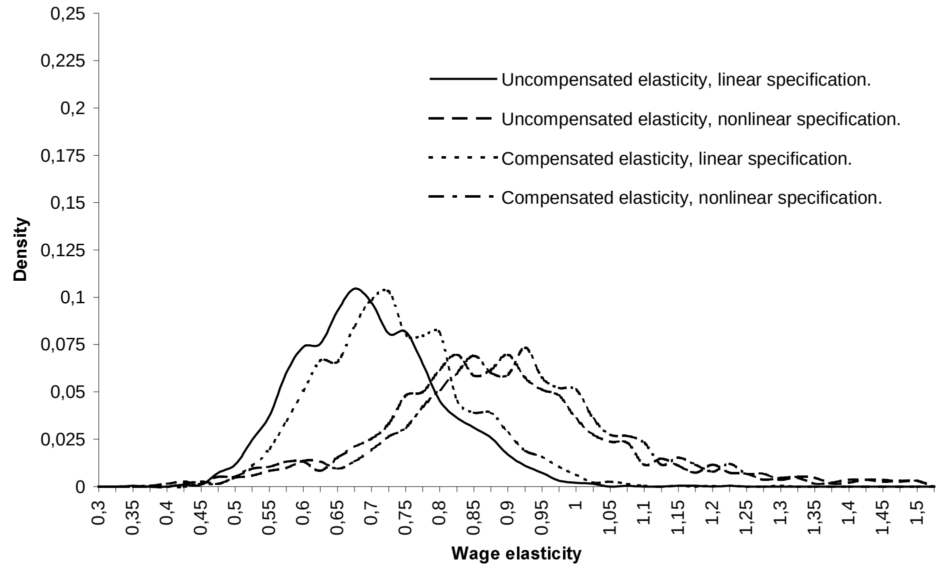
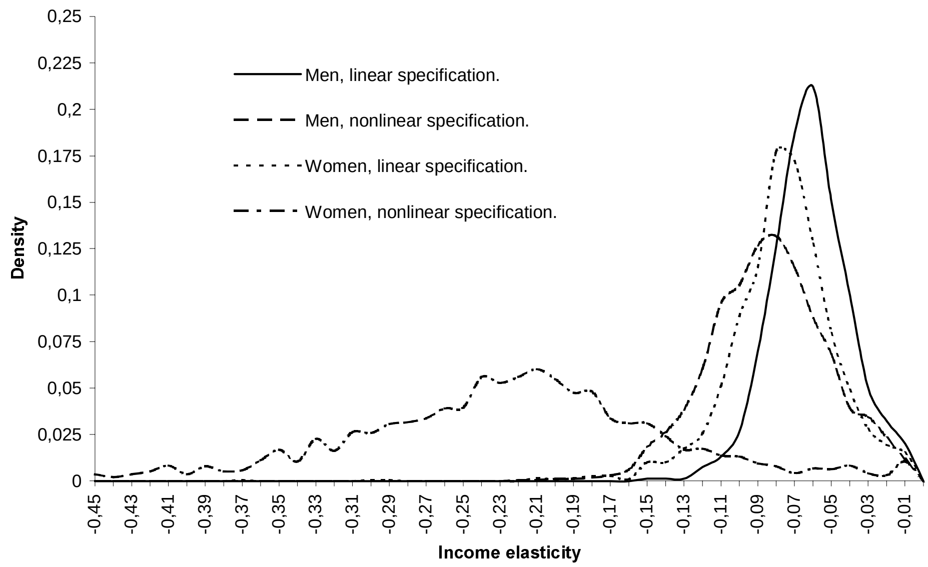


Figure 4. *The smoothened distribution of the income elasticity. Results from both linear and non-linear specifications. (Smoothened by a moving average).*



The non-linear specification shows higher wage elasticities compared with the linear specification for both men and women. The same is the case for the income elasticity. In all the specifications we find a significantly negative income effect giving an average income elasticity of approximately -0.07 for men and -0.15 for women.

For men we find an average compensated wage elasticity of 0.13 in the linear specification and of 0.23 in the nonlinear specification. Thus, the non-linear specification increases the average elasticity by approximately 0.1. On the other hand, the uncompensated wage elasticity is also increased from 0.18 in the linear specification to 0.29 in the non-linear specification. For women we observe a considerably higher wage coefficient than for men. We find an average compensated wage elasticity of 0.68 in the linear specification and of 0.91 in the non-linear specification. Hence, like for men, the non-linear specification seems to increase the wage elasticity. The compensated wage elasticity is found to be 0.72 and 0.94 on average.

Other results.

The present study is the first Danish study to use the Hausman estimation approach. Other Danish labour supply studies use other empirical estimation methods. However, a number of Swedish studies have applied the Hausman approach and we will compare our estimation results with these as well as earlier Danish studies. Some of these studies are estimated using data on working men and women only, and in order to facilitate the comparison, we have re-estimated the model on working individuals only.

Earlier studies by Graversen (1996a, 1996b) give average wage elasticities of 0.17 and 0.35 for married women and of 0.17 for married men. In these studies the average income elasticity is estimated to be -0.03 for married women and -0.39 for married men. However, the definition of virtual income differs in the case of married men compared to the present study. Hence, these results are not directly comparable except for the married women[13]. In a panel study on married households in 1980-86, Smith (1995) uses an iterative fixed effect procedure and finds female wage elasticities of 0.06-0.09, male wage elasticities of 0.09, and income elasticities of 0.01 and -0.02, respectively. Using an iterative least squares procedure, Dex & Smith (1990) find wage elasticities of 0.45 and income elasticities of -0.07 for married women in a cross section data set from 1980 while Pedersen & Smith (1995) find wage elasticities of 0.08 for married men and of 0.04 for married women and income elasticities close to zero for both in a cross section data set from 1994. Thus, the present paper presents elasticities either close to or numerically higher than earlier Danish results using other estimation techniques.

When we exclude nonparticipants from the empirical sample, a few common changes seem to happen concerning the estimation results. As can be seen in Table 3, the average wage elasticities are reduced by approximately 50% compared to the results in Table 2. The absolute value of the income elasticity is reduced for men but increased for women. These changes indicate that we

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[13] Graversen (1996a) estimates separate labour supply function for men and women on a cross section sample from 1990. He uses a double hurdle model and distinguish between voluntary and involuntary unemployment. The spouse's disposable income is included in the nonlabour income for the women but not for the men. However, Graversen uses a linearized budget constraint and corrects for the endogeneity of taxes by a method developed by Smith & Blundell (1986). Graversen (1996b) estimates the labour supply response to tax changes for women using a panel data set from 1986-1990. He uses a difference-in-difference approach, where the average difference in response for groups exposed by a tax reform is related to a similar group which is not exposed by the reform.

have to be careful when we interpret and use the results from these estimations. Hence, it will be wrong to estimate a model on participants only and interpret the results as being representative for the entire labour force and vice versa. The variance of the measurement error as well as the heterogeneity error is also reduced in all cases by approximately 50%. It also seems to be a fact that house ownership and the province dummy affect the supply decision less, that the number of children still matters for the women but still not for the men. The age profile is still non-linear but with smaller coefficients than is the case when nonparticipants are excluded.

Table 3. *Annual labour supply (in thousands) for married men and women in 1990. Only working individuals (h|h>0), i.e. all wage rates are positive and observed.*

Parameter	Men				Women			
	Linear		Non-linear		Linear		Non-linear	
	Estim.	S.dev	Estim.	S.dev	Estim.	S.dev	Estim.	S.dev
β								
$\ln(w_{net})/10$	-	-	1.4367	0.2410	-	-	4.7278	0.4275
$w_{net}/100$	0.2108	0.0273	-	-	0.5718	0.0732	-	-
γ								
$(y/w_{net})/10{,}000$	-	-	-0.1744	0.0763	-	-	-0.3810	0.0621
y/100,000	-0.0445	0.0129	-	-	-0.1315	0.0193	-	-
Constant	1.3100	0.1312	0.8773	0.1575	0.9561	0.1942	-0.7212	0.2365
Age/100	1.1604	0.6128	0.9828	0.6262	2.5379	0.9622	3.0933	0.9215
$Age^2/1{,}000$	-0.1485	0.0702	-0.1284	0.0171	-0.3613	0.1115	-0.4560	0.0996
House owner	0.0276	0.0097	0.0252	0.0097	0.1248	0.0219	0.1374	0.0212
Province	0.0322	0.0126	0.0381	0.0126	-0.0287	0.0222	0.0108	0.0195
Child 0-2 years	-0.0413	0.0199	-0.0445	0.0203	-0.0440	0.0325	0.0219	0.0404
Child 3-6 years	0.0028	0.0178	0.0043	0.0179	0.0474	0.0378	-0.0182	0.0418
# of children	0.0099	0.0072	0.0112	0.0073	-0.0376	0.0139	-0.0331	0.0119
σ_ϵ(measurement)	0.1772	0.0126	0.1681	0.0137	0.3445	0.0292	0.2908	0.0419
σ_υ(heterogeneity)	0.1449	0.0163	0.1588	0.0160	0.2346	0.0443	0.3432	0.0444
Mean log($\mathcal{L}$)	0.0487		0.0456		-0.6999		-0.6016	
Av. elasticities *								
ϵ_{ucw_net}	0.0710	0.0169	0.1091	0.0105	0.1956	0.0375	0.6594	0.1748
ϵ_{cw_net}	0.0956	0.0234	0.1265	0.0105	0.2606	0.0488	0.6943	0.1688
ϵ_y	-0.0292	0.0119	-0.0213	0.0081	-0.1193	0.0503	-0.3463	0.1633

Note: Predicted wage rates are used when wage rates are missing. The reference person is a house renter, who lives outside the Capital area and has no children. * Average of calculated elasticities. The standard deviations of the elasticities are the standard deviations on the empirical mean and are not corrected for the fact that the elasticities are calculated from estimated parameters.

Starting with Blomquist (1983), several Swedish studies have used the Hausman approach on Swedish data. The institutional set up in Sweden is in many ways like the Danish so it is natural to compare results for Sweden with the present results for Denmark. Table 4 summarizes some of the main Swedish results from the 1980s and the 1990s. The elasticities in Table 4 are typically calculated for an individual with average or median value of the explanatory variables. Hence, a comparison of variance and skewness in the distributions of the elasticities can not be made. A comparison of these statistics could very well be more informative than our simple comparison of means. However, with the information available we can not pursue this potential difference further.

Table 4. *Swedish labour supply elasticities using the piecewise linear Hausman model and the present elasticities form Table 2 and Table 3.*

Sample population and author.	Specification and subsample	Wage elasticity Uncompensated	Wage elasticity Compensated	Income elasticity
Men				
Blomquist (1983)	linear; h|h>0	0.08	0.11	-0.04
Blomquist & Hansson-Brusewitz (1990)	linear & quadratic; h|h>0	0.08-0.13	0.08-0.13	-0.013- 0.002
Aronsson & Karlsson (1993)	linear; h|h>0	0.09-0.11	0.11-0.12	-0.021- -0.009
Flood & MaCurdy (1992)	linear; h|h>0	0.16	0.24	-0.10
Sacklén (1996)	linear & non-linear; h|h>0	0.08-0.16	0.09-0.17	-0.005- -0.025
The present study	linear; h|h≥0	0.13	0.18	-0.06
	non-linear; h|h≥0	0.23	0.29	-0.08
	linear; h|h>0	0.07	0.10	-0.03
	non-linear; h|h>0	0.11	0.13	-0.02
Women				
Ackum Agell & Apel (1991)	linear; h|h>0	0.11	-	-0.17
Blomquist & Hansson-Brusewitz (1990)	linear & quadratic; h|h≥0	0.77-0.79	0.79-0.86	-0.24- -0.06
Aronsson (1991)	linear; h|h≥0	0.93	1.07	-0.04
The present study	linear; h|h≥0	0.69	0.72	-0.07
	non-linear; h|h≥0	0.91	0.94	-0.23
	linear; h|h>0	0.20	0.26	-0.12
	non-linear; h|h>0	0.66	0.69	-0.35

Note: The **linear** specification means: $h=\beta w+\gamma y$. The **quadratic** specification means: $h=\beta w+\gamma y+\delta w^2$. The **non-linear** specification means: $h=\beta \ln(w)+\gamma y/w$.

Compared to the results in Table 2, we find that the wage elasticities for men in the Swedish studies are all lower than or very close to the elasticities we find in the linear specification. However, they are very similar to the results for working men in Table 3. If we include nonparticipants in the non-linear specification, we find an uncompensated wage elasticity which is higher than that of the Swedish studies. If we exclude nonparticipants, our results are very similar to the Swedish results for men. We find the compensated wage elasticities to be larger than found in Sweden when we include nonparticipants, except when we compare with the study by Flood & MaCurdy (1992). With respect to the income elasticity our findings are numerically a little higher than (including nonparticipants) or equal to (excluding nonparticipants) the Swedish results. Hence, we conclude that the main difference between our results and the Swedish results stems from the inclusion of nonparticipants in the Danish study.

There are only a few Swedish studies on female labour supply which uses the Hausman approach. Two Swedish studies give uncompensated wage elasticities below but close to 1 in a setup where nonparticipants are included and accounted for in the empirical sample. We find an average uncompensated wage elasticity of 0.68 in the linear specification and a larger of 0.91 in the non-linear specification. Hence, our results indicate a Danish wage elasticity which is very close to those found in Sweden. This is also the case with the compensated wage elasticities. We also find Danish income elasticities which are similar to the Swedish results. If we estimate the model for working women only, our elasticities drop by approximately 50%. Hence, as expected the inclusion of nonparticipants seems to be of great importance for the results, especially for women.

6. The labour supply response to an increase in the zero tax allowance on labour income.

The elasticities found in Section 5 illustrate the marginal responsiveness. Due to kink points on the individuals' budget constraints some individuals may get stuck at a kink point meaning no change in labour supply even though they experience a large change in their marginal tax rate or in non-labour income. Hence, it is necessary to calculate the actual labour supply response using the algorithm described in Section 3[14]. Since the empirical sample used in the present paper is not representative for the entire population or the entire labour force, we have to interpret the simulation results as partial responses only. Hence, the policy implications have to be done taking into account the nonrepresentative empirical sample. Therefore, in the following we simulate the

[14] The usual disclaimer when we use the Tobit specification to model labour supply has to be included here. Since the same coefficients determine both the participation decision and the number of work hours given participation, we may have a case where the number of hours dominate over participation. Thus, a model where the participation decision and the number of work hours are estimated separately may show larger participation effects (and a smaller work hours effect), see Table 2 and Table 3.

responses for men and women separately. We will look at three different changes of the tax system. The third reform is simulated under three different assumptions on how the reform will be financed. First, as a non-financed reform, secondly as a lump sum tax financed reform and lastly, as a reform financed by an increased progressivity in the three highest income tax rates. Table 5 shows the kink points and tax rates on each segment in the reforms. The 1990 tax system is the sampling year for the empirical data.

Table 5. *The marginal tax rates on labour income on each segment and the kink points in the 1990 tax system and the three reforms.*

Tax rate (%)	1. segment	2. segment	3. segment	4. segment	5. segment
1990 tax system	0	50.8	56.8	68	-
+50% in zero tax allowance	0	50.8	56.8	68	-
1998 reform	8	43.3	48.8	63.4	-
New proposed reform	8	39.8	43.3	48.8	63.4
Change in tax rate at (1990 prices)		1. kink	2. kink	3. kink	4. kink
1990 tax system	0	26950	144900	222800	-
+50% in zero tax allowance	0	40425	144900	222800	-
1998 reform	0	26850	118647	214541	-
New proposed reform	0	29833	113329	118647	214541

Note: For comparable reasons all figures are in 1990 prices. The actual kink values deviate from individual to individual since capital income also influence the position of some of the kink points. Thus, the figures assume zero capital income and zero deductions. In the 1998 reform, the average county and municipal tax rates are assumed to be 30.4% in total (1996 percentages).

The first and second "reform" both use the 1990 tax system[15] as the reference case. In the first reform we simulate the labour supply response from a 50% increase of the zero tax allowance on labour supply. Thus, we only change the marginal tax rate indirectly through an upward shift in the budget constraint. In the second reform, we simulate the labour supply response from the 1998 tax reform[16]. In both of these two reforms, we assume that the cost in form of lost tax revenue is captured fully by the government, i.e. the reforms are not budget neutral.

[15] See Graversen (1995) and Pedersen (1993) for a description of the tax system in 1990.

[16] See Ministry of Finance (1995) for a description of the 1998 reform of the Danish tax system. However, we assume that the total upper tax limit is 59% and not 58% as proposed in the reform. The reform was put into force in 1994 and is supposed to be fully implemented in 1998. The main difference to the 1990 tax system is a lower marginal tax rate on labour income, especially in the upper end of the tax scale.

The third reform has recently been proposed by the Ministry of Finance et al (1996), OECD (1996) among others. The reform is basically an earned-income-tax-credit (EITC) on labour income and its main purpose is to increase the incentives in the participation decision so the difference in disposable income of employees with low salaries and of unemployed becomes significantly positive. However, it is unclear how the reform will be financed. We simulate the labour supply response from this reform[17] under three different assumptions regarding the financing of the reform. Instead of using the 1990 tax system, we use the 1998 tax system as the reference case. In the first simulation, the third reform is non-financed (Reform 3^{I}). In the second simulation, the reform is made budget neutral by a lumpsum tax (Reform 3^{II}). Finally, the reform is made budget neutral by an increased progressivity on high incomes (Reform 3^{III}), i.e. the marginal tax rates on segments three to five are increased equally, see Table 5.

The labour supply responses from the simulations are presented in Table 6 where we give the participation response and the response in working hours conditional on a positive participation. In the simulations of the reforms we use parameter estimates from both the linear and the non-linear specifications presented in Table 2. The large standard deviations on the average response in annual hours of labour supply in Table 6 indicate that variation in the individual response is large although the average response may be small. The first reform and reform 3^{I} and 3^{II} can be considered to be reforms where the purpose is to increase the participation incentives for individuals with low wage rates, while the second reform tends to reduce the marginal disincentives, i.e. increase the work hours. Reform 3^{III} is a mix of increased participation and work hours incentives for low wage rate individuals and decreased marginal work hours incentives for high wage rate individuals[18].

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[17] The reform starts with the fully implemented 1998 reform and then the proposal is an employment allowance of 10% on labour income up to a level (130,000 DKK in 1998) which is a little less than the level of unemployment insurance. In total, the reform decreases the marginal tax rate on labour income by approximately 3.8 %-points in the interval up to 130,000 DKK (in 1998). The tax reduction can be non-financed (reform 3^{I}), financed by a lump sum tax (reform $^{3II)}$ or it can be financed by an increased progressivity in the following tax rates (reform 3^{II}). We simulate all three cases. The average labour income is in 1990 235,354 DKK for married men and 139,100 DKK for married women, see Table 1.

[18] Another potential effect of this more progressive tax scheme is the potential effect on the wage formation. If the labour market is dominated by unions a more progressive tax scheme may influence the wage setting and reduce wage increases and thereby increase employment, see Hansen et al (1995). However, the focus in the present analysis is restricted to the supply effects.

The 50% increase in the zero tax allowance gives a small negative response in labour supply. The response in working hours is approximately -0.45% and zero % for men and women respectively. The participation response is negligible and smaller than -0.01%. The response in labour supply from the 1998 reform compared to the 1990 tax system is considerable. The response in working hours given participation is approximately 3.2% for men and 9.3% for women. The participation response is close to 0 for men and approximately 14.2% for women. The positive change in working hours was to be expected since the marginal tax rate is decreased from 1990 to 1998 by 4 to 7 %-points, and the biggest change have been for the low incomes, see Table 5.

Table 6. *The average annual changes in labour supply from a change in taxes.*

Empirical specification and reform type	Men		Women	
	Participation rate	Conditional hours*)	Participation rate	Conditional hours*)
	---%-point---	----annual hours----	---%-point---	----annual hours----
Linear specification				
+50% in zero tax allowance	-0.00	-6.6 (34.9)	0.01	1.3 (95.0)
1990 tax system to 1998 reform	-0.03	40.1 (55.8)	1.19	111.0 (115.9)
1998 reform to reform 3^{I}	-0.03	-2.2 (52.8)	0.17	16.1 (103.9)
1998 reform to reform 3^{II}	-0.09	-9.1 (107.8)	0.21	17.4 (100.8)
1998 reform to reform 3^{III}	-0.05	-17.7 (84.6)	-	-
Non-linear specification				
+50% in zero tax allowance	-0.03	-7.2 (3.1)	-0.08	-1.4 (16.0)
1990 tax system to 1998 reform	0.00	61.0 (26.8)	1.49	120.7 (52.9)
1998 reform to reform 3^{I}	-0.00	-2.1 (6.4)	0.22	12.5 (24.0)
1998 reform to reform 3^{II}	0.00	0.9 (6.4)	0.22	13.0 (24.1)
1998 reform to reform 3^{III}	-0.00	-9.1 (9.3)	-	-

Note: Empirical standard deviation in (.). *)Conditional hours are working hours conditional on positive participation. The simulations are performed for men and women separately. Hence, a balanced reform for the men is only financed by the men and vice versa with a balanced reform for the women. Reform 3^{I} is a non-financed employment allowance. In reform 3^{II} it is financed by a lump sum tax and in reform 3^{III} it is financed by an increased progressivity on the high tax rates, see Table 5 and footnote 17.

The third reform reduces the labour supply for men and increases the labour supply for women. Since it is a reform which decreases the marginal tax rates on low incomes, it does not change the marginal tax rate for most men but it does change the marginal tax rate for a considerable group of women. However, the lower tax rates on segment two increases the virtual income for the men. Thus, the negative response is mainly an income effect. For the women the effect from the lowered marginal tax rate dominates and gives a positive response. In the non-financed case, reform 3^{I}, the response in working hours is approximately -0.13% and 1.13% for men and women respectively. The corresponding participation response is -0.01% and 0.23%. A lump sum financing of the budget deficit from the reform, reform 3^{II}, does not change these figures much. If the reform is instead financed by higher marginal tax rates on segment three to five, reform 3^{III}, we find an eight-times larger negative response in working hours, i.e. responses of approximately -0.95% and of -0.035% in participation for the men. However, it was not possible to calculate the impact from reform 3^{III} for the married women. There is no stable solution for this reform. When the progressivity was increased in order to finance the reform, the labour supply response became so negative that the tax revenue loss increased instead of decreased. The initial tax revenue loss to be financed in the third reform was approximately 4,150 DKK and 3,600 DKK on average (in 1990 DKK) for the men and women respectively.

7. Conclusion.

In the paper we present the first Danish estimation results using the piecewise linear “Hausman” estimation approach. We estimate labour supply functions for married Danish men and women separately using cross section data from 1990. We model the joint decision of participation and hours. Furthermore, we control for measurement errors and unobserved heterogeneity of preferences. Thus, the model takes account of the significant share of nonparticipants among women as well as the known measurement error in the observed labour supply variable. Both a linear and a non-linear labour supply function are estimated. We do not find any evidence of a backward bending labour supply curve. However, we do find evidence of a non-linear labour supply curve.

We find average uncompensated labour supply elasticities of 0.13-0.23 and 0.69-0.91 for married men and women respectively. The compensated elasticity is approximately 0.05 higher. The income elasticity is found to be approximately -0.06- -0.08 and -0.08- -0.23 for men and women respectively. These results are very similar to earlier Swedish results which use the same estimation methods. The inclusion of nonparticipants in the estimations almost doubles the labour supply elasticities (except the income elasticities) when we compare with results from an estimation on participants only. Hence, it seems to be very important for the conclusions and policy implications whether nonparticipants are included in the estimations or not.

Finally, we use the estimation results in a simulation of the labour supply response on various tax reforms. However, the empirical data is representative neither for the entire population of married individuals nor for the remaining labour force since we have to exclude self-employed, individuals in education and pensioners among others. Hence, the interpretation of the policy implications have to be carefully done taking into account the nonrepresentative empirical sample. An increase in the zero tax allowance decreases the labour supply by 7 and 0 hours per year for men and women respectively. The same figures for the change from the 1990 (sample year) to the 1998 tax system are approximately 50 and 115 hours. A recently proposed reform which lowers the marginal tax rates for low income earners decreases the labour supply for men with 2 hours per year. Women increase their labour supply by approximately 15 hours per year. When we make the last reform revenue neutral by a lump sum tax, the figures are almost unchanged for men and they increase by approximately 1 hour per year for women. When we make the reform revenue neutral by increased marginal tax rates for high income earners, we find a decrease of 15 hours per year for the men. However, for the group of women there is no stable solution to this kind of refinancing of the reform. Their labour supply decreases faster than the revenue increases.

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Appendix 1.

Table A1. *Gross wage rate and full time participation estimates for married men and women in 1990. (Conditional OLS and probit regressions)*

Parameter	Men				Women			
	Gross wage rate		FT Participation		Gross wage rate		FT Participation	
	Estim.	Std.dev	Estim.	Std.dev	Estim.	Std.dev	Estim.	Std.dev
Constant	-10.044	33.657	-1.253	1.029	-28.869	20.517	-1.283	0.719
Age	4.970	1.440	0.133	0.044	4.256	0.884	0.107	0.030
Age^2	-0.056	0.016	-0.002	0.000	-0.054	0.011	-0.002	0.000
Experience	1.500	0.648			1.312	0.484		
$Experience^2$	-0.019	0.012			-0.009	0.014		
House ownership	17.701	2.920	0.398	0.116	4.583	1.651	0.465	0.073
Province	-19.053	2.537	-0.129	0.114	-8.210	1.679	-0.125	0.068
Education								
Low education	37.655	8.436	0.380	0.129	7.882	4.029	0.095	0.080
Mid education	70.558	15.911	0.250	0.301	-12.011	8.354	0.471	0.157
Long education	98.368	20.758	0.443	0.197	-36.605	12.043	0.439	0.130
Education	-14.203	3.504			-5.648	2.001		
$Education^2$	1.162	0.337			1.871	0.295		
Children								
Child 0-2 years	-0.788	4.388	-0.217	0.193	1.058	2.870	-0.129	0.125
Child 3-6 years	3.568	4.802	-0.143	0.206	4.192	2.563	0.093	0.122
# of children	2.351	1.544	0.043	0.073	-2.747	1.039	-0.164	0.044
Union								
Male	-12.466	3.165			-4.907	4.734		
Female					1.088	3.195		
Clerk	-5.957	5.811			-7.978	2.178		
Academic	11.129	5.343			8.946	6.406		
Noninsured	3.514	22.549						
Skill								
Manager	-21.826	16.012			25.385	6.368		
Office	-49.282	16.156			17.277	7.024		
Skilled	-44.813	16.116			22.506	9.875		
Unskilled	-42.340	16.113			14.862	8.111		
Sector								
Primary	26.039	11.016	-0.401	0.351	-38.374	23.097	-1.599	0.308
Manufacturing	28.303	3.840	0.273	0.162	13.102	2.457	0.247	0.104
Construction	27.323	5.125	-0.249	0.197	17.568	7.147	-0.261	0.260
Trade	26.422	4.538	0.523	0.227	-0.674	3.283	-0.176	0.116
Service	22.286	4.450	-0.144	0.144	12.682	2.097	0.031	0.088
No group	-54.823	86.080	-3.342	0.255	-32.588	13.989	-1.259	0.110
Unemployment								
Degree	0.032	0.009			0.023	0.004		
Age unempl.	-0.096	0.123	0.001	0.005	0.171	0.087	-0.000	0.004
Educ. unempl.	0.494	0.122	0.001	0.001	-0.032	0.060	-0.001	0.002
Occup. unempl.			-0.006	0.003			0.002	0.000
λ_p	40.062	62.093			38.299	18.087		
$R^2_{adj.}$ (Obs.)	0.373	(1,502)		(1,812)	0.399	(1,134)		(2,113)

Appendix 2.

For the model with censored hours at zero[19] the predicted labour supply is calculated as

$$E(h) = \Phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right)*x\theta + \frac{1}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}*\phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right) \tag{A.1}$$

Naturally, the wage rate and the virtual income used in the x vector is chosen according to the algorithm described in Section 2.

Hence, the elasticities in the linear (Blomquist 1983) specification becomes

$$\begin{aligned}
\epsilon_{ucw} &= \frac{\delta h}{\delta w}\frac{w}{h} = \Phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right)*\beta*\frac{w}{h} \\
\epsilon_y &= \frac{\delta h}{\delta y}\frac{y}{h} = \Phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right)*\gamma*\frac{y}{h} \\
\epsilon_{cw} &= \frac{\delta h}{\delta w}\frac{w}{h}\Big|_s = \epsilon_{ucw}-\frac{w*h}{y}*\epsilon_y
\end{aligned} \tag{A.3}$$

The elasticities in the non-linear (Duncan 1990) specification becomes

$$\begin{aligned}
\epsilon_{ucw} &= \frac{\delta h}{\delta w}\frac{w}{h} = \Phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right)*\left(\beta - \gamma*\frac{y}{w}\right)*\frac{1}{h} \\
\epsilon_y &= \frac{\delta h}{\delta y}\frac{y}{h} = \Phi\left(\frac{x\theta}{\sqrt{\sigma_\epsilon^2+\sigma_\nu^2}}\right)*\gamma*\frac{y}{w*h} \\
\epsilon_{cw} &= \frac{\delta h}{\delta w}\frac{w}{h}\Big|_s = \epsilon_{ucw} - \frac{w*h}{y}*\epsilon_y
\end{aligned} \tag{A.2}$$

[19] This corresponds to a one-limit Tobit specification, which is used in the present paper since the upper limit is not binding for anyone in the empirical sample.

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