Institute for Fiscal Studies

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IFS Working Paper W16/03

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April 2013, this draft February 2016

Abstract

We estimate a dynamic model of employment, human capital accumulation - including education, and savings for women in the UK, exploiting tax and benefit reforms, and use it to analyze the effects of welfare policy. We find substantial elasticities for labor supply and particularly for lone mothers. Returns to experience, which are important in determining the longer-term effects of policy, increase with education, but experience mainly accumulates when in full-time employment. Tax credits are welfare improving in the UK and increase lone-mother labor supply, but the employment effects do not extend beyond the period of eligibility. Marginal increases in tax credits improve welfare more than equally costly increases in income support or tax cuts.

Acknowledgements: We thank four anonymous referees and the editor for helpful comments. This research has greatly benefited from discussions with Joe Altonji, Mike Brewer, David Card, Jim Heckman, Enrico Moretti, Hamish Low and Corina Mommaerts. We are also grateful to participants at the EEA Summer Meetings, the IZA/SOLE transatlantic meeting, the NBER TAPES conference and seminars at Yale University, the University of Mannheim, IFS, the University of Copenhagen, U. C. Berkeley and the DIW for their comments. This research is funded by the ESRC Centre for the Microeconomic Analysis of Public Policy and the NCRM node Programme Evaluation for Policy Analysis, both at the IFS. Financial support from the ESRC, grant number RES-000-23-1524, is gratefully acknowledged. Costas Meghir thanks the Cowles foundation and he ISPS at Yale and the ESRC under the Professorial Fellowship RES-051-27-0204 for funding. The usual disclaimer applies.

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1 Introduction

The UK, the US and many other countries have put in place welfare programs subsidizing the wages of low-earning individuals and especially lone mothers, alongside other income support measures. Such programs can have multiple effects on careers and social welfare: on the one hand, they change the incentives to obtain education, to work and to accumulate human capital and savings; and on the other hand, they offer potentially valuable (partial) insurance against labor-market shocks. We develop an empirical framework for education, life-cycle labor supply and savings that allows us to study the longer-term behavioral and welfare effects of such programs.[1]

Our focus in this paper is on how such benefits affect the careers of women. As mothers they are the main target group of these welfare programs and are most responsive to incentives.[2] A sizable proportion of them become single mothers at some point in their lives, have low labor market attachment and are vulnerable to poverty (see Blundell and Hoynes, 2004, for example). Indeed, a motivation for in-work benefits is to preserve the labor-market attachment of lower-skill mothers and to prevent skill depreciation, which may underlie longer-term poverty.[3]

With the notable exception of Keane and Wolpin (2007, 2010) earlier work has focussed mostly on the short-term effects of in-work benefits on labor supply,[4] which are central to the optimal design of such benefits as shown by Saez (2002). However, this is not the whole story, because welfare benefits can affect the returns to education, the accumulation of human capital through experience as well as savings both because of their wealth effects and because they affect the extent to which people are insured against shocks; all these may change labour supply in the longer term. Thus we extend the literature and consider how welfare benefits and taxes affect careers of women through these various channels, beyond the period-by-period changes in employment.

[1]Throughout the paper we use interchangeably the terms "benefits", "subsidies", "transfers", "welfare" and "welfare programs" to denote government transfers to lower-income individuals.

[2]See Blundell and MaCurdy (1999) and Meghir and Phillips (2012) for surveys of the evidence.

[3]See Goldin (2006 and 2014), Shaw (1989), Imai and Keane (2004) and Heckman, Lochner and Cossa (2003).

[4]Eissa and Liebman (1996) estimate the impact of EITC on female labor supply; Hotz and Scholz (2003) review the literature on the effects of the US Earned Income Tax Credit; Card and Robins (2005) and Card and Hyslop (2005) assess the effects of the Canadian Self-Sufficiency Project on employment and wages; Blundell and Hoynes (2004), Brewer et al. (2006) and Francesconi and van der Klaauw (2007) assess the employment effects of the UK's Working Families' Tax Credit reform of 1999.

We study the UK tax and welfare system, which saw numerous reforms over the 1990s and 2000s, with major increases to in-work benefits, or tax credits, between 1999 and 2002. We thus start our analysis by examining how these reforms affected the short-run labor supply of lone mothers and the educational decisions of young women. Using a quasi-experimental framework, we verify that the reforms increased lone mother labor supply and reduced educational attainment, as expected.

Following this reduced form analysis, we estimate a dynamic life-cycle model of female education choice, labor supply, wages and consumption/savings over the life-cycle, which is capable of addressing the longer-term effects of policy. Our data is drawn from 18 annual waves of the British Household Panel Survey (BHPS) covering the years 1991 to 2008. We combine these data with a tax and benefit simulation model to construct the household budget constraint in all its detail, incorporating taxes and the welfare system and the way it has changed over time.

In the model, at the start of their life-cycle, women choose between three possible education levels (secondary, high school and university), taking into account the implied costs as well as the expected returns and volatility associated with each choice, both of which are affected by taxes and benefits. Once education is completed they make period-by-period employment and savings decisions depending on wages, preferences and family structure, which evolves over the life-cycle. Importantly, wages are determined by education and experience, which accumulates or depreciates depending on whether individuals work full-time, part-time or not at all. While male income, fertility and marriage are exogenous, they are driven by stochastic processes that depend on education and age. In this sense our results are conditional on the observed status quo process of family formation, which differs by education.

The policy reforms, are an important source of exogenous variation, which we use to estimate our dynamic model and to validate that it can replicate the effects we estimate quasi-experimentally. Over our 18-year observation period, new cohorts enter adulthood facing different tax and welfare systems, which changes the expected value of each education choice. Moreover reforms take place over their life-cycle at different ages, differentially affecting their returns to work. Individuals are *ex-ante* heterogeneous because of differing family background, which can affect their preferences, wages, costs of education and responses to tax and benefit changes. The interaction between the reforms and the observable individual type thus provides exogenous variation that we use in the estimation of the dynamic model. To help explain education choice we also use a parental liquidity shock when the woman was 16, net of the effects of any observable family background characteristics.

Our paper addresses a number of important research questions. First, we study the effects of incentives on the labor supply of women and produce Marshallian and Frisch elasticities for various demographic groups. Second, we look at how individuals make decisions on education and, more generally, at how human capital evolves over the lifecycle depending on the interaction between education, employment and working hours. Third, by developing a framework that can explain the labor supply and education responses to incentives and their long-term effects for earnings capacity and savings, we also contribute to the understanding of the broader impact of taxes and welfare benefits and their role in redistribution, insurance and incentives. Within this context, our model and empirical results are directly relevant for the design of optimal income tax and human capital policies that balance incentives and insurance, as developed by Stantcheva (2015).

We find moderate labor supply elasticities overall: the Frisch elasticity of labor supply is 0.63 on the extensive (participation) margin and 0.24 on the intensive one (part-time versus full-time). The elasticities are substantially higher for single mothers with secondary education only, who are the main target group of the tax credit program.[5] Relatively large estimated income effects lead to lower Marshallian elasticities.

Our results display large and significant returns to labor-market experience for full-time work, especially for women who completed a 3-year university degree or more. Part-time work does not contribute to human capital growth, but does attenuate the depreciation of skills relative to not working. Those with secondary education earn little or no returns to experience. The differences in the accumulation of experience between part-time and full time work and the complementarity with education are central to understanding the longer term effects of tax credits.

Using the model, we find that tax credits increase the labor supply of lone mothers, but decrease

[5] Our elasticities are somewhat lower than those estimated by Keane and Wolpin (2010) but exhibit similar variation with education and family demographics.

that of married mothers.[6] Most lone mothers are so for a limited period, being married at some other earlier stage of their child-rearing life. This, combined with the fact that the UK tax credit system encourages part-time work at the expense of full-time, leads to an average zero net effect on accumulated experience. The resulting employment rates among mothers of adult children are the same as they would have been in the absence of tax credits. However, tax credits are overall welfare improving. Finally, we consider the implications of assessing tax credits at the individual rather than at the family level, making it part of the single-filing tax system in the UK. The effect of this reform on the savings, experience accumulation and wages of mothers of young children is sufficiently strong to lead to a decline in employment (relative to the system of joint assessment) once eligibility ceases because children have grown. It is also an expensive reform that increases taxation substantially and is overall welfare reducing.

Our paper builds on a long history of dynamic life-cycle models.[7] However, the closest model to ours is that developed in Keane and Wolpin (2007, 2010 - KW). These papers use NLSY data to estimate a dynamic model of schooling and human capital accumulation (through work experience), labor supply, fertility, marriage and welfare participation and to analyze the effects of welfare on these outcomes in the US economy. Instead, we look at the UK case, where the welfare system is more generous and entitlement to benefits spreads higher in the income distribution than in the US. Moreover, we focus on a period of critical expansion of welfare for families that significantly changed the working incentives of mothers and, potentially, the value of education for women. This variation is used in estimating our model.

A key distinguishing feature of our model to those of KW is that we allow for savings, a central ingredient given the motivation of our paper. We focus on savings because assets are the main channel for (self) insurance in an economy with incomplete insurance and credit markets. They

[6]The data does not distinguish between married and cohabiting individuals and neither does the welfare system. We use "married" as a shorthand for someone living with a partner.

[7]Our model is related to Heckman and MaCurdy (1980) who developed the life-cycle model of female labor supply, to Eckstein and Wolpin (1989) who introduced a dynamic discrete choice model of labor supply, wages and fertility, to Keane and Wolpin (1997) who estimate a dynamic model of education, occupational choice and labor supply for men as well as to Lee (2005), Adda et al. (2013) again for men and to Shaw (1989), Heckman, Lochner and Taber (1998) and Imai and Keane (2004) who consider lifecycle models of labor supply and consumption with human capital accumulation. It also relates to the life-cycle consistent models of labor supply and consumption developed by MaCurdy (1983), Altonji (1986), Blundell and Walker (1986), Arellano and Meghir (1992), Blundell, Meghir and Neves (1993) and Blundell, Duncan and Meghir (1998).

will be sensitive to the risk profile associated to each level of education and will also be affected by the structure and generosity of the welfare programs. Our study relates to the *entire* population - not just a very low skill and poor subgroup - and hence asset accumulation is an important feature of the lifecycle. Indeed we document that holding assets is to varying degrees relevant for all education groups, particularly once we account for housing. Counterfactual simulations that change public insurance programs would give an incomplete picture of the welfare effects if they did not allow individuals to change their savings behavior because they would ignore the change in insurance value and give a distorted view of behavior. Moreover, the fit of many aspects of the model worsens substantially when we ignore assets.

A simplification with respect to KW is the way we treat fertility and marriage. While they allow these to be fully endogenous, we condition on the observed processes when carrying out counterfactual analysis.[8] A more complete treatment of this interesting issue is left for future research because of the formidable computational demands that it entails.

We begin with a description of the tax and welfare systems in section 2. Section 3 describes the data and the quasi-experimental results. Section 4 describes the model and section 5 estimation. Section 6 presents the estimated parameters. The model fit, and its implications are discussed in section 7 while section 8 discusses counterfactual analysis. Section 9 concludes.

2 Tax and Welfare Policy in the UK

The UK personal tax and transfer system comprises a small number of simple taxes (mostly levied at the individual level), and a set of welfare benefits and tax credits (usually means-tested at the family level). Over the period of our data, which extends from 1991 to 2008, there have been numerous reforms. Tables 1 and 2 summarize some of the key parameters of the system at four critical points in time. For computational economy, the model we estimate will assume

[8] Beyond the differences in savings and in the treatment of family formation, the studies have many other differences. For example, we use a detailed description of the personal taxes and benefits operating in our observation window to obtain a realistic representation of the work incentives faced by women and how they change over time. Our identification strategy also differs from that adopted in Keane and Wolpin (2010) because we use the policy variation induced by the reforms to estimate the model.

that individuals face these four systems, ignoring smaller reforms in periods in between. However, some reforms did take place at times in between, particularly over the 1999 to 2002 period. This is important for our reduced form analysis.[9] Appendix F provides more detail.[10]

Table 1: Working Tax Credit and Income Support under different tax and transfer systems - lone mothers and mothers with low-wage partners working full-time; 1 child families

		Lone mother				Mother in couple Partner working full-time			
		1995	1999	2002	2004	1995	1999	2002	2004
	Income Support								
(1)	Maximum award	109.7	108.6	122.0	62.9	0.0	0.0	0.0	0.0
(2)	Withdrawal rate	100%	100%	100%	100%	100%	100%	100%	100%
	Tax Credits								
	Maximum awards								
(3)	Work contingent component, no CC costs	93.6	96.5	117.1	115.7	43.9	43.2	74.9	47.0
(4)	Work contingent component with CC costs	93.6	96.5	186.3	184.9	83.3	96.5	147.7	119.8
(5)	Not work contingent component	0.0	0.0	0.0	47.2	0.0	0.0	0.0	47.2
(6)	Withdrawal rate	70%	70%	55%	37%	70%	70%	55%	37%
	Female earnings at which tax credit award is exhausted								
(7)	no childcare costs	298.2	294.2	402.0	1255.5	61.7	60.8	142.3	1052.1
(8)	with childcare cost	384.9	407.9	596.7	1255.5	131.9	148.6	335.6	1052.1

Notes: Tax and benefit systems as in April each year. CC: Child care. Figures for mothers in couples assume partner works full-time at the April 2004 minimum wage. Work requirement is 16 hours per week for 1 adult (rows 3 and 4) or all adults for CC component (difference between rows 4 and 3). Monetary amounts expressed in £ and in weekly terms, uprated to January 2008 prices using RPI. Detailed notes in Appendix F, Table 33.

Income Support (IS) and tax credits are the two key elements of the UK benefit system over this period. Table 1 shows changes in the the awards, taper rates[11] and eligibility faced by lone mothers and mothers in couples with a full-time working partner on the minimum wage.

IS is a benefit for families and acts as an income top up, causing an implicit marginal tax rate of 100%. It depends on family circumstances – number of children and adults and their ages. Between April 1999 and April 2002, there was a big increase in the generosity of the child additions for younger children, which were later removed and partly relabelled as the non-work contingent part of tax credits, called Child Tax Credits (rows 1 and 5 in Table 1). The increase in the IS award between 1999 to 2002 was gradually implemented annually (row 1).[12] Couples where at least one

[9]In estimation, the 1995 system covers the period up to 1996; the 1999 system covers 1997 to 1999; the 2002 system covers 2000 to 2002 and the 2004 system covers 2003 to 2008.

[10]For a comprehensive discussion of UK taxes and transfers, see Browne and Roantree (2012) and Browne and Hood (2012).

[11]These are the rates of benefit withdrawal as family earned income increases and lead to implicit tax rates on earnings.

[12]In real terms, the maximum subsidy increased from £108.58 in 1999 to £114.77, £119.99 and £122.04 in 2000, 2001 and 2002, respectively.

Table 2: Tax rates and thresholds under different tax and transfer systems

	1995	1999	2002	2004
Income Tax: thresholds				
Personal allowance	95.5	105.9	106.0	103.1
Starting rate upper limit	182.1	142.5	150.1	147.0
Basic rate upper limit	753.4	789.7	792.6	785.3
Income Tax: rates				
Starting rate	20%	10%	10%	10%
Basic rate	25%	23%	22%	22%
Higher rate	40%	40%	40%	40%
National Insurance: thresholds				
Lower earnings limit (LEL)	81.67	83.82	106.27	102.81
Upper earnings limit (UEL)	619.54	634.99	698.54	689.17
National Insurance: rates				
Entry fee (up to LEL)	2%	0%	0%	0%
Main rate (earnings in LEL-UEL region)	10%	10%	10%	11%
Rate above UEL	0%	0%	0%	1%

Notes: Amounts expressed in weekly terms and uprated to January 2008 prices using RPI. Allowance for couples is the married couple allowance and additional personal allowance. Tax and benefits systems as in April each year.

of the partners works full-time at the minimum wage are not entitled to IS as their income exceeds the upper limit for entitlement.

Tax credits are a means tested benefit for working families with children similar to the US Earned Income tax credit. Entitlement is conditional on working except for the Child Tax Credits component mentioned above. Eligibility to the work contingent component requires at least one adult working 16 or more hours a week and at least one dependent child. Furthermore, eligibility to childcare support (difference between rows 3 to 4 in Table 1) in couples requires both adults working at least 16 hours per week. Eligibility to an additional supplement occurs at 30 hours of work. In 2004, entitlement to tax credits was extended to working families without children but at much lower level of generosity.

Rows 3 and 4 in the Table 1 show the increase in work-contingent maximum awards over the period for families with a single dependent child and no or positive childcare expenses, respectively.[13] Over the 1999-2002 period, the maximum award increased continuously. For lone mothers with no childcare costs, it went from £96.52 in 1999 to £105.64, £110.84 and £117.14 in 2000, 2001 and 2002, respectively. At the same time, the rate at which the benefits are tapered away dropped

[13]Childcare expenses calculated for 40 hours per week at £2.60 per hour.

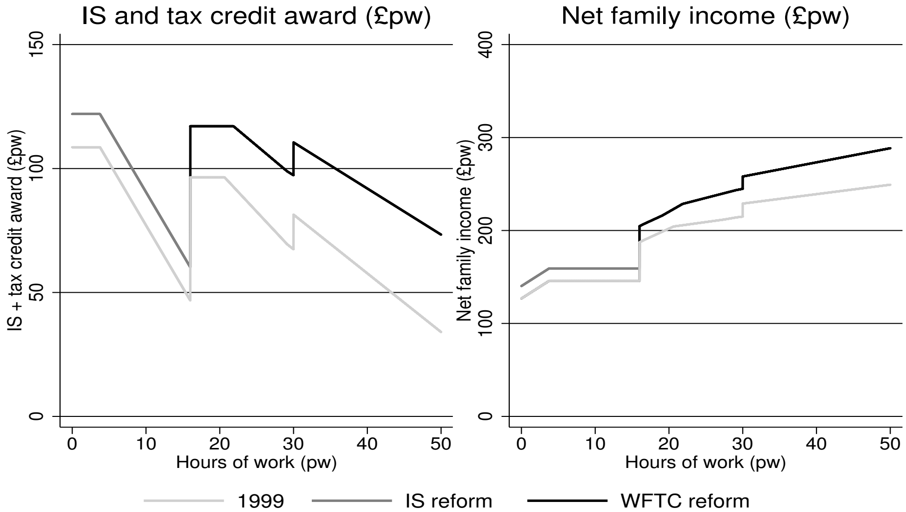
significantly (row 6), which implied that eligibility was extended to new better-off families (rows 7 and 8). By 2004, eligibility for a newly introduced family component of the Tax Credits was maintained by those with a weekly family income of £1086.32, and then slowly tapered at a rate of 6.67%. Childcare expenditures, which were simply deducted from earnings when evaluating eligibility (giving rise to an earnings disregard) up to 1999, generated a childcare credit worth 70% of the amount spent up to a limit of £135 per week by 2002. The reform in childcare support resulted in a sharp increase in the maximum award (row 4), from £96.52 in 1999 to £174.80, £180.00 and £186.30 in 2000, 2001 and 2002, respectively. This led the increase in entitlement observed for families with childcare expenditures (row 8).

The tax system is individually assessed and consists of the overlapping schedules of taxes and national insurance (both of which should be just perceived as tax rates), with their respective thresholds for each rate.[14] The fall in starting and basic tax rates, accompanied by a later change in National Insurance rates affected the incentives to work and the tradeoffs between part-time and full-time hours particularly for medium to high earners (Table 2). The most important changes not shown in the table include the decline in the basic tax rate from 25% in 1991-95 down to 24% in 1996 then to 23% in 1997 and to 22% in 2000. Also a new lower tax rate was introduced in 1992 at 20% and reduced to 10% in 1999.

The combined changes in taxes and benefits affected the work incentives of women across the income distribution, with the former/latter being potentially more relevant for high/low income families respectively. Previous studies have also highlighted the heterogeneous nature of the impact of these reforms, depending on family circumstances and interactions with other taxes and benefits (Brewer, Saez and Shephard, 2010). One important example is Housing Benefit, a large means-tested rental subsidy program potentially affecting low income families. HB covers up to 100% of rental costs, but the withdrawal rate is high (65% on net income). Families eligible for HB face strong disincentives to work that the WFTC reform does not resolve. Our model will account for the entire tax and welfare system and hence the integration between the various programs and their impact on incentives will be fully taken into account.

[14]Historically National Insurance was supposed to fund pensions. However, this is a Pay-as-you-go component of the UK pensions system and NI is effectively part of the income tax system.

Figure 1: IS/tax credit award and budget constraint for low-wage lone parent



Notes: Lone parent earns the minimum wage (April 2004) and has one child aged 4 and no expenditure on childcare or rent. All monetary values in 2008 prices.

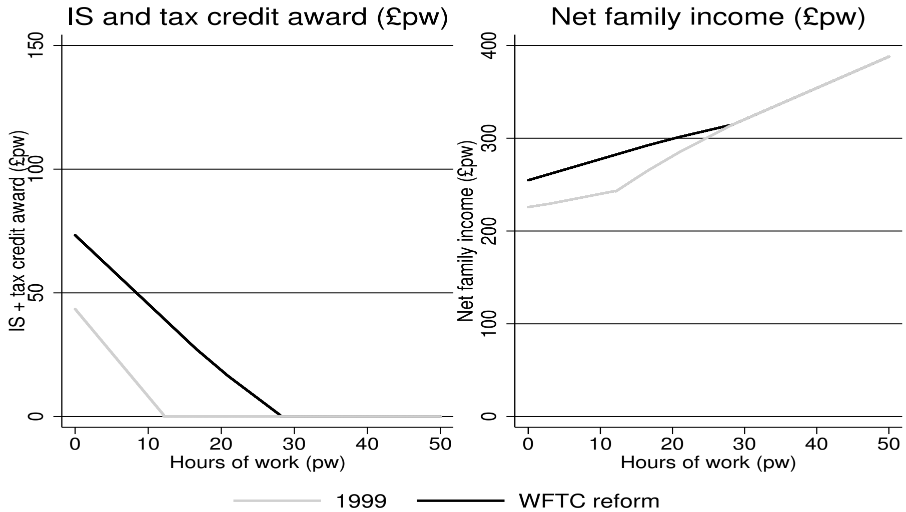
Figure 1 depicts the structure of the two systems. The left panel shows the amount of benefit eligibility, while the right panel shows the resulting amount of disposable income, both as a function of hours worked at the minimum wage. Eligibility for benefits at 16 hours and then at 30 generate the upwards shifts. The increase in net income is not as big as the increase in maximum tax credit award described above because tax credits count as income in the calculation for some other benefits not described here, but taken into account in the model. Figure 2 provides the corresponding transfers and budget constraints for a woman with same characteristics but with a partner working full time (if the partner does not work, the budget constraint is similar to that in Figure 1).

3 Data and reduced form analysis

3.1 The Panel Data Sample

In estimation we make use of 18 waves (1991 to 2008) of the British Household Panel Survey (BHPS). All individuals in the original 1991 sample and subsequent booster samples remain in

Figure 2: Tax credit award for low-wage parent with low-wage partner working full time



Notes: Parents earn the minimum wage (April 2004) and have one child aged 4 and no expenditure on childcare or rent. Partner works 40 hours per week. All monetary values in 2008 prices. IS reform absent from figure because family not entitled to IS.

the panel from then onwards, apart from some lost because of attrition. Other individuals have been added to the sample in subsequent periods – sometimes temporarily – as they formed families with original interviewees or were born into them. All members of the household aged 16 and above are interviewed, and a large set of demographic, educational and labor market information is recorded, including expenditures on childcare and assets (the latter only every 5 years).

The unit of observation are women, to which we link information from the interview with the partner when applicable. Families where the female is self-employed have been dropped to avoid the difficulties relating to measuring their hours and earnings.[15] Our full data set is an unbalanced panel of 3,901 women aged between 19 and 50 observed at some point during the 1991-2008 period. Almost 60% of those are observed for at least 5 years and over 20% are observed for at least 10 years, 25% are observed entering working life from education. Some summary descriptive statistics by education and family composition are presented in Table 3. Further data details are provided in Appendix A.

Our model does not deal with macroeconomic growth and fluctuations. In estimating the model

[15]The entire histories of 2.9% of self-employed women were dropped and partial histories (from the moment they move to self employment) were dropped for another 3.1% of women

Table 3: Distribution of family types in 2002 – women aged 19-50

	Mothers		Childless	Number of
	singles	in couples	women	observations
All	0.10	0.44	0.46	2,096
	(0.007)	(0.011)	(0.011)	
		By education		
Secondary	0.15	0.49	0.36	839
	(0.012)	(0.017)	(0.017)	
High School	0.08	0.42	0.50	853
	(0.010)	(0.017)	(0.017)	
University	0.03	0.39	0.58	404
	(0.008)	(0.024)	(0.025)	

Notes: Based on BHPS data for 2002. Standard errors in parenthesis under estimates.

we therefore first remove aggregate growth from all monetary values, including the monetary parameters in the tax and welfare system (such as tax thresholds and eligibility levels).[16] To limit the importance of measurement error in earnings and especially working hours, the wage distribution was trimmed at percentiles 2 and 99 from below and above, respectively.[17]

Finally, assets play an important role in our model since they are a source of self-insurance and saving is likely to respond to changes in taxes and welfare. Indeed Table 4 shows that assets are relevant for all education groups: even among the lowest education group 58% hold some positive financial assets. Once housing is taken into account net wealth holdings can be substantial.

Table 4: Assets by Education

	Financial Assets			Housing		
	Proportion	Net assets (£1,000)		Proportion	For owners (£1,000)	
Education	positive	average	[p10,p90]	Owners	Value	[p10,p90]
Secondary	0.58	3.0	[-1.9 , 8.3]	0.69	127.4	[51.9 , 225,6]
High-school	0.74	4.9	[-2.9 , 16.1]	0.74	158.7	[57.0 , 287.7]
University	0.82	9.9	[-5.1 , 28.2]	0.85	206.2	[75.0 , 379.1]

Notes: BHPS data. Values in 1,000s British pounds, 2008 prices. Excludes private and public pension wealth. Financial assets net of debts, includes zeros. Gross house values. [p10,p90] in columns 3 and 6 stands for inter-decile range.

[16] We run 3 regressions, one for each education level, of log wages on time dummies and dummies of Scotland and Wales, and create 3 education specific wage indices from the estimated time dummies. Then we aggregate these indices using the (time-invariant) distribution of education for the entire population of workers aged 25-59 in the sample to construct an aggregate wage index. All real monetary values (using the CPI) are then re-scaled using this index to remove real growth.

[17] The censoring of the distribution from below is at £3.4 per hour in 2008 prices, well below the minimum wage.

3.2 The Impact of the Tax Credit Reforms on the Labor Supply of Single Mothers

The WFTC reform substantially increased the maximum benefit award both directly and through increases in support for childcare. It also decreased the rate at which benefits are withdrawn when earnings increase. It thus improved the incentives for single mothers to work. The contemporaneous reform to the income support (IS) system reduced the real value of the adult related benefit, affecting all women (irrespective of children), but increased the child related benefit. This latter reform counteracted somewhat the improved incentives for mothers with children due to the WFTC reform.

We use single women without children as a comparison group to estimate the effect of the WFTC and IS reforms on the labor supply of single mothers in a difference-in-differences framework - an approach first used to estimate the effects of EITC on labor supply by Eissa and Liebman (1996) and also used in the UK by Brewer et al. (2006). The data here is drawn from the UK Labor Force Survey, a repeated cross section which is much larger then the BHPS and hence contains enough single mothers.

In the top panel of Table 5 we show results of a simple difference in differences estimator for employment, comparing the pre-reform 1999 data to the first post reform period in 2002 separately for each education group.[18] This is a linear probability model with employment as a dependent variable. The reported coefficient is the interaction of being a single mother with a post-reform dummy (2002). The regression also includes a dummy for single mother, and a full set of dummies for time, age and age of the youngest child. The results indicate that the employment rates for secondary and high school educated lone mothers increased by between four and five and a half percentage points above the employment rates of similar single women without children; these are highly significant. Those who have completed university are unaffected, as we expect, because typically their earnings will be too high to benefit from the more generous support.

As a first robustness check we then use data from 1995 to 2004, which allows us to test for

[18] The reforms were implemented gradually, resulting in an empirical design that is not appropriate for a simple discontinuity estimator.

Table 5: Difference-in-differences employment regressions for lone mothers vs single women

	(1) Secondary	(2) High-School	(3) University
1999 compared to 2002 - Before and after all WFTC reforms			
Impact on employment	0.042***	0.055***	-0.005
Standard error	(0.011)	(0.015)	(0.016)
Pooled Sample 1995-2004			
Impact on Employment	0.0413**	0.0474*	-0.0095
	(0.0178)	(0.0266)	(0.0341)
lone-mothers x pre-reform linear trend	0.0016	-0.0086	-0.0105
	(0.0040)	(0.0067)	(0.0087)
N	24,648	8,113	5,088

Notes: Data from the Labour Force Survey. Standard errors in parentheses. Top Panel: two period differences in differences comparing pre-reform employment (1999) to post-reform (2002) for treatment (lone mothers) and comparison group (single women with no children). Lower panel: pooled regression for 1995-2004, including pre-reform differential trend between lone mothers and single childless women. All regressions include a a full set of dummies for time, age and age of youngest child and an indicator for being a single mother. Impact on employment is coefficient on lone-mother x post-reform. ***,**,* indicates statistical significance at 1%, 5% and 10% respectively.

differential trends between the two comparison groups using the periods preceding the reforms targeting single mothers specifically. We use a similar linear probability model for employment, but now also control and test for pre-reform differential trends by adding an interaction of being a single mother with a linear trend in the pre-reform period. Again, the estimated impact is the coefficient of the interaction term between being a single mother and a dummy for post 2002. The results are in the lower panel of Table 5. The impacts are basically the same as before and the coefficient on the differential trend is completely insignificant and very small in all cases.

Table 6: Placebo effects on employment based on pre-WFTC reform data

	Secondary education				High-school				University			
After period	1996	1997	1998	1999	1996	1997	1998	1999	1996	1997	1998	1999
Before period 1995	-0.003	0.001	-0.008	-0.009	0.025	-0.011	0.014	0.012	-0.036*	-0.028	-0.018	-0.035*
	(0.011)	(0.012)	(0.012)	(0.012)	(0.017)	(0.016)	(0.016)	(0.016)	(0.021)	(0.020)	(0.020)	(0.020)
1996		0.004	-0.005	-0.005		-0.033**	-0.009	-0.013		0.013	0.018	0.001
		(0.011)	(0.011)	(0.011)		(0.016)	(0.016)	(0.016)		(0.018)	(0.019)	(0.019)
1997			-0.009	-0.007			0.026*	0.024			0.007	-0.013
			(0.011)	(0.011)			(0.015)	(0.016)			(0.017)	(0.017)
1998				0.002			0.000	-0.003				-0.017
				(0.011)			(0.001)	(0.015)				(0.017)

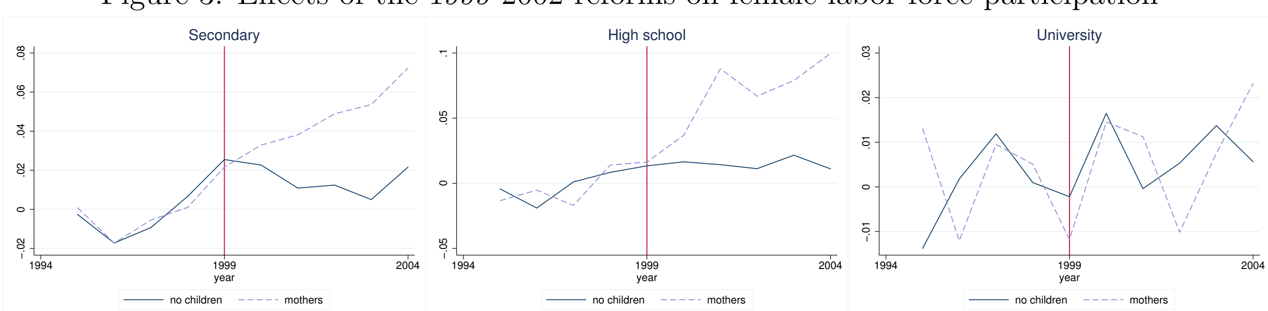
Notes: Data from the Labour Force Survey. Standard errors in parentheses. Difference-in-differences estimates compare lone mothers with single women with no children (treatment and comparison groups) in pairs of years before and after pseudo-treatment. Linear probability model of employment including time and single mother dummy and single mother dummy x post pseudo reform, the coefficient of which is the pseudo impact reported. Other covariates included dummies for age and age of youngest child. Each coefficient is from a separate regression. **,* indicates statistical significance at 5% and 10% respectively.

To further validate the approach we also implemented a set of placebo estimates on pairs of years from the pre-reform period of 1995 to 1999, a period when no reforms took place that would have affected our two groups differentially. Estimates for the various pairs are presented in Table 6: they are all very small and insignificant (except one in the High School group), with standard errors of the same magnitude as those in Table 5.

Finally, Figure 3 presents a graphical comparison of the labor force participation of single women without children to single mothers (the comparison and treatment groups, respectively). For presentational purposes, we set the average labor force participation to be the same across the demographic groups prior to the reform. The vertical line corresponds to 1999, when the reform process for tax-credits started; it continued until the end of our observation period. These graphs demonstrate visually that both groups evolved in the same way before the reform, irrespective of education. But the trends diverge after the reform process started for the two lower education groups, for whom the reform is most relevant, with an increase in the participation of single mothers relative to that of single women with no children. As expected, the participation of university-graduated single mothers looks unaffected by the reform as most will not be eligible for in work benefits at their level of pay.

While the effects we estimate are specific to this institutional context, this exercise serves to show that the combined reforms did indeed cause increases in the labor supply of single mothers and establishes the order of magnitude that we can expect our model to replicate. It also shows that the reforms are an important source of exogenous variation for the model.

Figure 3: Effects of the 1999-2002 reforms on female labor force participation



Notes: The dotted line represents the participation rate of single mothers, who were affected by the reform. The solid line represents the participation rate of single women without children, who were not affected by the tax credit changes. We normalize the participation rate of both groups to average zero pre-reform. The actual participation rates in 1999 for each of the education groups in ascending order of education are 0.87, 0.94, 0.95 for singles with no children and 0.41, 0.65 and .0.80 for lone mothers. The x-axis is year. The vertical line shows the last pre-reform year, 1999.

3.2.1 Education choice and the welfare reform

The WFTC and IS reforms as well as tax reforms may also change education choices for young people if they are perceived as permanent. This is because they change the future returns to education and the amount of risk associated with each choice, particularly in the middle and low end of the income distribution.

Consider first Figure 4. It shows the proportion of people in education at age 16, when it is still compulsory, and at 17-21, when most post-compulsory education happens. For the latter, there is a clear break in trend in 1999, at the time the reforms started being implemented. While suggestive, using the break in trend to infer the impact on education is not a credible approach. Quite apart from the fact the reforms were implemented gradually post 1999, there were other time varying factors that may have induced this change in trend. For example, there were tax reforms both before and after 1999 as well as an introduction of University fees in 1998 (£1000 per year) and a means tested educational subsidy for high school in 2004.[19] As a result it does not make much sense to use 1999 as a single break point of policy affecting education. Moreover, there is no equivalent to the comparison group we used when considering the effects on labor supply since everyone is affected by changes in the policy environment at the time of their education choice.

To get a handle on how the policy induced changes in economic incentives affect education, we specify a much simplified economic model where education choice depends on expected income under alternative education choices. The approach we follow is similar in spirit to that of Blundell, Duncan and Meghir (1998) for tax reform and labor supply and of Gruber and Saez (2002) for estimating the taxable income elasticity.

We start by the observation that welfare and tax reform will affect people differently depending on their background characteristics, which place them at different points on the earnings distribution (in expectation). For example, if a person is predicted to have high earnings and strong labor market attachment (even without post-compulsory education) their life-time expected income

[19] The Education Maintenance Allowance - see Dearden et al. (2009) for an evaluation preceding the rollout.

Figure 4: Trend in educational participation by age group

Notes: The top line is the school participation rate of those who are 16 and for whom attendance is compulsory. The lower line represents participation in post compulsory schooling for ages 17-21. The x-axis is year.

will not be very sensitive to changes the welfare parameters, which concern people with low labor market attachment and low pay. By contrast the expected income of an individual whose background characteristics predict her to be often out of work or in low pay will be very much affected by the welfare reforms.[20] We can exploit this insight to estimate the effect of the reforms as mediated by changes in expected income. This is particularly useful because the same sort of variation will be used in the structural model, but in a more complex setting.

To achieve this, we simulate life-cycle disposable income paths (including predicting spells out of work) conditional on each of the three possible educational choices. These are constructed as a function *only* of the tax and welfare system when the person was 17 and of observable family background. We then construct expected lifetime income conditional on just compulsory secondary education (EY_C), conditional on just high school (EY_{HS}) or university (EY_U).[21]

We need to be parsimonious in allowing for family background because we later build on this

[20]Family background includes the education of both parents (five levels each), number of siblings and sibling order (dummies for no siblings, three or more siblings, and whether respondent is the first child), books in childhood home (three levels) and whether lived with both parents when aged 16.

[21]To construct expected income we use the estimated earnings and transition equations from the structural model introduced later in the paper to simulate sequences of disposable incomes over the lifecycle, conditional on each of the three education choices, initial family background (summarized in two factors) and on the tax/welfare system prevailing when the person was 17. We then average over many different career paths for each education level, conditioning only on the family background characteristics and the relevant tax/benefit system. In this way the expected income per education varies only with family background and tax and welfare system.

approach to specify our model, in which background characteristics enter preferences and wages. Thus we have to limit the size of the state space.[22] Our solution was to extract two principal component factors (f_1 and f_2) from the set of background characteristics.[23] In this way we use all information in a parsimonious and efficient way. The resulting variability in the expected income measures depends *only* on the policy reforms and the two factors.

Defining the outcome variable as a dummy for attendance in post compulsory schooling (PC_{it}) we run the regression

$$PC_{it} = \text{time dummies} + \alpha_1 f_1 + \alpha_2 f_2 + \alpha_3 \ln(EY_C) + \alpha_4 \ln(EY_{HS}) + \alpha_5 \ln(EY_U) + u_{it}$$

The results are presented in Table 7. The first factor (f_1) has a strong positive effect on educational attainment, confirming it can discriminate across different types: educational attainment differs by about 20 percentage points over the support of f_1. The second factor is not significant. In columns 1-3 we include the simulated value of expected lifetime income for the lowest education group only. This is always highly significantly negative as expected (since it makes the lowest level of education relatively more attractive). The result remains unchanged and significant when we include differential trends by background factors (column 2) and even when allow for these trends to differ pre and post 1999 (column 3 – we can do this because reforms are implemented throughout the period and there is more than just pre and post 1999 variability; all included regressors explain only 38% of the variability in $\ln EY_C$).

The bottom of Table 7 shows that the average expected incomes corresponding to all education levels increased following the reform, but EY_C followed by EY_{HS} increased the most as expected given the nature of the reforms. Column 4 in the Table shows that the expected incomes corresponding to the two higher education groups have a positive effect as expected but are less

[22]We could construct a one dimensional probability of attending post-compulsory education by regressing post-compulsory schooling attendance on family background in one single cross section and then use the resulting predicted probability as the variable discriminating between types of individuals. However, Abadie et al. (2014) show that this is likely to lead to biased effects of heterogeneous impacts.

[23]Using this more limited information rather than all family background variables does not cause bias, but it could reduce efficiency. The first principal component accounts for 17% of the data variability. It is associated with more educated parents, fewer siblings, being the eldest child and more books at home.

Table 7: The Effect of expected income on post-compulsory schooling

	(1)	(2)	(3)	(4)
$ln(EY_C)$	-0.6388^{**}	-0.6417^{**}	-0.6215^{**}	-1.4018^{**}
	(0.3180)	(0.3181)	(0.3076)	(0.5298)
$ln(EY_{HS})$				1.0553
				(0.7130)
$ln(EY_U)$				0.0705
				(0.4632)
f_1	0.0968^{***}	0.1035^{***}	0.0999^{***}	0.1063^{***}
	(0.0085)	(0.0154)	(0.0197)	(0.0203)
f_2	-0.0135	0.0431^{***}	-0.0024	-0.0079
	(0.0102)	(0.0141)	(0.0184)	(0.0207)
$f_1 \times t$		-0.0010	0.0006	0.0008
		(0.0029)	(0.0034)	(0.0034)
$f_2 \times t$		-0.0053^{***}	-0.0055^{*}	-0.0054^{*}
		(0.0019)	(0.0030)	(0.0030)
$f1 \times t \times post - ref$			-0.0228	-0.0235^{*}
			(0.0136)	(0.0134)
$f2 \times t \times post - ref$			0.0233^{**}	0.0219^{**}
			(0.0102)	(0.0103)
$f1 \times post - ref$			0.0571	0.0577
			(0.0534)	(0.0527)
$f2 \times post - ref$			-0.0596	-0.0569
			(0.0374)	(0.0379)
Time dummies	Yes	Yes	Yes	Yes
	Treatment Effect			
Average Effect	-0.0089^{**}	-0.0090^{**}	-0.0087^{**}	-0.0090^{**}
St. Error	(0.0044)	(0.0044)	(0.0043)	(0.0044)
Changes in Expected income by Education group comparing 1999 to 2002				
$\Delta \ln \left(\overline{EY_C}\right) = 0.0140$ $\Delta \ln \left(\overline{EY_{HS}}\right) = 0.0097$ $\Delta \ln \left(\overline{EY_U}\right) = 0.0042$				
N	1030			

Notes: Linear probability model on BHPS data. Cohorts 1970-85. The dependent variable is one for those with post-compulsory education and zero otherwise. $post - ref$ is a dummy for post-reform (cohorts 1982+); t is a linear time trend; f_1 and f_2 are the first two principal components extracted from the family background variables (the education of both parents (five levels each), number of siblings and sibling order (dummies for no siblings, three or more siblings, and whether respondent is the first child), books in childhood home (three levels) and whether lived with both parents when aged 16.) The means of the factors (f_1, f_2) are (0.9, -0.033), the lowest quartile, the median and the top quartile are (-0.067, -1.02), (1.217, -0.086) and (2.08, 0.92) respectively.

significant, particularly so for EY_U which is the least affected by the reforms.

The results are consistent with what we expect and are remarkably robust. Put together they imply that the changes in expected income induced by the reform cause a decline in post-compulsory education of 0.9 percentage points (st. error 0.44). Given that EY_C changed by 1.4%, this is a substantial effect. When we repeat this exercise using as dependent variable university attendance (versus less) we obtain a decline of 0.52 percentage points, which however is not significant (st. error 0.46). As we shall see these effects are closely replicated by the structural model we describe below.

4 Model

The reduced form analysis establishes the responsiveness of important decisions to changes in taxes and transfers. However, it has little to say about the mechanisms underlying choices and ignores the effects of risk on behavior. The model we develop below allows us to understand the longer term effects of policy on behavior and on welfare, to carry out counterfactual analysis and to address policy questions from a normative perspective as well (see Stantcheva, 2015 for example).

4.1 Outline of the model

At the age of 17 a woman chooses between leaving education with a secondary degree, completing high school or completing college. Upon completing education, women enter the labor market at the age of 19 for those completing high school or less, and at the age of 22 for university graduates. From then onwards, we model annual consumption and labor supply choices – one of unemployment, part-time or full-time employment. Women retire at the age of 60 (the state pension retirement age for all women over this period), and live for another 10 years from their accumulated savings.[24] Households are credit constrained and, with the exception of university loans, they cannot borrow.

In every period a woman may have a child (up to the age of 43), may get married or get divorced. These events occur randomly over the life-cycle according to an education-specific stochastic process that depends on her current family arrangements and that replicates what we see in the data. For computational reasons we simplify the problem by not treating these demographic events as explicit choices. Hence our counterfactual simulations are conditional on the status quo processes and abstract from the implications of changes in behavior in those dimensions.[25] However,

[24]See also Attanasio, Low and Sanchez-Marcos (2008) and, for men, French (2005) and van der Klaauw and Wolpin (2005).

[25]Studies that endogenize marriage and fertility decisions include van der Klaauw (1996), Francesconi (2002),

changing educational decision implies a change in the relevant marriage and child-bearing process. Moreover, the model accounts for marital sorting by education as observed in the data (see for example Chiappori, Iyigun and Weiss, 2012).

Wages depend on actual experience, which may depreciate when out of work and accumulates at potentially different rates when working part-time versus full-time. This explains how career breaks and part-time work shape female wages and work incentives. Individual productivity is subject to persistent shocks, whose distribution depend on unobserved preferences for work and constitute an important source of risk.[26]

Observed *ex ante* heterogeneity in the model is driven by the woman's family background, summarized by the two principal component factors we introduced earlier; to keep the size of the state space manageable we discretize them into binary indicators when they are included in preferences for working and wages – they form four distinct observed types.

Educational choice depends on the background factors and on a liquidity shock to parental income. We measure this as the residual from a regression of parental income when the woman was 16 on the entire set of background variables – intended to control for permanent income, which is possibly correlated with preferences and abilities. We assume this does not affect preferences and wages, acting as an exclusion restriction, and its role is to explain differences in educational attainment of otherwise identical individuals, attributing these to liquidity constraints.

Women also differ in unobserved dimensions. At 17, they each draw a random cost of education and a random preference for work (consisting of a utility cost of part time work and a utility cost of full time work); both inform the education choice. When starting working life, they draw an initial productivity level from a distribution that depends on their random preference for work and their education. In addition to these, there are persistent idiosyncratic shocks to wages and male earnings, which will be described later.

All choices are affected by the tax and welfare system, which differs by cohort and defines dispos-

Keane and Wolpin (2010) and Adda et al. (2015).

[26] See also Huggett et al. (2011), who consider heterogeneity in wage profiles, and Adda et al. (2015), who allow for a flexible specification of human capital accumulation by working hours.

able income under each employment option. Further reforms to the system during working life are treated as unexpected surprises. We use FORTAX, a tax and benefit micro-simulation tool to draw accurate budget constraints by family circumstances, accounting for all the detail in the tax and welfare system in place at each point in time.[27] We now explain the model formally.

4.2 Working life

In each year of her adult life, a woman maximizes expected lifetime utility taking as given her current characteristics and economic circumstances. These are her age (t), education (s), accumulated assets (a), work experience (e), idiosyncratic productivity (υ), her family background (x_1, x_2) where x_j is a dummy for whether above the median in the distribution of factor f_j,[28] and a two-dimensional discrete unobserved factor $\theta = (\theta_F, \theta_P)$ characterizing her preferences for working full time (θ_F) or part time (θ_P). They also include her family circumstances and related information: the presence of a partner (m), his education ($\tilde{s}$), whether he is employed or not ($\tilde{l} = F/O$ for Full-time hours and Out of work, respectively) and productivity ($\tilde{\upsilon}$), the presence of children (k), age of the youngest child (t^k) and whether she has access to free childcare (d_{cc}). We denote by X_t the vector of state variables in period t, including these two sets of variables. In all that follows, lowercase letters represent individual observed characteristics, the tilde denotes men's variables, uppercase letters are for market prices and sets of variables, and Greek letters are reserved for the model parameters and unobserved shocks. Except for unobserved preferences for work and productivity, all other shocks and random components of the model are independent of each other.[29]

We assume that utility is intertemporally separable, and that instantaneous utility depends on consumption per adult equivalent, female labor supply, family background, family circumstances and preferences for work. Her instantaneous utility is non-separable between consumption and

[27] See Shephard (2009) and Shaw (2011).

[28] Discretizing the factors is an approximation used to limit the size of the state space and make the problem computationally tractable. In principle we could improve the approximation by adding more discrete points.

[29] To be clear, the random components of the model of the working life are the female preferences for work, whether she has access to free childcare when working, her productivity, the arrival of a child, the arrival and departure of a partner, and his education and productivity.

leisure. At age t it is given by

$$u\left(c_t, l_t; \theta, Z_t\right) = \frac{\left(c_t/n_t\right)^{\mu}}{\mu} \exp\left\{U\left(l_t, \theta, Z_t\right)\right\} \tag{1}$$

where n is the equivalence scale,[30] c is total family consumption, l is female labor supply and assumes three possible values: not working (O), working part-time (P) and working full-time (F). The function U reflects how the marginal utility of consumption changes with working, by the woman's education, background characteristics and family demographics; it is normalized to zero if the woman is not working. Finally, μ is the curvature parameter determining both risk aversion and the elasticity of intertemporal substitution. Since μ will be negative, a positive U for $l = \text{P, F}$ implies that working reduces the utility of consumption and that consumption and labor supply are complements as indeed is the case in Blundell, Browning and Meghir (1994), who use consumption data from the UK.[31] U is specified as follows

$$\begin{aligned} U\left(l_t, \theta, Z_t\right) &= \begin{cases} 0 & \text{if } l_t = \text{O} \quad \text{(Out of work)} \\ \theta_l + Z_t' \alpha(l_t) & \text{if } l_t = \text{P or F} \quad \text{(Part time or Full time)} \end{cases} \\ \text{where } \alpha(l_t) &= \alpha_F + \alpha_P \times \mathbf{1}(l_t = P) \end{aligned}$$

where Z_t is a subset of the woman's characteristics, including whether she is single or with a partner, and whether she is a mother; these are interacted with a dummy for the three education levels (secondary, high school or university). It also includes a dummy for the age of the youngest child (0-2, 3-5, 6-10 or 11+), a dummy for the partner working or not and the background factors x_1 and x_2, allowing preferences to depend on background.

The bivariate vector $\theta = (\theta_F, \theta_P)$ reflects unobserved heterogeneity and can take two values: one for low utility cost of work and one for high cost of work.[32] The values of θ, the probability of being low-cost of work, and the other unknown utility parameters described by $\alpha(l)$ for $l = F, P$

[30] n=1 for singles, 1.6 for couples 1.4 for mother with child and 2 for a couple with children.

[31] For more evidence on this see Ziliak and Kniesner (2005) and Shaw (1989).

[32] We did experiment with a richer distribution of unobserved heterogeneity, but this did not significantly improve the fit of the model or change the results.

are estimated alongside the other parameters of the model.

At any age t during working life, the woman's decision problem can be written as:

$$V_t(X_t) = \max_{\{c_\tau, l_\tau\}_{\tau=t,\ldots\bar{t}}} \mathrm{E}\left\{ \sum_{\tau=t}^{\bar{t}} \beta^{\tau-t} u(c_\tau, l_\tau; \theta, Z_\tau) \middle| X_t \right\} \quad \text{subject to the Budget constraint}$$

where the expectation E is taken over all future random events conditional on the available information X_t, β is the discount factor and V_t is the optimum value of discounted present and future utility. $\bar{t}$ is 10 years after retirement and the family lives off its savings during the retirement period.[33]

The budget constraint is described in terms of the asset evolution equation

$$\begin{cases} a_{t+1} &= (1+r)a_t + h_t w_t + m_t \tilde{h}_t \tilde{w}_t - T(l_t, X_t) - Q\left(t^k, h_t, \widetilde{h}_t, m_t\right) - c_t \\ a_{t+1} &\geqslant \underline{a}_s, \text{ with initial and terminal conditions: } a_0 = 0 \text{ and } a_{\bar{t}+1} = 0 \end{cases} \quad (2)$$

where r is the risk-free interest rate, $(w, \tilde{w})$ are the hourly wage rates of wife and husband, $(h, \tilde{h})$ are the working hours of wife and husband (respectively 0, 18 and 38 hours corresponding to O, P and F for women, and 0 and 40 corresponding to O and F for men), and $\underline{a}_s$ represents the borrowing limit; the latter is either zero or the amount of the student loan borrowed (a negative number). The tax and transfer function, T, unifies the tax and welfare system, describing the total incentive structure faced by an individual at all income levels and turns out to be a complex non-concave, non-smooth and often discontinuous function of income, hours of work and family composition. It depends on hours because tax credits in the UK depend on hours thresholds (16 and 30).[34] Households start life with a particular tax and welfare system and face reforms over their lifetime, which are treated as unanticipated. The age at which the reforms occur varies depending on the cohort to which individuals belong.

[33] This ensures that individuals save towards retirement above their social security contributions, which in the UK only replaces a small proportion of their working earnings.

[34] T includes income tax, social security contributions, and the main subsidies for working-age families, namely income support, job-seekers allowance, tax credits, housing benefit, council tax benefit, child benefit. These are described in appendix F, together with the main reforms over 90s and 00s.

Finally, Q are childcare costs. Pre-school children need childcare whenever no adult is staying at home, and school-age children only need childcare outside the school day as education is publicly provided. Childcare costs are zero for those with access to informal care ($d_{cc} = 0$) the probability of which is estimated from the data, and only depend on the age of the youngest child. Hence we specify

$$Q\left(t^k, h_t, \widetilde{h}_t, m_t\right) = \begin{cases} h_t * CC_h & \text{if } d_{cc} = 1 \text{ and } t^k \leqslant 5 \text{ and } \left(\widetilde{h}_t = 40 \text{ or } m_t = 0\right) \\ 18 * CC_h & \text{if } d_{cc} = 1 \text{ and } 5 < t^k \leqslant 10 \text{ and } h_t = 38 \text{ and } \left(\widetilde{h}_t = 40 \text{ or } m_t = 0\right) \\ 0 & \text{all other cases} \end{cases}$$

where CC_h is the constant per-hour rate, which we set to a number obtained from the data.

Female human capital and earnings dynamics The female wage process including the distribution of all shocks is education-specific (indexed by s). It is given by

$$\ln w_t^m = b_{s,0} + b_{s,1}x_1 + b_{s,1}x_2 + (\gamma_{s,0} + \gamma_{s,1}x_1 + \gamma_{s,2}x_2)\ln(e_t + 1) + \upsilon_t + \xi_t \tag{3}$$

$$\ln w_t = \ln w_t^m - \xi_t \tag{4}$$

$$e_t = e_{t-1}(1 - \delta_s) + g_s(l_{t-1}) \tag{5}$$

$$\upsilon_t = \rho_s \upsilon_{t-1} + \zeta_t \tag{6}$$

where $\ln w_t^m$ is the observed hourly wage rate, ξ is iid Normal measurement error, $\ln w_t$ is the wage rate on which individual decisions are based and e_t is experience.[35] Importantly, we also allow for the background variables (x_1, x_2) to affect wage levels and growth. The individual productivity process, υ_t, follows an AR(1) process with normally distributed innovations, ζ_t; hence, purely transitory variation in wages is attributed to measurement error and does not affect the decision process. The initial productivity shock is distributed as a mixture of two normals with means that depend on unobserved preferences θ.

Experience depreciates at a rate δ_s per period; its accumulation depends on whether the person

[35] w_t^m is the ratio of usual weekly earnings by usual weekly hours, the latter being capped at 70.

is working full time or part time: $g_s(F) = 1$ while $g_s(P)$ is an education specific number to be estimated, defining the experience value of part time work. The experience profile of wages is concave as in Eckstein and Wolpin (1989) if the return to experience in wages $(\gamma_{s,0}+\gamma_{s,1}x_1+\gamma_{s,2}x_2)$ is smaller than one.

Male employment and earnings We assume men in couples either work full-time ($\tilde{l} = F$) or are out of work ($\tilde{l} = O$). Their hourly wage and employment are exogenous and are given by

$$\text{Prob}\left[\tilde{l}_t = \text{F}\,|X_t\right] = \begin{cases} \text{Prob}\left[\tilde{\nu}_{1t} > b_1\left(t, \tilde{s}_t, \tilde{l}_{t-1}\right)\right] & \text{if } m_{t-1} = 1 \\ \text{Prob}\left[\tilde{\nu}_{0t} > b_0\left(t, \tilde{s}_t\right)\right] & \text{if } m_{t-1} = 0 \end{cases} \quad (7)$$

$$\ln \tilde{w}_t^m = \tilde{b}_{\tilde{s}} + \tilde{\gamma}_{\tilde{s}} \ln(t-18) + \tilde{\upsilon}_t + \tilde{\xi}_t, \quad t > 18 \quad (8)$$

$$\ln \tilde{w}_t = \ln \tilde{w}_t^m - \tilde{\xi}_t \quad (9)$$

$$\tilde{\upsilon}_t = \tilde{\rho}_{\tilde{s}} \tilde{\upsilon}_{t-1} + \tilde{\zeta}_t \quad (10)$$

where $\ln \tilde{w}_t^m$ is measured log wage, $\ln \tilde{w}_t$ is the log wage that matters for decisions and $\tilde{\xi}$ is taken to be an iid normal measurement error.[36] The shock to wages $\tilde{\upsilon}_t$, is an AR(1) process with normal innovations and normal initial values, all dependent on his education, $\tilde{s}$. The dependence between the earnings and employment of spouses is captured by the correlation in their education levels, as will be detailed below.

The dynamics of family composition Family dynamics are stochastic and education specific but exogenously set to reproduce the patterns observed in the data. If a child is present then $k = 1$ and t^k is her/his age. In the model only the age of the youngest child matters for preferences and costs. Hence, when a new child arrives we reinitialize t^k to zero. The probability that a new child arrives depends on the age and education of the woman, whether she has other children and the

[36] In order to avoid including both male and female age in the state space and so as to allow for the fact that female and male age are highly correlated in practice, we include female age in the male earnings equation instead of male age. This simplifies the computations, while allowing age effects on male earnings, which is important in a life-cycle model.

age of the youngest child, and whether she is married (described by m). It is given by

$$\text{Prob}\left[t^k = 0 \mid t, s, k_{t-1}, t^k_{t-1}, m_{t-1}\right] \tag{11}$$

Once a child is born, she/he will live with the mother until (and including) 18 years of age. If the woman is married then $m = 1$ and $\tilde{s}$ is the education of the partner. The transition probability is given by

$$\text{Prob}\left[m_t, \tilde{s}_t \mid t, s, m_{t-1}, \tilde{s}_{t-1}, k_{t-1}\right] \tag{12}$$

where $\tilde{s}_{t-1}$ ($\tilde{s}_t$) is only observed if $m_{t-1} = 1$ ($m_t = 1$).[37]

4.3 Educational choice

Investments in education are decided at the start of active life, when the woman is aged 17, based on the balance of realized costs and expected value of each educational alternative. Labor market entry happens at 19 for those with high school or less ($s = 1$ or 2) and at age 22 for university graduates ($s = 3$) and there is no re-entry into full time ducation.[38] The opportunity cost of education for those aged 17-18 is captured by the estimated non-pecuniary costs of education. The optimal choice of education is defined by

$$s = \underset{s \in \{1,2,3\}}{\text{argmax}} \left\{W_s\left(X_{17}\right) - B_s\left(X_{17}\right)\right\}$$

where B_s measures the utility costs of the investment, defined as

$$B_s\left(X_{17}\right) = \pi_{1s} f_1 + \pi_{2s} f_2 + \pi_{5s} y_p + \varpi_s.$$

[37]As specified, fertility, marriage and the type of spouse depend on education but not on other choices such as labor supply, and does not depend on experience. This simplification allows us to estimate these processes outside the full dynamic model, simplifying considerably the computations.

[38]Individuals choosing to acquire professional education, including that providing on-the-job training, are classified as students when aged 17 to 18. It is being assumed that individuals 18 and younger have loose labor-market attachment, not conducive of experience accumulation.

y_p is the liquidity shock to parental income (after removing all observed information on permanent family characteristics when the woman is 16 years old); (f_1, f_2) are the continuous parental background factors, which capture permanent family heterogeneity and are discretized as described before to enter the rest of the model; ϖ_s is the unobserved utility cost of education s, assumed to be normally distributed with variance σ_s^2. Finally, W_s is the discounted expected value of lifetime utility if the woman chooses education level s. It is given by

$$W_s(X_{17}) = \begin{cases} \mathrm{E}\left[V_{19}(X_{19})\,|X_{17}, s\right] & \text{if } s = 1, 2 \\ \mathrm{E}\left[\max\limits_{c_{19}, c20, c_{21}} \left\{\sum_{t=19}^{21} \beta^{t-19} u(c_t, F; \theta, Z_{17}) + \beta^{22-19} V_{22}(X_{22})\right\} \middle| X_{17}, s\right] & \text{if } s = 3 \end{cases}$$

where Z_{17} summarizes the relevant information for the instantaneous utility (as in equation (1)) and it is assumed that university years carry a utility cost similar to that of full-time work in excess of the education specific preferences described by ϖ_s. University students fund their consumption needs and education costs, that vary across generations depending on the tuition fees (D), out of their institutional student loans. Therefore, optimization is therefore subject to the budget constraint

$$\begin{aligned} a_{19} &= a_{17} = 0 \\ a_{22} &= -(1+r)^2 c_{19} - (1+r) c_{20} - c_{21} - D \quad \text{if } s = 3 \end{aligned}$$

5 Estimation

We follow a two-step procedure to estimate the parameters of the model. In a first step we estimate the equations for the predetermined elements of the model, given education choices, including the dynamics of marriage, divorce, fertility, male labor supply, male earnings and the cost of childcare. Details and estimates can be found in Appendix B.

We set the utility function coefficient μ to -0.56 giving a risk aversion coefficient of 1.56, consistent with the findings in Blundell, Browning and Meghir (1994) and Attanasio and Weber (1995), both of which allow for nonseparability of leisure and consumption as in this model. Finally, the annual discount factor β is set to 0.98 as for example in Attanasio, Low and Sanchez-Marcos (2008).[39] The annual risk-free interest rate is set to 0.015, which is slightly lower than the discount rate thus implying that agents have some degree of impatience. The tuition cost of university education is allowed to vary as it changed over this period and the credit limit for university students (and graduates throughout their life) is £5,000 consistent with university education policy of the late 1990s in the UK. No further credit is allowed. The remaining parameters determining preferences and female wages are estimated using the method simulated of moments.[40]

Estimation exploits the policy changes over time. In order to use this available source of exogenous variation, we construct moments conditional on the two factors representing family background, on the value of the parental liquidity shock (that affects education choice) and on the year in which the individual became 16, which determines the original tax and welfare system they were facing as well as the age at which they faced any subsequent reforms. In this way we allow for the variation induced by changes in the policy environment and how this impacts different types of people based on their background, to help identification of the parameters. This implies that the model is estimated by comparing the behavior of different cohorts, who are facing different policy environments. Hence a key identifying assumption is that preferences do not change across cohorts and that differences can be attributed to policy changes.

We then solve the model and simulate the lifecycle choices of 19,505 women (5 replications of the 3,901 women profiles observed in the BHPS) using the observed distribution of family background and parental liquidity shock and the history of the tax and welfare systems that she faced. Our solution algorithm underlying these simulations is described in the web appendix and is based on a modified version of the algorithms in Fella (2014) and Iskhakov et al. (2015). The main difficulty in solving dynamic problems that combine discrete and continuous choices is that the the value function is neither smooth nor concave. The way we deal with these issues is described in Appendix C.

[39] We have experimented varying the discount factor to as low as 0.95, but we did not get substantive changes in behavior.

[40] Original references are Lerman and Manski (1981), McFadden (1989) and Pakes and Pollard (1989). See also Gourieroux, Monfort and Renault (1993a and 1993b) or Gallant and Tauchen (1996).

For each simulated profile, we select an observation window that matches her data counterpart so that the simulated sample exactly reproduces the time and age structure of the observed data. Again to limit the computational burden we impose the simplification that women face up to four policy regimes over the observation window, representing the main tax and benefits systems operating during the 1990s and early 2000s.[41] Finally, we compute the moments using the simulated dataset, equivalent to those computed using observed data and evaluate the objective function. The estimates $\hat{\Theta}$ are defined by

$$\hat{\Theta} = argmin_{\Theta}\{\Sigma_{k=1}^{K}[(M_{kN}^{d} - M_{ks}^{m}(\Theta))^2/Var(M_{kN}^{d})]\} \quad (13)$$

where the sum is over the K moments, M_{kn}^{d} denotes the k_{th} data moment estimated over N observations, $M_{ks}^{m}(\Theta)$ represents the kth simulated moment evaluated at parameter value Θ over s simulations.

As suggested by Altonji and Segal (1996) we do not use the asymptotically optimal weight matrix because of its potentially poor small-sample properties. The simulation procedure controls for any initial conditions problem by starting the simulation at the start of life. Unobserved heterogeneity is allowed for in the construction of the simulated moments. The moments we match are listed in Appendix D. We compute asymptotic standard errors following Gourieroux, Monfort and Renault (1993). This corrects for the effects of simulation noise.[42]

6 Parameter estimates

Table 8 reports the estimates for the female wage process. Both the wage rates at the start of working life and the returns to experience increase with education. We illustrate the effect of education on wages in row 4, which shows the mean wage rates by education for 25 year-old

[41] As mentioned earlier, we adopted the 1995, the 1999, the 2002 and the 2004 regimes and assumed they operated over the periods prior to 1996, 1997 to 1999, 2000 to 2002 and 2003 onwards, respectively.

[42] Estimation of the standard errors of the structural parameters takes the parameters estimated in the first estimation stage as fixed. Allowing for the variation in first stage to be accounted in estimating second-stage standard errors is prohibitively demanding in terms of computation time.

women who have continuously worked full-time. In row 8 we show the average return to experience, which increases with education, pointing to a complementarity between education and on-the-job learning.

Table 8: Female wage equation and experience accumulation

		Education		
		Secondary (1)	High school (2)	University (3)
(1)	Intercept ($b_{s,0}$)	5.406	5.547	6.949
		(0.030)	(0.038)	(0.071)
(2)	increment: high factor 1 ($b_{s,1}$)	0.005	0.018	0.061
		(0.040)	(0.038)	(0.066)
(3)	increment: high factor 2 ($b_{s,2}$)	0.014	-0.186	0.045
		(0.036)	(0.031)	(0.048)
(4)	Mean hourly wage rate at 25	7.19	8.64	10.55
		(.050)	(.067)	(.317)
		Returns to experience		
(5)	baseline ($\gamma_{s,0}$)	0.152	0.229	0.306
		(0.006)	(0.009)	(0.011)
(6)	increment: high factor 1 ($\gamma_{s,1}$)	0.054	0.014	-0.002
		(0.009)	(0.009)	(0.010)
(7)	increment: high factor 2 ($\gamma_{s,2}$)	-0.002	0.029	-0.006
		(0.008)	(0.008)	(0.008)
(8)	Mean value of the coefficient on experience	0.16	0.25	0.30
		(.008)	(.012)	(.014)
		Distribution of unobserved productivity		
(9)	autocorrelation coefficient: ρ_s	0.925	0.916	0.880
		(0.006)	(0.006)	(0.008)
(10)	st. deviation of innovation in productivity: $\sqrt{\mathrm{Var}(\zeta_s)}$	0.125	0.154	0.139
		(0.005)	(0.005)	(0.005)
(11)	mean of initial productivity for type I: $\mathrm{E}(\upsilon_{0s}\vert\text{type I})$	0.140	0.111	0.306
		(0.011)	(0.028)	(0.015)
(12)	st. deviation initial productivity: $\sqrt{\mathrm{Var}(\upsilon_{0s})}$	0.145	0.202	0.223
		(0.012)	(0.015)	(0.016)
		Human capital dynamics		
(13)	while in Part-Time work: $g_s(P)$	0.150	0.096	0.116
		(0.015)	(0.022)	(0.013)
(14)	depreciation rate: δ_s	0.081	0.057	0.073
		(0.008)	(0.008)	(0.009)

Notes: Standard errors in parentheses. Mean hourly wages (row 4) are assessed at age 25 if women worked full time since the start of their working life. The mean returns to experience (row 8) are averages over the population, conditional on education. The mean initial productivity (row 11) is for individuals with high preferences for working (type I). The population mean initial productivity is zero.

Human capital depreciates between 5.7% and 8.1% a year depending on the education group (row 14), which imposes a very large cost for time spent out of work. Importantly, when working part-time the amount of human capital accumulated is a fraction of that accumulated in full time jobs (row 13), at most barely counteracting the effects of depreciation. For example, a year of part-time work is worth only 15% of a full time one in terms of acquired experience among the lowest skill group. Effectively working part-time leads to almost no improvements in human capital for women who have little accumulated experience, and may even be associated with a loss of human capital for the more experienced individuals. This result, together with the persistence of working choices, contributes to explaining why, in the cross section, women working part-time are paid on average a lower hourly rate than those working full-time – we term this the *part-time penalty*.

A key element of the model is the stochastic process of wages, because it is a main source of uncertainty and leads people to value programs for the insurance they provide. The autocorrelation coefficient, ρ_s, reported in row 9, is very high but not quite a unit root. The standard deviation of the shocks (row 10) implies a high degree of uncertainty for next period's wage rate and there is substantial heterogeneity in wages at the start of life (row 12). Finally, the family background factors shape the wage profiles of the two lower education groups but not (significantly) that of college graduates.

In Table 9 we report the preference parameters determining the U function in equation 2. In reading the table note that positive and larger values of the coefficients make working less attractive because utility is negative (i.e, the parameter driving risk aversion, μ in equation (1), is negative). Moreover the coefficients in column (3) on part-time work are incremental to those in full-time work and reflect the difference of part-time from full-time work.

The parameters in column (1) of Table 9 imply that U for full time work is always positive, meaning that working carries a utility cost for all groups. The parameters in column (3) are negative but smaller in absolute terms than the ones in column (1), implying part-time work yields a lower disutility than full-time work. The utility cost of working is higher for single women than for women in couples. These results are consistent with similar employment rates across marital status for women without children and lower employment rates among lower-educated single mothers than among their married counterparts. Children, particularly of pre-school age, increase the utility costs of working and more so for full-time. Preferences depend on education, particularly amongst singles. Indeed to rationalize the data given the budget constraint, the single university graduates are attributed a higher disutility from full-time work. We also find that the

Table 9: Estimates of preference parameters – function U in equation (1)

		coeff (1)	st. error (2)	coeff (3)	st. error (4)
		Utility parameters			
		all employment α_F		part-time employment α_P	
(1)	Singles, no children: Sec	0.344	(0.011)	-0.269	(0.009)
(2)	Singles, no children: HS	0.412	(0.013)	-0.315	(0.012)
(3)	Singles, no children: Univ	0.555	(0.014)	-0.382	(0.012)
(4)	Married, no children: Sec	0.226	(0.013)	-0.154	(0.009)
(5)	Married, no children: HS	0.222	(0.011)	-0.156	(0.008)
(6)	Married, no children: Univ	0.276	(0.013)	-0.180	(0.010)
(7)	Single mothers: Sec	0.375	(0.010)	-0.161	(0.006)
(8)	Single mothers: HS	0.330	(0.019)	-0.142	(0.015)
(9)	Single mothers: Univ	0.372	(0.016)	-0.184	(0.066)
(10)	Married mothers: Sec	0.226	(0.011)	-0.168	(0.009)
(11)	Married mothers: HS	0.233	(0.012)	-0.180	(0.009)
(12)	Married mothers: Univ	0.282	(0.015)	-0.212	(0.012)
(13)	Child aged 0-2	0.156	(0.010)	-0.095	(0.008)
(14)	Child aged 3-5	0.093	(0.010)	-0.067	(0.009)
(15)	Child aged 6-10	0.047	(0.008)	-0.027	(0.007)
(16)	Partner working	-0.077	(0.009)	0.066	(0.007)
(17)	High background factor 1	0.002	(0.007)	0.000	(0.005)
(18)	High background factor 2	0.006	(0.006)	0.001	(0.005)
		Unobserved heterogeneity in cost of work			
		full-time employment θ_F		part-time employment θ_P	
(19)	Type I	-0.193	(0.006)	-0.093	(0.005)
(20)	Type I: probability	0.361 (.005)			

Notes: Standard errors in parentheses. The utility costs of working full-time and part-time for preference type II are selected to set the population mean of the utility parameters θ_F and θ_P to zero.

presence of a working partner (row (16)) further reduces the cost of working, implying some complementarity between the labour supply of partners (as in Blundell, Pistaferri, and Saporta-Eksten, 2012). It is interesting that family background does not directly affect preferences.

As in the reduced form analysis, Table 10 shows that family background matters for education and increased parental liquidity at 16 increases attainment and particularly so for University attendance. Beyond this, the unobserved random costs of education are also important in driving education choices, which explains why observationally similar people make different education decisions.

Mothers may face positive childcare costs if all adults in the household are working, in which case the cost of childcare is £2.60 per working hour for children under the age of 5 or per working

Table 10: Estimates of preferences for education and probability of positive childcare costs if working

		High School		University	
		coeff	st. error	coeff	st. error
		(1)	(2)	(3)	(4)
(1)	intercept	-0.053	(0.025)	0.682	(0.015)
(2)	background factor 1	0.227	(0.012)	0.363	(0.014)
(3)	background factor 2	0.009	(0.022)	0.299	(0.011)
(4)	parental liquidity shock when aged 16	0.305	(0.158)	0.695	(0.036)
(5)	st. deviation unobserved utility cost of education ($\sqrt{\mathrm{V}\varpi_s}$)	1.579	(0.093)	1.015	(0.183)
(6)	Probability of positive childcare costs	0.576 (.014)			

Notes: Residual parental income constructed from regression of parental income on all long-term background characteristics when the woman is 16 years old.

hour in excess of 18 hours per week for children aged 5 to 10. The probability that this happens is estimated to be about 58% (row 6 of Table 10), meaning that the rest have informal sources of childcare.

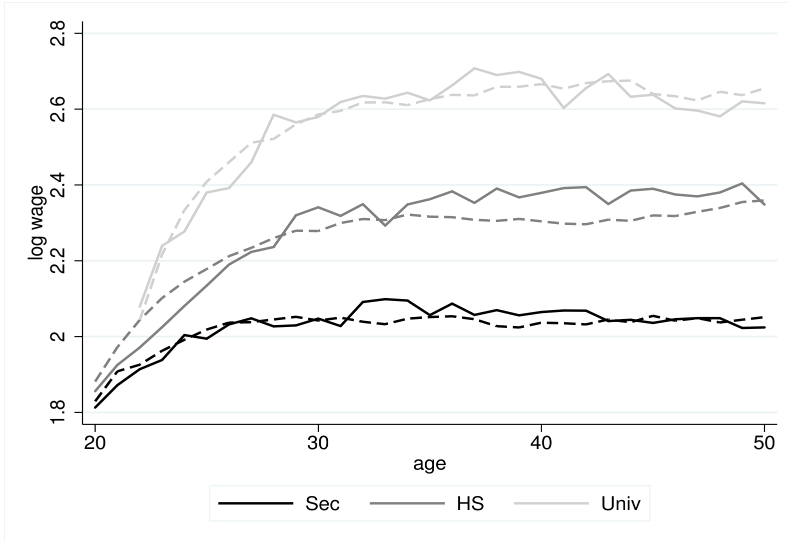
7 Model fit and Implications for Behavior

7.1 Wages and Employment

The life-cycle profiles of wage rates for working women are presented in Figure 5 for each education group. These fit the observed profiles well and show the lowest education group having the most flat profile becoming steeper for higher education groups. Figure 6 shows that this pattern is replicated across the percentiles of the life-cycle wage distribution and demonstrates that the model can reproduce the observed dispersion of wages. The flattening out in the observed profiles is in part because of the increasing prevalence of part-time work later in the life-cycle. Part-time workers have very low returns to experience according to our estimates, just about managing to avoid depreciation of human capital.

The part-time penalty relative to women working full-time continuously is illustrated in Figure 7. To understand its implications for wage formation, given actual labor supply behavior, we show the effect of switching off components of wage growth in Table 11. Thus the part-time penalty

Figure 5: Mean log wage rates for working women over the life-cycle by education: data versus model



Notes: BHPS versus simulated data, in solid and dashed lines respectively. 2008 prices.

implies female wages are lower by between 5.3% and 7.8% when the woman is 50 and given the observed periods of part-time work. If in addition we eliminate the experience cost of being out of work wages would be higher by between 10.5% and 14.3% at 50. The realized cost of part-time and out-of-work spells by age 50 are lowest for the least educated group, despite their lower labor market attachment, since their return to experience is actually very low. This component of the model is crucial for understanding the mechanisms through which welfare programs can have longer run effects.

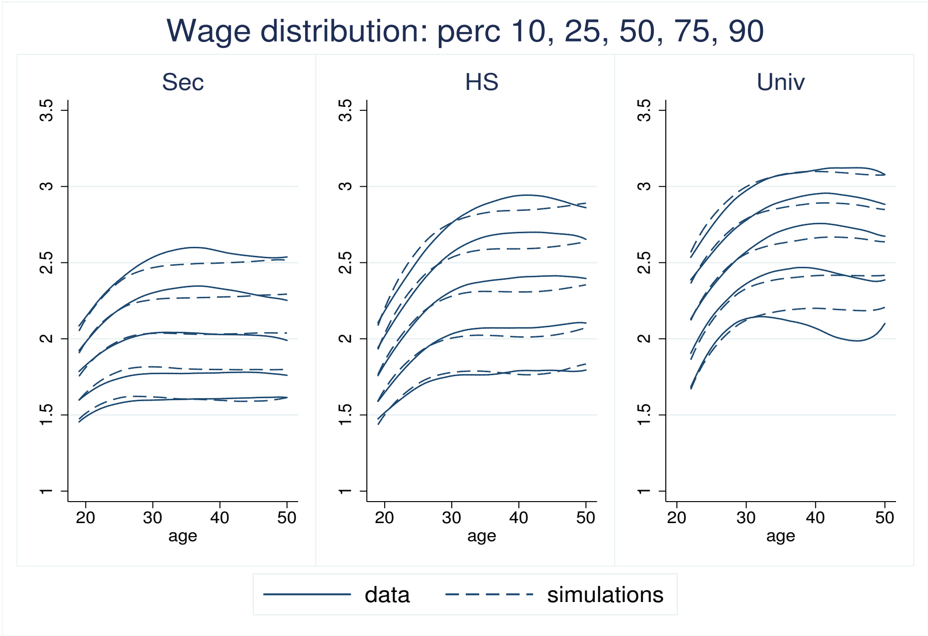
Table 11: The effect of observed part-time and non-work patterns on wages at 50

	No part-time penalty	No penalty for not working *and* no part-time penalty
Secondary (%)	5.3	10.5
High School (%)	7.0	12.5
University (%)	7.8	14.3

The first column shows the effect on wages at 50 if the amount of experience gained from part-time work is the same as that of full time work; the second column cancels, in addition, the experience cost of not working. The pattern of part-time work and full-time work is kept fixed at what actually happens.

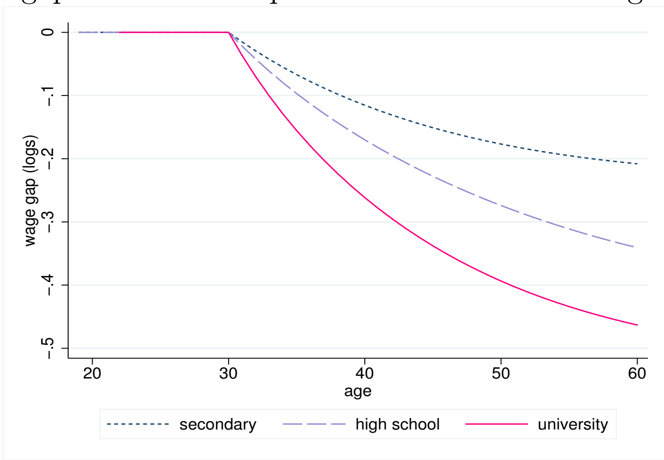
Figure 8 shows lifecycle employment patterns. The top panel shows that employment rates are

Figure 6: Distribution of log wage rates for working women over the life-cycle by education: data versus model



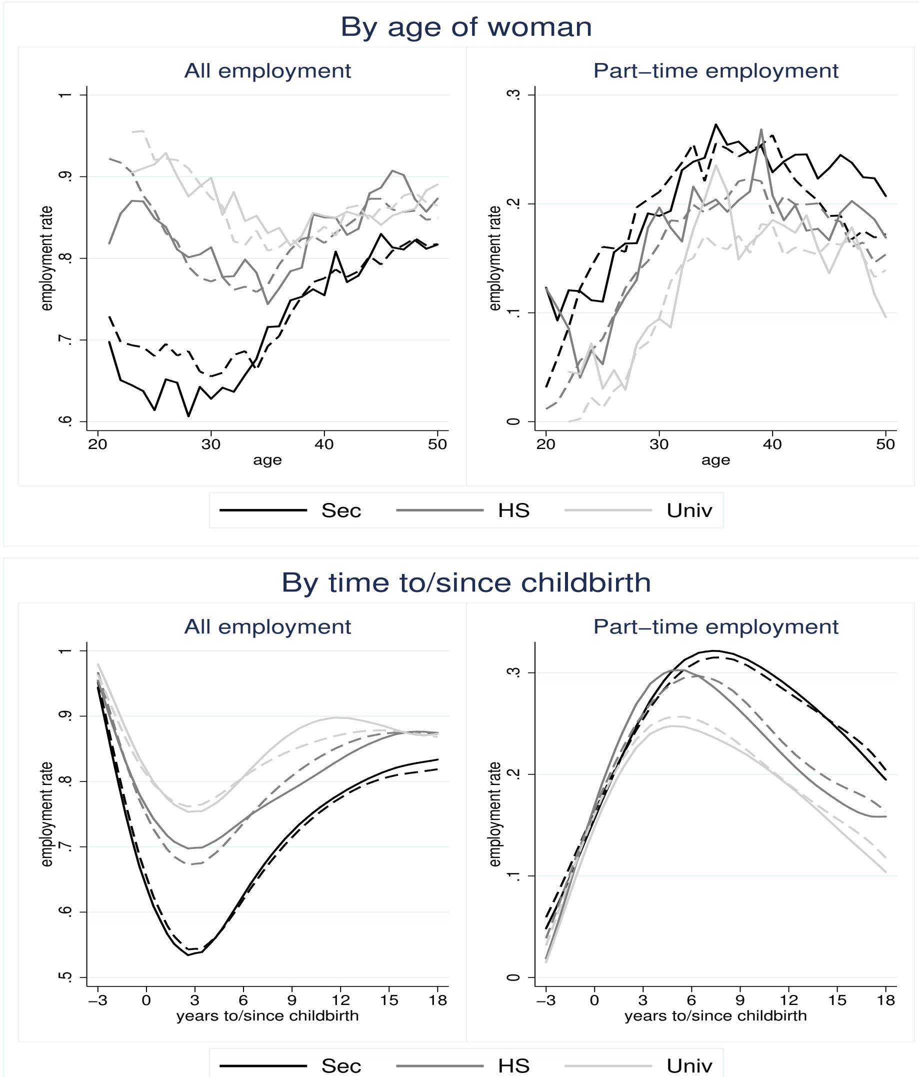
Notes: BHPS versus simulated data. 2008 prices. All curves smoothed using kernel weights and a bandwidth of 2 years.

Figure 7: Experience gap for women in part-time work from the age of 30; by education



Notes: All values in log wage units. Curves represent difference in accumulated experience between women taking part-time work from the age of 31 onwards as compared to taking full-time work over the same period, all conditional on full-time employment up to the age of 30.

Figure 8: Female employment rates over the life-cycle and by time to/since childbirth: data versus model



Notes: BHPS versus simulated data, in solid and dashed lines respectively. Lines by time to/since childbirth in the bottom panel are smoothed using kernel weights and a bandwidth of 2 years.

U-shaped, reflecting child rearing, and increase with education. In the lower panel we align these graphs with reference to the timing of births. The dip in employment caused by children is less pronounced for higher levels of education. The model fits these patterns remarkably well. A full set of model comparisons with the data moments used in estimation is presented in Appendix D.

In Table 12 we emulate the differences-in-differences estimator for the full set of reforms implemented between 1999 and 2002 and shown earlier. Given the nature of the exercise, where we are looking at immediate short-run effects, we do not allow education choices to respond and we treat the reform as a surprise. This estimator compares the employment of single mothers (the treatment group) to similar single women without children. The simulation in Table 12 produces an estimated difference-in-differences parameter of 5.6 percentage points (pp) increase in employment resulting from the reforms for the secondary education group. This compares to a difference-in-differences estimate from the data of 4.2pp. For high school graduates the simulation and the estimate are 4.9pp and 5.5pp respectively. All these differences are small and well within the margin of estimation error; similarly for the University group the effects are very small in both data and simulation.[43] Although, we used the reforms in estimation as a source of variations, we did not target the effect itself and the fact the results match is encouraging for the model.

Table 12: The impact of the reforms on the employment rates of lone mothers – model simulations versus DiD data estimates

		Secondary	High school	University
(1)	Estimates based on LFS data	4.2	5.5	-0.5
	St. Error	(1.1)	(1.5)	(1.6)
(2)	Model simulation	5.6	4.9	1.4

Notes: Row 1 displays the result from the difference-in-differences as in the top panel of Table 5. Row 2 shows the results of similar calculations on simulated data from the model.

7.2 Education choice

To validate the model predictions on education, we use the reduced-form specification of education choice and the implied effects of the change in expected lifetime income induced by the 1999-2002 reforms described in column (4) of Table 7 and compare them to the simulated effects of the same reform. Row 2 in Table 13 shows that the model predictions are close to the reduced form estimates. The impact is larger at the high school level as expected, but is also noticeable at the university level (albeit not significant in the data). The reform increases the generosity of benefits and increases the range of income that allow eligibility and, crucially, reduces income risk for low to medium income families. The model implies that this may impact education choices even at a high level for a small group of women.

[43] See Eissa and Liebman (1996) for similar differences-in-differences estimates of the US Earned Income Tax Credit in the US.

Table 13: The impact of the reforms on education attainment – model simulations versus data estimates

		High school	University
(1)	Estimates based on BHPS data	-0.0090	-0.0052
	St. Error	(0.0044)	(0.0046)
(2)	Model simulation	-.0069	-0.0049

Notes: Row 1 displays the data estimates of the average impact of the 1999-2002 reforms on education attainment, as in column 4 of Table 7. Row 2 shows model predictions of the impact of the same reform under revenue neutrality.

Finally, we simulate the effect of reducing University tuition by £1000. We find that University attendance increases by 1.9 percentage point. As a comparison Kane (2003) and Deming and Dynarski (2009) find that $1000 decrease in tuition in the US increases college attendance by 3-5 percentage points. Our effect is thus smaller, but comparable. The implication is that in the US the impact of welfare on educational attainment may perhaps be larger than what we find here for the UK.

7.3 Elasticities of labor supply

Table 14: Elasticities of labor supply

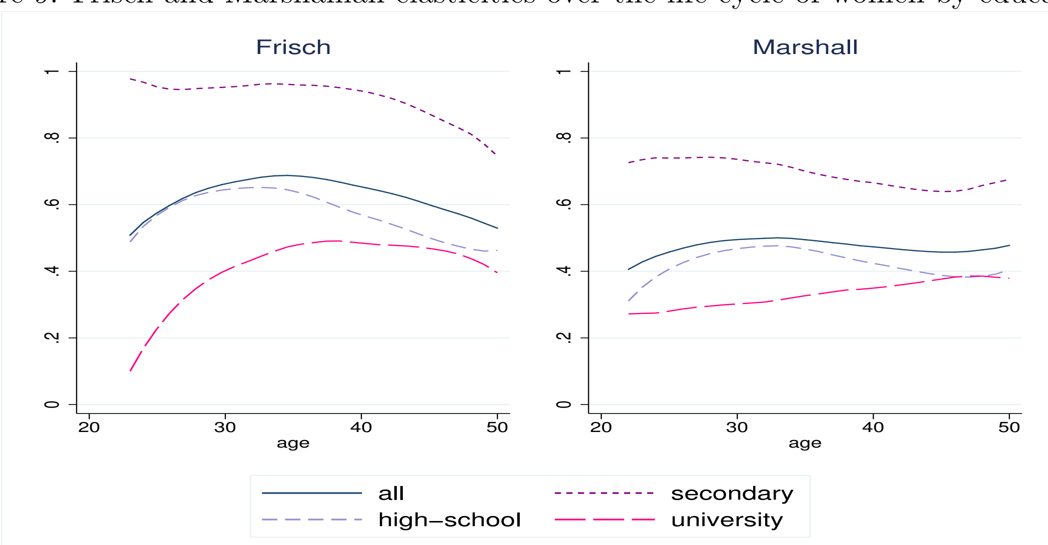
	Frisch			Marshall		
	extensive		intensive	extensive		intensive
	elasticity	derivative	elasticity	elasticity	derivative	elasticity
All women	0.627	0.510	0.240	0.475	0.386	0.210
			By education			
Secondary	0.914	0.675	0.327	0.689	0.509	0.280
High school	0.567	0.469	0.223	0.428	0.354	0.198
University	0.427	0.375	0.180	0.331	0.291	0.158
			By family composition			
Single women with no children	0.532	0.486	0.159	0.419	0.383	0.055
Lone mothers	2.240	1.275	0.452	1.362	0.775	0.378
Women in couples, no children	0.264	0.242	0.163	0.220	0.203	0.167
Women in couples with children	0.688	0.522	0.316	0.553	0.419	0.304

Notes: Calculations based on simulated data under the 1999 tax and benefits system. The derivatives in columns 2 and 5 measure the *percentage point change* in labor supply, in response to a 1% increase in net earnings. All effects are measured in the year the change in earnings occurs.

Simulated wage elasticities of labor supply are presented in Table 14. Marshallian elasticities are obtained by perturbing the entire profile of wages and comparing the outcome of the simulation across the original and the new profile keeping education choices fixed; as such they account for wealth effects. The Frisch elasticities are responses to an anticipated change in the wage at one age at a time and computing the effect at each age separately. Since the perturbation in the latter case is very small there are no wealth effects; together with the anticipated nature of the perturbation, this allows us to interpret the values in the first three columns of the Table as a marginal utility of wealth constant or Frisch elasticities.

Frisch elasticities differ from Marshallian elasticities due to wealth effects, although with experience dynamics there is no necessity for Frisch elasticities to be larger. We find that participation is more elastic than hours, a result that is common in the empirical literature.[44] Mothers are more responsive to changes in net wages than women with no children, another typical result in the empirical literature.[45] Finally, secondary educated women are also much more responsive to incentives, particularly on the intensive margin.

Figure 9: Frisch and Marshallian elasticities over the life-cycle of women by education



Notes: Based on simulated data using the 1999 tax and benefit system.

The elasticities also vary with age as illustrated for both the Frisch and the Marshallian elasticities in Figure 9. Their profile is strongly influenced by changes in family composition over the life-cycle, which counteract the downward pressure on labor elasticities created by higher returns to

[44] See the survey of participation and hours elasticities in Meghir and Phillips (2010)

[45] See Blundell, Meghir and Neves (1993), or Blundell, Duncan and Meghir (1998).

work at younger ages due to human capital accumulation (see Imai and Keane, 2004). They peak when family formation and childrearing are most important – which happens at an increasing age with education – and then fall gradually from then onwards. It is however notable that the elasticities are always low for college graduates, and the Marshallian elasticities (as well as the Frisch elasticities to a less extent) show the monotonically increasing pattern with age predicted in labour supply models with human capital accumulation. The income elasticities on the extensive margin are about -0.4 for all education groups and decline in absolute value with age to about -0.3, with minimal variation across education groups.

7.4 The role of savings

Savings are an important margin of response to welfare reform if individuals adjust assets to achieve the desired amount of self-insurance depending on the policy environment; this in turn will have an effect both on predicted behavior and on the estimated welfare effects of a reform. To show how behavioral responses can be distorted by ignoring assets, we re-estimated the model shutting down any borrowing or savings and forcing people to live off their current income (including any welfare payments).[46] When we do this, the loss of fit is particularly pronounced for the proportions moving in and out of work. One reason for this is that, in the absence of savings, employment becomes the only way to smooth consumption. This distorts the accumulation of experience and the model can no longer fit wage profiles as well as before, particularly for university graduates, for whom both savings and experience are more important. For them, the simulated profiles overestimate observed wage growth beyond age 40. For related reasons, the estimated Marshallian elasticities are higher when we shut down savings. Particularly pronounced differences are for the extensive margin Marshallian elasticities for single mothers and the intensive ones for single women with no children. These are the two groups who are missing husband's income, which can provide some diversification and smoothing of shocks. A comparison of Marshallian elasticities with and without savings is provided in appendix E.

[46] In particular, the model without savings does not include tuition fees or loans, and does not account for savings towards retirement.

Finally, some estimated models use a utility function that is linear in consumption, which makes savings irrelevant. The insurance component of welfare benefits will not be valued by the risk neutral individuals of these models. However, studies of consumption imply individuals are risk averse (see for example, Blundell, Browning and Meghir, 1994). Ignoring this aspect would give an incomplete picture of the role of welfare benefits and indeed taxes.

8 The Long Run Effects of Tax and Benefit Reforms

8.1 Tax Credits

We now turn to the longer run effects of tax credits and some aspects of their design in the UK. These are impacts that can only be reasonably evaluated by a structural model that accounts for the longer run effects of the dynamics, including changes in education choice and in the accumulation of experience.

The main motivation for tax credits was to provide income support to low income mothers, while preserving their labor market attachment and avoiding the erosion of their human capital during the child-baring period. So how effective are they in achieving their aims? In what follows, we discuss the simulated effects of two revenue neutral reforms allowing for responses on education, employment, hours and savings. First we compare outcomes under the 2002 system, with the tax credits are in place, to those that would occur had they been removed - we report the effect of having tax credits, funded by increasing the basic rate of tax. Then we consider the effects of assessing eligibility for the tax credits on personal rather than family income, thus integrating tax credits to the individual based UK tax system. In the tables, individuals are classified based on their pre-reform educational choice, to avoid composition effects in the comparisons.

Tax credits have a large positive effect on the employment of single mothers (Table 15, rows 1-3). The effects are stronger for part-time employment as expected from their design, but are also sizable even for full-time hours with the exception of University-educated mothers. On the other hand, mothers with a partner decrease their labor supply: tax credits are assessed at the family

Table 15: Effects of tax credits

		Pre-reform education choice					
		Secondary		High School		University	
		Impact on Employment: Mothers of Dependent Children (0-18)					
		Single	Married	Single	Married	Single	Married
(1)	All (pp)	20.4	-6.6	19.9	-3.6	8.5	-1.0
(2)	Full-time (pp)	09.3	-3.6	07.5	-2.4	-2.1	-1.1
(3)	Part-time (pp)	11.1	-3.0	12.3	-1.2	10.6	0.1
		Impact on Employment: Mothers of Adult Children (19+)					
(4)	All (pp)	0.4		0.3		0.0	
(5)	Full-time (pp)	0.4		-0.0		-0.2	
(6)	Part-time (pp)	-0.0		0.3		0.2	
		Impact on Education and Wages					
(7)	Education (pp)	0.84		-0.19		-0.65	
(8)	Wages: mothers of child aged 19+ (%)	-0.20		0.05		-0.29	
		Impact on Assets (%)					
(9)	no children	-3.3		-2.1		-1.5	
(10)	dependent child (0-18)	-7.2		-5.3		-2.6	
(11)	adult child (19+)	-2.3		-1.7		-1.3	
		Impact on Lifetime Disposable Income and Welfare					
(12)	Disposable Income (%)	-1.09		-0.25		-0.87	
(13)	Consumption equivalent (%)	2.49		0.89		-0.27	
(14)	Adjustment in the basic rate of Income Tax to fund reform: +0.9pp						

Reform is revenue neutral by adjusting the income tax rate. Education is allowed to adjust. Educational classification fixed at the pre-reform (no tax credits) choice. All effects are percentage points change (pp) or percent changes (%) as marked.

level and the family may receive the credit if the male partner is working; in such case, her earnings reduce the overall family entitlement; hence tax credits are a work *disincentive* for mothers with a partner. Finally, as expected we see a shift towards less educational attainment (row 7) since tax credits reduce the return to education.[47]

However the remarkable result in this table is that the employment of women with adult children, who are no longer entitled to benefits, remains unaffected by the introduction of the benefit (rows 4-6). It implies no long-run impact of tax credits on labor market attachment, beyond the time they are eligible to receive it. The reason for this important result is that their wages, as of when their children have grown, remain unchanged (row 8). To understand why, one must view the impact on labor market experience from a life-cycle perspective: most single mothers are so for a limited period, only in just over 50% of the cases for 5 years or more, and most children are born to married mothers (about 70% among low-medium skilled women, and just under 85% among

[47]See also Keane and Wolpin, 2000 on this issue.

University graduates). This implies that tax credits can have opposite effects on the same woman over her life-time: when in a couple the incentive is to work less, which reduces the experience capital; when a lone mother the incentive is to work more, but mainly part-time hours, which helps avoiding depreciation but does not build experience. The net effect is that on average wages remain the same by the time children have grown up.

The effects are heterogeneous. In Table 16 we focus on a small but important group: those who brought up their children as lone mothers exclusively. When eligible for tax credits they work more as per the above results. So when their child becomes an adult (19 years old) and they stop being eligible for tax credits the accumulated experience increases their wage by 5.8% for the lowest educated group, 3.3% for the high school group and not much for the university group, compared to if no tax credits were ever available. This should incentivize them to work after the termination of eligibility. However, tax-credits also have a wealth effect: when their youngest child reaches 19, secondary educated women who raised their children as lone-mothers have accumulated 37% more assets and high school graduates 9.5%. These are sizable effects on savings that counteract the effect of experience, leading to a *decrease* in the employment rate of this group. The overall effect on lifetime disposable income is positive – a combined effect of the transfer and the increased work effort during child-rearing years.

Table 16: Effects of tax credits on mothers of 19 year olds who have always been a lone-mother

	Secondary	High School	University
All employment when child is 19+ (pp)	-0.9	-1.0	0.0
Part-time employment when child is 19+ (pp)	0.0	0.9	0.0
Full-time employment when child is 19+ (pp)	-0.9	-1.9	0.0
Wages when child is 19 (%)	5.8	3.2	-0.2
Assets when child is 19 (%)	37.3	9.5	-0.4
Lifetime disposable income (%)	7.9	6.3	1.71

Education is allowed to adjust. Educational classification fixed at the pre-reform choice. All effects are percentage points change (pp) or percent changes (%) as marked.

The inability of tax credits to cause longer term attachment to the labor market for lower education groups – beyond the time where they are offered – is consistent with the results by Card and Hyslop (2005). They found that the Canadian Self-Sufficiency Program, which provided incentives for welfare mothers to work for a limited period, did not improve their employment after the program ended and did little to increase their wages.

Finally, tax credits lead to a decrease in savings in response to the increase in publicly provided insurance (Table 15, rows 9-11). Despite the decrease in disposable income and an increase in the basic tax rate of 0.9pp to fund the program (Table 15, rows 12 and 14), the overall welfare gain following from this *revenue neutral* reform is equivalent to a 0.82% increase in consumption overall. This shows the effects of increased insurance. From the table we see that most of this gain is concentrated among the lowest education group, for whom disposable income also decreases the most on average. [48]

The opposing incentive effects produced by the UK tax credit system, depending on whether a woman is married or not raises the question as to whether they should better be assessed based on individual income, integrated with the regular individualized income tax system, or as they are now, i.e. assessed on family income. Such a reform is potentially expensive because many women married to well-payed partners will become entitled to the benefit, but it improves the incentive structure and preserves the principle of individual taxation. We consider this reform, funded by increasing the basic tax rate, and contrast it to the 2002 system where tax credits are assessed at the family level.

The results are presented in Table 17. This reform increases the employment of married mothers because her earnings no longer reduce family entitlement; indeed she has to work to obtain the credit. However, in the new long run steady state single mothers work *less*. As before, this response can only be understood in a dynamic context. The increased employment when married reduces the human capital depreciation. However, tax credits in the UK are also effectively a tax on full-time work, which declines substantially compared to baseline for the same group of

[48] The values of consumption compensation is the solution to the equation:

$$EV_0 = E\sum_t \beta^{a-\underline{A}} \frac{((1-r)c_{1a}/n_{1a})^{\mu}}{\mu} \exp\{U(l_{1a}, X_{1a}) + \theta(l_{1a})\}$$

where the index 0/1 stands for the pre/post-reform solutions and the value function is evaluated at different stages in life for different rows. The equation can be solved for r, yielding:

$$r = 1 - \left(\frac{EV_0}{EV_1}\right)^{\frac{1}{\mu}}.$$

Table 17: Effects of assessing tax credits at the individual level - integrated with the 2002 tax and benefit system

		Pre-reform education choice					
		Secondary		High School		University	
		Impact on Employment: Mothers of Dependent Children (0-18)					
		Single	Married	Single	Married	Single	Married
(1)	All (pp)	-3.7	29.6	-4.3	21.6	-4.6	15.0
(2)	Full-time (pp)	-6.3	-16.2	-7.3	-19.2	-9.8	-18.0
(3)	Part-time (pp)	2.6	45.8	3.0	40.7	5.2	33.1
		Impact on Employment: Mothers of Adult Children (19+)					
(4)	All (pp)	-2.8		-2.8		-3.7	
(5)	Full-time (pp)	-8.7		-6.6		-7.3	
(6)	Part-time (pp)	4.1		2.9		1.4	
		Impact on Education and Wages					
(7)	Education (pp)	1.97		-0.82		1.15	
(8)	Wages for mothers of child aged 19+ (%)	-3.7		-5.7		-5.9	
		Impact on Assets (%)					
(9)	no children	-12.4		-11.5		-11.4	
(10)	dependent child (0-18)	21.3		8.3		-2.8	
(11)	adult child (19+)	6.8		0.0		-6.4	
		Impact on Lifetime Disposable Income and Welfare					
(12)	Disposable Income (%)	0.93		-3.43		-7.6	
(13)	Consumption equivalent (%)	0.64		-2.43		-1.0	
(14)	Adjustment in the basic rate of Income Tax to fund reform: +8.5pp						

Reform is revenue neutral by adjusting the income tax rate. Education is allowed to adjust. Educational classification fixed at the pre-reform choice. All effects are percentage points change (pp) or percent changes (%) as marked.

mothers (row 2, Table 17). Because of the part-time penalty on wages this leads to a counteracting reduction in human capital accumulation, on average. Thus, the net effect is a decline in wages by 1.3% at the point when some become single mothers.[49] The increased benefits while married also increases saving, so that when women become lone mothers their assets are up by 18% relative to baseline.[50] In addition, the tax rate has increased substantially to fund this reform (row 14, table 17). The combined effects of the resulting lower net wages and increased savings produces the decline in employment for single mothers. By the time they are no longer eligible for benefits because their children are grown, their wages have declined substantially (see row 8, Table 17), taxes are higher and assets for the lowest education group remain 6.8% higher than at baseline; as a result they continue having lower employment relative to the case of family assessed benefits,

[49] The effect on wages is larger for university graduates (-2.4%) than for secondary and high-school educated women (-0.2% and -1.7%, respectively). This is because the former have higher returns to experience.

[50] The corresponding effects on assets by education are +30%, +16% and +6% for secondary, high-school and university graduates, respectively.

given the current design.

The reform also discourages education and leads to a decline in post-compulsory schooling of nearly 2 percentage points. Overall, lifetime disposable income declines for all but the lowest education group driven also by the large increase in taxation required to fund this new system. The end result from individualising tax credits is an overall decline in welfare equivalent to 8.3% of consumption, with only the lowest education group being better off, in part because of redistribution but also from increased insurance. Thus ignoring family income when defining eligibility for benefits can be very costly and lead to unintended effects on incentives in the longer run.

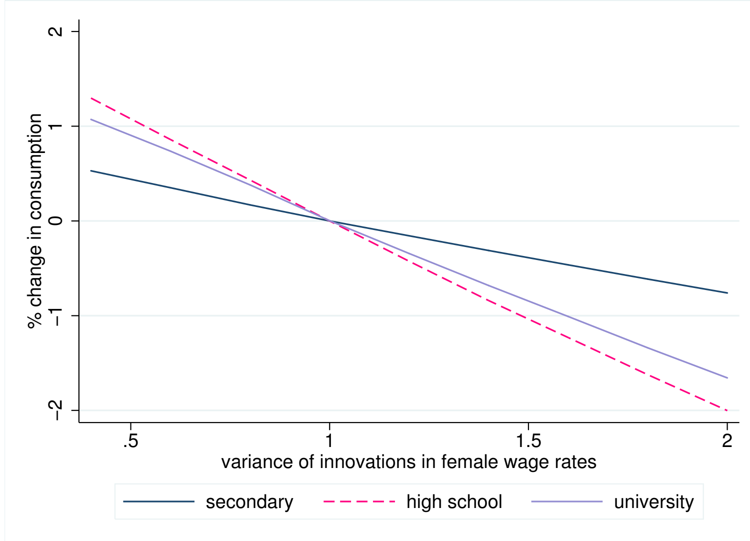
8.2 Comparing alternative policies

Broadly speaking the model we have developed here can be the basis for an optimal design of taxes and benefits in a dynamic economy with education choice as analyzed for example by Stantcheva (2015). While this is an ambitious and interesting exercise it is beyond the scope of this paper. Here we consider how local departures from the existing system are likely to affect welfare. The result will depend on the interplay between work incentives and preferences for insurance and income. To illustrate the extent of insurance implicit in the current system, which is the point of departure, we show in Figure 10 the amount of life-cycle consumption that an individual is willing to give up (positive or negative) to keep the status quo, as a function of changes in the variance of wages. Women with the lowest level of education are the least sensitive to changes in risk, which reflects the relatively high level of insurance already offered to those at the lower end of the pay distribution. The other two groups seem less well insured and they value declines in risk much more and to a similar extent.

We now consider the welfare implications of expanding tax credits further, as opposed to increasing the income support program or cutting taxes. To do this we implement changes to each on the 2002 tax and benefit system, all costing 0.5% of baseline pre-tax earnings.

We allow for responses in education, labour supply and savings. The clear winner among the programs are tax credits, where on average individuals are willing to pay 1.09% of consumption

Figure 10: Willingness to pay in consumption terms: value of risk by education



Notes: Based on simulated data under the 2002 tax and benefit system. The vertical axis is the percentage of consumption one is willing to give up to move from the actual variance (marked as 1) to a proportionate change as per the horizontal axis. Consumption compensation calculated at start of working life, after education.

Table 18: Impacts of an exogenous increase in public spending distributed through alternative routes

		Basic tax rate			Tax credits award			Income support award		
		Effects by pre-reform education choice								
		Sec	HS	Univ	Sec	HS	Univ	Sec	HS	Univ
(1)	Lifetime gross earnings	0.19	0.13	0.10	-0.21	-0.33	-0.56	-1.28	-1.25	-0.88
(2)	Lifetime disposable income	0.68	0.77	0.88	0.84	0.36	-0.24	-0.15	-0.48	-0.54
(3)	Welfare (post-education)	0.48	0.63	0.45	1.38	0.78	0.77	0.72	0.32	0.30
		Overall effects on welfare								
(4)	Pre-education	0.80			1.09			0.51		

Notes: % changes. Educational classification is based on pre-reform choices. Welfare, measured in % consumption change to which it is equivalent. The values measure the impact of exogenously increasing public spending by 0.5% of total gross earnings and distributing it through a drop in the basic tax rate of 0.95 percentage points, an increase in the tax credits maximum award of £22.2 per week and an increase in the IS award of £10.0 per week. All comparisons are against the 2002 tax and benefits system.

for the additional benefit (row 4). The second preferred alternative is a tax cut with a willingness to pay of 0.80% of consumption. This is despite the fact that both gross and disposable incomes are higher following a tax cut and can be partly attributed to the better targeted insurance of tax credits (rows 1 and 2). Tax cuts is also the only policy that improves the incentives to invest in education, but the effect is small with the share of university graduates increasing by 0.1 percentage points. The least preferred program is income support, with a willingness to pay of 0.51%: while it offers good insurance at the bottom, it is associated with a large decline in gross and disposable income. Thus, in all cases the distortionary nature of income support, with its 100% marginal tax rate, makes it the least preferable program despite its basic insurance property (it provides a strong income floor).

All education groups prefer the tax credits changes (row 3). This is true even for university graduates, who lose 0.2% of their disposable income under tax credits due to a shift towards lower education (row 2). The second best option for both university and high-school educated women in tax cuts. But secondary educated women prefer an increase in income support to tax cuts as their generally lower earnings make them less likely to benefit from a lower tax rate.

9 Conclusions

Tax and welfare policies that affect employment decisions may change individual careers by affecting the accumulation of human capital, including education decisions, as well as savings. Evaluating such policies requires us to take these features into account, ultimately informing the design of policies that are welfare improving.

In this paper we use reforms to the tax and welfare system and the way they impact different demographic groups to establish that they cause changes in both labor supply and educational decisions. We then develop a dynamic life-cycle model of women's labor supply, human capital formation (including both education choice and work experience) and savings. We estimate this model on a long household panel from the UK and we use numerous tax and welfare reforms as a source of exogenous variation. We pay particular attention to the detailed modeling of the tax and welfare system and the way it was reformed.

Using the model we estimate Frisch and Marshallian labor supply elasticities, both at the extensive and the intensive margin (part-time versus full-time) and we show how they vary over the life-cycle and by household structure. Elasticities are generally high, but below one, except for single mothers with pre-school children, where they exceed one, underlying the strong responses of this group to work incentives.

We then use the model to evaluate the overall impact of the UK tax credits implemented under the 1999-2002 WFTC reform. A key substantive result is that tax credits, while inducing many low education mothers into work, do not affect their wages and employment in the long term, beyond the time they receive the subsidy. In part this is because their design encourages part-time work, which we demonstrate has low value in terms of human capital accumulation. It is also due to the low return to experience that we find for lower education women. Tax credits also discourage educational attainment. However, they are the preferred way of providing some insurance because the moral hazard element is low due to the built in work incentive. This is to be contrasted with income support, with an associated 100% marginal tax rate, which has a strong moral hazard effect and is thus less effective in improving overall welfare.

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Web Appendix A: Data

Estimation is based on all 18 yearly waves of the British Household Panel Survey (BHPS), covering the period from 1991 to 2008. Apart from those who are lost through attrition, all families in the original 1991 sample and subsequent booster samples remain in the panel from then onwards. Other individuals have been added to the sample in subsequent periods – sometimes temporarily – as they formed families with original interviewees or were born to them. All members of the household aged 16 and above are interviewed.

We select the sample of women in all types of family arrangement observed while aged 19 to 50. Our full dataset is an unbalanced panel of 3,901 women observed for some varying period during the years 1991 to 2008. Almost 60% of these women were observed for at least 5 years and just over 20% were observed for at least 10 years; 25% are observed entering working life from education and for 18% parental earnings when the respondent was aged 16-17 is observed. A great deal of information is collected for them, including family demographics, employment, working hours and earnings as well as those of a present partner, women's demographics such as age and education, demand for childcare and its cost. Moreover, historical data provides information on the characteristics of their parental home when they were aged 16, including whether lived with parents, parent's education, employment status, number of siblings and sibling order, books at home.

Some definitional and data preparation procedures should be mentioned for clarity. *Employment* is determined by present labor-market status and excludes self-employment. The paths of women who report being self-employed are deleted from that moment onwards. Only women working 5 or more hours per week are classified as employed. We consider employment choices from the age of 19 for women with secondary and high school education, and from the age of 22 for women with university education.

Working hours refer to the usual hours in main job including overtime. We discretised labour supply using a three-point distribution: not working (0 to 4 hours per week, modelled as 0 hours), working part-time (5 to 20 hours per week, modelled as 18 hours) and working full-time (21 hours or more per week, modelled as 38 hours). The employment status and working hours observed at one point in the year are assumed to remain unaltered over the entire year.

Earnings are the usual gross weekly earnings in the main job. *(Hourly) wage rates* are the ratio of weekly earnings to weekly hours capped at 70. The wage distribution is trimmed at percentiles 2 and 99 from below and above, respectively, and only for women working at or above 5 hours per week to reduce the severity of measurement error in wage rates.

Wage rates are de-trended using the aggregate wage index (for both men and women of all education levels), and all other monetary parameters in the model, including all monetary values in the annual sequence of tax and benefit systems, were deflated using the same index. To construct this index, we run 3 regressions, one for each education level, of trimmed wages on time dummies and dummies of Scotland and Wales. We create 3 education specific wage indices from the coefficients in time. Then we aggregate these indices using the distribution of education for the entire population of workers aged 25-59 in the sample. This is the wage index we use. Any real monetary values (using the CPI) are then re-scaled using this index.

Family type includes four groups: single women and couples without children, lone mothers and couples with children. Women are assumed to have children only after finishing education, once entering the labor market. Cumulated *work experience* is measured in years. *Individual assets* at the beginning of adult life are the total of savings and investments net of debts. They are truncated at zero, never allowed to be negative. *Education* is classified in 3 categories: secondary or compulsory (completed by the age of 16), high school or equivalent (corresponding to A-levels or equivalent qualifications) and university (3-year degrees and above).

Web Appendix B: Parameters estimated outside the structural model

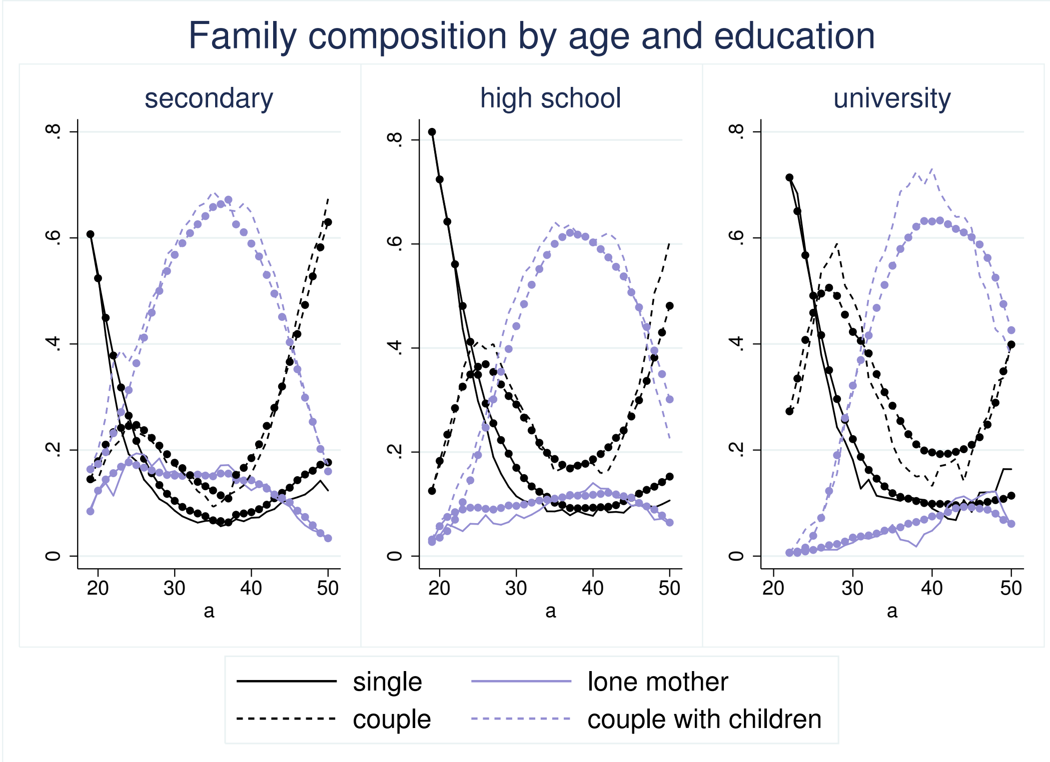
Externally set parameters

Two parameters are chosen from pre-existing estimates: the coefficient, μ, set to -0.56, giving a risk aversion coefficient of 1.56 (consistent with evidence in Blundell, Browning and Meghir, 1994, and Attanasio and Weber, 1995). This choice implies that the utility is always negative, and so the higher is the argument in the exponential - U in equation (1) - the lower is overall utility. Hence, positive and larger values of the parameters in U make working less attractive. The discount factor, β, is set to 0.98, a typical value in the literature (see e.g. Attanasio, Low and Sanchez-Marcos, 2008). Moreover, the risk-free interest rate is set to 0.015, which is slightly lower than the discount rate thus implying that agents have some degree of impatience. Tuition costs of university education amount to £3,000 (uprated to 2008 prices) for the three-year program and the credit limit for university students (and graduates throughout their life) is £5,000 (also uprated to 2008 prices), both reflecting the university education policy of the late 1990s in the UK. For everyone else, credit is constrained.

Family transitions

Family transition probabilities were estimated using linear probability regressions, weighted to ensure an equal number of women at each age.

Figure 11: Family demographics by female age – data and simulations



Notes: Distribution of family types by age of woman. Data in solid lines, simulations in dashed lines.

The probability of a partner arriving is estimated by regressing a dummy for partner arrival on a fourth order polynomial in female age among single women aged 55 or less. This is done separately for each of the nine combinations of female and partner education level. Arrival probabilities in the first period of working life are taken directly from the data, and are set to zero after 55. The probability of a partner leaving is also described by a fourth order polynomial in female age, estimated on all women aged 20–69. This is done separately by spouses' education and presence of children.

The probability of a child arriving is estimated by regressing a dummy for child arrival on a second order polynomial in female age and, for families with children, a second order polynomial in age of next youngest child and a linear interaction with female age. This is done separately for each female education level and by couple status. The probability of a child arriving is set to zero from when the woman reaches 43 onwards.

Figure 11 shows the distribution of family composition by female age and education for both observed data and model simulations. The displayed simulated profiles are reasonably close to the observed data ones. They show that secondary educated women are more likely to become mothers early on and to experienced lone-motherhood than high school and university graduates.

Male employment and earnings

Table 19 reports the estimates for male working status and earnings by his education. This is relevant only for women in couples as we do not seek to solve the men's problem. However, the partner's employment and income changes the family budget constraint and the work incentives of women in couples.

Rows 1 to 3 display estimates from a probit regression and show that the employment probability generally increases with education and is very persistent (row 3). Estimates for the log wage equation suggest only mild differences in wage rates by education (row 4) but strong differences in wage progression, with more educated men experiencing steeper wage profiles over time (row 5). We set the autocorrelation coefficient in the male productivity process to 0.99, close to a unit root. Having tried several alternative exclusion restrictions within a Heckman (1979) selection model of male employment and earnings, we found no evidence of statistically significant selection. Hence, we assume that the residuals in the employment and wage equations are uncorrelated.

Table 19: Exogenous parameters: married men employment and wage rates by education

		Man's education		
		secondary	further	higher
Employment probabilities				
(1)	new couples	0.74	0.87	0.83
		(0.02)	(0.02)	(0.03)
(2)	ongoing couples: intercept	0.05	0.37	0.58
		(0.02)	(0.02)	(0.04)
(3)	ongoing couples: previously employed	1.52	1.40	1.28
		(0.03)	(0.03)	(0.06)
Log wage equation				
(4)	log wage rates	1.94	2.07	2.05
		(0.07)	(0.08)	(0.15)
(5)	log woman's age minus 18	0.09	0.18	0.35
		(0.04)	(0.03)	(0.07)
(6)	St. Deviation of innovation to productivity	0.37	0.36	0.39
	(new couples)	(0.12)	(0.13)	(0.18)
(7)	St. Deviation of innovation to productivity	0.12	0.10	0.10
	(ongoing couples)	(0.04)	(0.03)	(0.5)

Notes: Standard errors in parenthesis below the estimate. Sample sizes are: 665 observations for new couples, 31,946 observations for all couples and 16,318 for continuously employed men.

Families with positive childcare costs pay £2.60 (standard error 0.04) per working hour. Childcare is required for every hour when all adults in the household are working if the child is 5 or younger, and is only necessary for older children under the age of 10 if all adults work full-time.

Web Appendix C: Computational details on the solution and estimation of the model

The estimation and simulation exercises require the solution of the female life-cycle model. Since there is no analytical solution to the problem, we approximate numerically the policy functions for labour supply, consumption and education choices conditionally on the woman's information at each period of her life (the state variables, described by X at the start of section 4.2). We do this by backward recursion, starting from the end of life (age 70).

A key feature of our model is that it models the joint consumption and labour supply decisions over the working years of women, where the former is a continuous choice while the latter is discrete. The numerical solution of problems with simultaneous discrete and continuous choices is considerably harder than that of problems with only continuous or only discrete choices, explaining the limited existing work on such models. Some studies (e.g. French and Jones, 2011; Adda, Dustmann and Stevens, 2015) have opted for discretising the space of the continuous choice. More recently, solution methods to handle discrete and continuous choices have been proposed by Fella, 2014, and Iskhakov et al., 2015. Our solution method is close but not identical to the methods advanced by these two papers, and hence we describe it here.

The main difficulty in solving dynamic problems that combine discrete and continuous choices is that the smoothness and concavity of the value function that is typical of continuous problems – and that ensures the existence and uniqueness of a solution that is itself continuous and, if interior, is the root of the optimality condition (Euler equation) – does not hold in a problem with a discrete choice variable. The addition of a discrete choice makes the value function piecewise concave, with kinks falling at the points where the agent is indifferent between any two possible alternatives along the discrete choice domain; these then translate into discontinuities in the optimal choice of the continuous variable (consumption or savings).

Kinks created by present choices at time t – what Iskhakov et al. (2015) call *primary kinks* – do not pose difficulties. They can be dealt with by conditioning the continuous choice on the discrete choice in a first step, followed by the choice of the alternative with highest value in the second step. This is computationally more demanding than the purely continuous problem because the root of the Euler equation must be calculated for each point in the domain of the discrete choice, but the solution method is a trivial extension of that for a purely continuous problem.

However, kinks propagate backwards through the (expected) continuation values - the *secondary kinks*. These are caused by indifference points in future choices, from $t + 1$ onwards, and hence cannot be easily conditioned on. The further back one moves, the more kinks there will be. Furthermore, associated with secondary kinks are discontinuities in future choices, which need to be accounted for in the Euler equation as they affect the marginal utility of the continuous choice variable at both time t and $t+1$. This implies that the Euler equation is no longer a sufficient optimality condition, even after conditioning on the discrete choice at time t.

As noticed by Iskhakov et al. (2015) and others before them (e.g. Gomes et al., 2001), kinks can be eliminated and the expected continuation value can be 'concavified' by uncertainty. This is the approach we explore given the rich characterisation of uncertainty we account for in the model.

In our problem, the kinks in the value function occur at the level of assets where the woman is indifferent between working full-time / part-time / not working, or at points in assets that lead optimally to indifference points in the future (all conditional on her present state). To see why, consider the value function for a given woman at working-life age t facing state X_t. Her value function is

$$V_t(X_t) \quad = \quad \max_{l_t \in \mathcal{L}(X_t)} \{V_t(X_t \mid l_t = O),\ V_t(X_t \mid l_t = P),\ V_t(X_t \mid l_t = F)\} \tag{14}$$

where

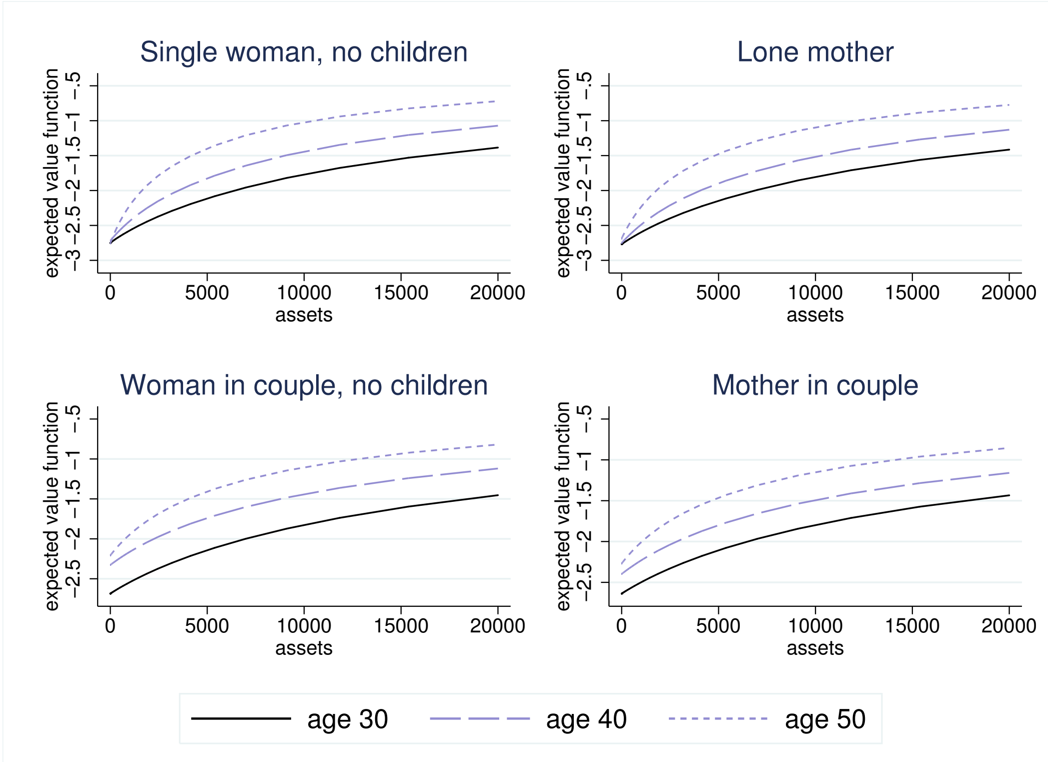
$$V_t(X_t \mid l_t = l) \quad = \quad \max_{c_t \in \mathcal{C}(X_t, l)} \{u(c_t, l; X_t) + \beta \mathrm{E}\left[V_{t+1}(X_{t+1}) \mid X_t, l\right]\} \tag{15}$$

$\mathcal{L}(X)$ represents the feasibility space for labour supply l given X and $\mathcal{C}(X,l)$ is the feasibility space for consumption c given (X,l). In the above expression, the expectation in the continuation value is taken with respect to the transition probability in a subset of variables in X: the woman's productivity shock (υ), the arrival of a new child (t^k changing to zero), the formation or dissolution of a marriage (m), the education of a new spouse $(\tilde{s})$, and the employment and productivity of a present spouse $(\tilde{l}, \tilde{\upsilon})$.

We are concerned with kinks in $\mathrm{E}V_{t+1}$. Clearly, for as long as the transition function for $\left(\upsilon, t^k, m, \tilde{s}, \tilde{l}, \tilde{\upsilon}\right)$ is non-degenerate and the kinks at $t+1$ vary with these variables, their presence will dilute the kinks in EV_{t+1}. Whether it is sufficient to 'concavify' the expected value function is a practical question. Using a fine grid of 50 points in assets, we inspect the concavity of our numerical approximation of the expected value function. This is a finer grid than we use to solve and estimate the model; it is used here with the purpose of finding non-concavities that could have been missed with a coarser grid. Figure 12 shows some examples of the profile of the expected value functions for different age groups. We have exhaustively inspected the value function at other points in the state space based both on the finer grid in assets used here and the coarser grid used for estimation and simulation. We found no evidence at the estimated parameterisation, that the expected value function is not globally concave.

Given a set of parameters and the solution of the female problem at time $t+1$, the critical step in the solution at time t is to calculate the optimal level of consumption (or, equivalently, next period assets) at each possible realization of the labor supply choice (l). This amounts to solving

Figure 12: Expected value functions; by age, family demographics and assets



Notes: Lines are numerical approximations of the value functions at selected age and family demographics by assets. Plots are for women of type I in utility cost of work, low background factors 1 and 2, with compulsory education only and at their average productivity level, the age of the youngest child is 10 for mothers, and the spouses of women in couples have completed compulsory education only and are working at their average productivity.

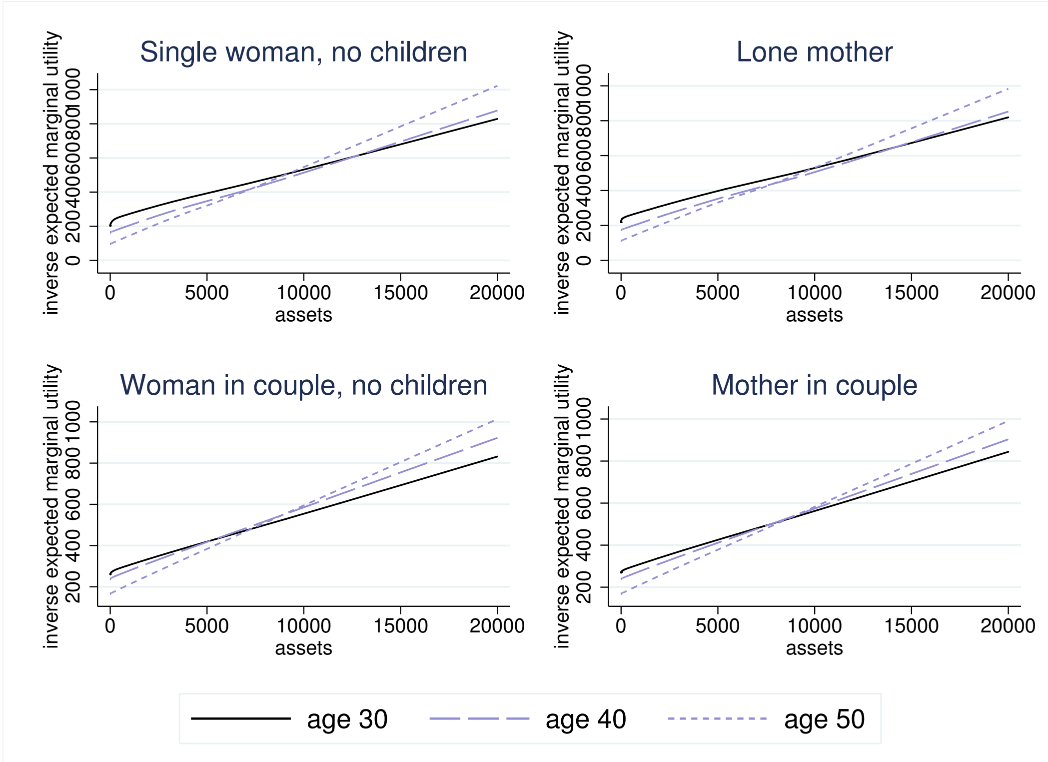
for the root of the Euler equation

$$\begin{aligned} c_t\left(X_t; l_t\right) &= \left(u_l'\right)^{-1}\left(\beta R \mathrm{E}\left[u'\left(c_{t+1}(X_{t+1})\right) \mid X_t, l_t\right]\right) \\ &= \left(u_l'\right)^{-1}\left(\beta R \sum_{l_{t+1}=O,P,F} P\left(l_{t+1} \mid X_t, l_t\right) \mathrm{E}\left[u'\left(c_{t+1}(X_{t+1})\right) \mid X_t, c_t, l_t\right]\right) \end{aligned} \tag{16}$$

where the $(u_l')^{-1}$ is the analytical inverse of the utility function with respect to consumption conditional on labour supply l, and is evaluated at the expected marginal utility of consumption at $t+1$, a function of the state variables at $t+1$. The expectations are conditional on information and choices at t.

A couple of comments are due at this stage. *First*, for a standard dynamic problem with continuous choice and a twice continuously differentiable and concave utility function, the policy function is monotonic in assets and there is a single solution to the above equation. This can be quickly located by searching for the point in consumption at which the difference between rhs and lhs of equation (16) changes sign. Fella (2014) shows that the monotonicity result extends to dynamic

Figure 13: Inverse marginal utility applied to the expected marginal utility function; by age, family demographics and assets



Notes: Lines are numerical approximations of the functions at selected age and family demographics by assets. Plots are for women of type I in utility cost of work, low background factors 1 and 2, with compulsory education only and at their average productivity level, the age of the youngest child is 10 for mothers, and the spouses of women in couples have completed compulsory education only and are working at their average productivity.

problems with discrete and continuous choice away from kinks since the value function is concave between any two consecutive kinks. Hence, there is at most a single interior solution within each concave section of the value function, which needs to be calculated so the global optimum can be determined. While Figure 12 above shows that, in our problem and for the estimated set of parameters, the expected value function is globally concave – ensuring that condition (16) is sufficient for an interior optimum – we do check for multiple roots during estimation since global concavity may not hold over the entire parameter space.

Second, although our solution approach to the approximation of the optimal consumption function is in the spirit of Carroll's Endogenous Grid Point method (Carroll, 2006), we do not follow his strategy of endogenously selecting a grid for assets at time t by solving equation (16) backwards having set a grid for assets at $t+1$. Instead, we follow the traditional approach of selecting a fixed grid in assets at time t and solve for the optimal consumption (or assets at $t+1$). This is facilitated by the observation that the rhs of (16) is nearly linear in assets at $t+1$ (or consumption at t) over most of its space. This is shown in Figure 13. We therefore use linear interpolation to solve the Euler equation on a grid of assets that is finer towards the lower bound of its domain, where the problem is more non-linear.

The following algorithm describes the solution procedure at time t, given the expected value and marginal utility functions at time $t+1$. For convenience, we split the state variables in two sets, depending on whether their realisation is known or not from the view point of the previous period, conditional on choice. So $X_t = (\Omega_t, \omega_t)$ where $\Omega = (\theta, x_1, x_2, s, a_t, e_t)$ is known by the woman at $t-1$ conditional on choice, and $\omega = \left(\upsilon_t, k_t, t_t^k, m_t, \tilde{s}_t, \tilde{l}_t, \tilde{\upsilon}\right)$ is uncertain. The goal is to compute the expected value function (EV_t) and the expected marginal utility function evaluated at the optimal choices (Eu'_t), where expectations are taken at $t-1$. Ω_t is known at $t-1$ conditional on the choices at that time but ω_t is not and needs to be integrated out. Hence, EV_t and Eu'_t are functions of (Ω_t, ω_{t-1}).

Inputs These include:

1. Numerical approximations of the expected value function and the expected marginal utility of consumption evaluated at the optimal choices at $t+1$. These are functions of (Ω_{t+1}, ω_t): $\mathrm{E}V_{t+1}(\Omega_{t+1}, \omega_t)$ and $\mathrm{E}u'_{t+1}(\Omega_{t+1}, \omega_t)$.
2. Grids for all pre-determined continuous variables at t: assets, experience (a_t, e_t).[51] The support of the discrete state variables (including the woman's family background, education, and preferences for working, whether children are present and the age of the youngest, whether she faces childcare costs as a mother of a young child, the presence of a partner his education and employment status) is fully represented in the solution.
3. Grids for the random productivity shocks for the woman and present partner at time t, $(\upsilon_t, \tilde{\upsilon}_t)$.[52] The grid points in the productivity shocks are the mid points (median) of the equal probability adjacent intervals of their entire support and hence the quadrature weights are constant.

Step 1 Approximate the policy function for consumption conditional on labour supply.

For each grid point of female characteristics (family background (x_1, x_2), preference type θ, education s, working experience e and productivity level υ), family demographics (children k, age of youngest child t^k, partner m) and the characteristics of a present partner (education $\tilde{s}$, employment status $\tilde{l}$ and productivity $\tilde{\upsilon}$):

1. Compute total family resources after taxes and benefits, call it I_t;
2. Compute next period experience, e_{t+1};
3. Interpolate $\mathrm{E}u'_{t+1}(\Omega_{t+1}, \omega_t)$ at e_{t+1};

[51] We use a grid of 6 points in each of the variables (a, e). The grid points in assets and experience are more concentrated towards the bottom of the domain of each variable, where the problem is more non-linear.

[52] We use a grid of 6 points in $\tilde{\upsilon}$ and of 12 points in υ to ensure that the domain of uncertainty in female wages, a key determinant of labor supply, is well covered.

4. Compute $c_t(X_t; l_t)$ that solves equation (16) by linear interpolation of $(u_l')^{-1}\left(\mathrm{E}u_{t+1}'(\Omega_{t+1}, \omega_t)\right)$ at $a_{t+1} = I_t - c_t(X_t; l_t)$;
5. Calculate $V_t(X_t; l_t = l)$ as in equation (15) by interpolating $\mathrm{E}V_{t+1}(\Omega_{t+1}, \omega_t)$ at $a_{t+1} = I_t - c_t(X_t; l_t)$.

Step 2 Compute the unconditional optimum:

1. Compute optimal labour supply by selecting the value of l that maximises $V_t(X_t; l)$;
2. Store the value function $V_t(X_t)$ and the marginal utility of consumption evaluated at the optimal choice, $u'(X_t)$.

Step 3 Calculate the expected value and marginal utility functions at time t as functions of (Ω_t, ω_{t-1}):

1. For each point in the grid of $(\upsilon_{t-1}, \tilde{\upsilon}_{t-1})$: integrate $V_t(X_t)$ and $u'(X_t)$ over the distribution of productivity shocks $(\upsilon_t, \tilde{\upsilon}_t)$ conditional on $(\upsilon_{t-1}, \tilde{\upsilon}_{t-1})$;
2. For each possible family type and spouse's employment status at $t-1$: integrate the resulting functions over the family transition rule and the employment probability of a present spouse.

Outputs Period t expected functions $\mathrm{E}V_t(\Omega_t, \omega_{t-1})$ and $\mathrm{E}u_t'(\Omega_t, \omega_{t-1})$.

Simulations are based on initial conditions for family background and parental income observed in the data, together with random draws of the entire profile of unobserved shocks. Given this information, individual optimal choices are calculated starting from the beginning of active life, age 17, and moving forward. As for the solution, the optimum is computed at each age in two steps, first by solving the Euler equation to calculate optimal savings at each labor supply point, then by selecting the labor supply that achieves maximum total utility. In doing so, however, the problem must now be evaluated outside the grid chosen for solution. In practice, this means that the continuation functions need to be interpolated over up to four dimensions: future assets and experience as before, along with present productivity shocks (for both spouses if women are married). We do this by linear interpolation.

The estimation procedure is implemented in two steps. The first step estimates all the exogenous parts of the model, including the dynamics of family formation (marriage, divorce, fertility, male labor supply and earnings, and the cost of childcare). In addition, two parameters are exogenously set: the coefficient of risk aversion and the discount rate.

The second step implements an iterative procedure to estimate the preferences and wages of women within the structural model. In each iteration, we start by solving the female life-cycle problem for a particular set of the estimating parameters, given the economic environment and the exogenously set parameters. We then simulate 5 replications of the life-cycle choices of 3,901 women observed in the data, conditional on observed family background and parental income. The same sequences of lifetime shocks are used in all iterations of the estimation procedure to avoid changes in the criterion function due to changes in the random draws. For each woman, we select an observation window such that the overall simulated sample exactly reproduces the time and age structure of the observed data. The simulations assume women face up to four policy regimes over the observation window, representing the main tax and benefits systems operating during the 1991-2008 period. We used the 1995, 1999, 2002 and 2004 regimes and assumed they operate over the periods prior to 1996, 1997 to 1999, 2000 to 2002 and 2003 onwards, respectively. Women into their active life over the entire period will experience all of these regimes at different stages of their lives. Younger and older women, who either enter or leave active life within our observation window, will experience only some of these policy regimes during the life period that we are modelling. We assume that women expect the tax and benefit system they face in each period to be permanent, so all reforms arrive unexpectedly. Finally, we calculate the simulated moments using the simulated dataset and the objective function. We use 248 moments to estimate 89 parameters.

The parameters are selected to minimise the distance between sample and simulated moments, where the weighting matrix is the inverse variance-covariance matrix of the data moments as described in equation (13) in the main text. The procedure described above calculates the value of the criterion function in each iteration of the optimization routine. Given the discrete choice of labor supply, our criterion may not be a smooth function of the model parameters everywhere in their domain (McFadden, 1989). We therefore use an optimisation routine that does not rely on derivatives. Specifically, we choose to use the Bound Optimization By Quadratic Approximation, which generates, in each iteration, a quadratic approximation of the criterion function that matches the criterion in a set of interpolation points (see Powell, 2009; implementation by Nag).

Web Appendix D: Model fit

Tables 20 to 30 display the full list of data moments used in estimation, together with their simulated counterparts and the normalized (by the data standard error) differences between the two. The estimation procedure was based on 248 moments, including education distribution and regressions (tables 20 and 21), employment rates (table 22), transition rates into and out of work (tables 23 and 24), coefficients from log wage regressions, percentiles of the distribution of log wages and year-to-year changes in wage rates by past working hours, age and years of work (tables 25 to 29), and the probability of positive childcare costs (table 30). All moments are education-specific. Among the 254 simulated moments, 44 fall outside the 95% confidence interval for the respective data moment, but many amongst these are very similar to their BHPS counterparts.

Table 20: Educational distribution

Moment	Data	Simulated	SE data	No. SE diff
	Secondary education			
all	0.248	0.251	0.020	0.108
low background factor 1	0.411	0.411	0.046	0.000
high background factor 1	0.196	0.199	0.021	0.140
low background factor 2	0.284	0.295	0.029	0.382
high background factor 2	0.206	0.197	0.027	0.316
	High School			
all	0.481	0.482	0.023	0.038
low background factor 1	0.473	0.459	0.047	0.303
high background factor 1	0.484	0.490	0.027	0.217
low background factor 2	0.524	0.523	0.032	0.025
high background factor 2	0.431	0.433	0.034	0.083
	University			
all	0.270	0.267	0.021	0.147
low background factor 1	0.116	0.130	0.031	0.463
high background factor 1	0.320	0.311	0.025	0.352
low background factor 2	0.192	0.182	0.025	0.409
high background factor 2	0.364	0.369	0.033	0.174

Table 21: Education regressions

Moment	Data	Simulated	SE data	No. SE diff
	High School			
constant	0.476	0.473	0.034	0.072
cohort 82+	-0.013	-0.012	0.055	0.034
background factor 1	0.009	0.012	0.020	0.140
background factor 2	-0.042	-0.038	0.016	0.236
cohort 82+ x factor 1	-0.010	-0.008	0.031	0.059
cohort 82+ x factor 2	-0.005	-0.017	0.026	0.426
log parental income	-0.010	-0.021	0.051	0.222
	University			
constant	0.192	0.198	0.021	0.263
cohort 82+	0.018	-0.014	0.037	0.884
background factor 1	0.076	0.077	0.012	0.087
background factor 2	0.067	0.071	0.012	0.305
cohort 82+ x factor 1	0.004	-0.001	0.024	0.222
cohort 82+ x factor 2	-0.038	0.012	0.022	2.200
log parental income	0.118	0.119	0.048	0.021

Table 22: Employment by education

Moment	secondary				high school				university			
	Data	Sim	SE data	SE diff	Data	Sim	SE data	SE diff	Data	Sim	SE data	SE diff
	All employment											
all	0.721	0.705	0.011	1.475	0.825	0.817	0.011	0.782	0.870	0.863	0.014	0.456
single women, no child	0.914	0.885	0.012	2.515	0.911	0.938	0.012	2.247	0.939	0.950	0.011	1.037
married women, no child	0.885	0.887	0.013	0.179	0.950	0.937	0.008	1.600	0.948	0.942	0.010	0.552
lone mothers	0.452	0.432	0.031	0.654	0.672	0.650	0.046	0.473	0.858	0.761	0.056	1.729
married mothers	0.639	0.637	0.016	0.122	0.722	0.717	0.018	0.283	0.770	0.764	0.029	0.197
partner working	0.759	0.751	0.012	0.710	0.823	0.825	0.013	0.203	0.848	0.854	0.019	0.322
youngest child 0-2	0.415	0.403	0.020	0.590	0.595	0.560	0.026	1.375	0.701	0.680	0.034	0.598
youngest child 3-5	0.525	0.534	0.022	0.422	0.709	0.676	0.025	1.282	0.735	0.764	0.041	0.706
youngest child 6-10	0.708	0.690	0.020	0.899	0.774	0.792	0.024	0.718	0.862	0.833	0.031	0.930
youngest child 11+	0.805	0.781	0.019	1.292	0.854	0.869	0.024	0.612	0.895	0.865	0.039	0.758
family bkg: factor 1	0.746	0.736	0.017	0.615	0.819	0.829	0.014	0.716	0.870	0.875	0.015	0.323
family bkg: factor 2	0.713	0.721	0.017	0.477	0.824	0.820	0.015	0.235	0.867	0.861	0.020	0.311
before-after (1999) difference	0.028	0.018	0.010	0.960	0.014	0.017	0.008	0.368	0.025	0.005	0.012	1.632
	Part-time employment											
all	0.207	0.199	0.009	0.906	0.159	0.158	0.010	0.112	0.123	0.122	0.012	0.071
single women, no child	0.055	0.046	0.011	0.857	0.053	0.033	0.009	2.335	0.040	0.033	0.012	0.518
married women, no child	0.125	0.117	0.013	0.660	0.059	0.053	0.010	0.541	0.034	0.039	0.008	0.612
lone mothers	0.181	0.177	0.023	0.193	0.167	0.159	0.032	0.229	0.097	0.088	0.037	0.250
married mothers	0.298	0.287	0.013	0.870	0.279	0.282	0.017	0.160	0.243	0.240	0.025	0.107
partner working	0.248	0.236	0.011	1.093	0.190	0.197	0.012	0.508	0.148	0.155	0.016	0.414
youngest child 0-2	0.219	0.220	0.015	0.096	0.256	0.257	0.020	0.064	0.241	0.243	0.028	0.059
youngest child 3-5	0.301	0.284	0.020	0.864	0.317	0.292	0.026	0.927	0.256	0.254	0.036	0.044
youngest child 6-10	0.332	0.329	0.020	0.168	0.284	0.307	0.025	0.914	0.235	0.226	0.041	0.215
youngest child 11+	0.273	0.231	0.022	1.898	0.192	0.183	0.027	0.332	0.170	0.156	0.044	0.330
family bkg: factor 1	0.170	0.173	0.013	0.216	0.152	0.143	0.012	0.793	0.127	0.114	0.014	0.937
family bkg: factor 2	0.203	0.195	0.013	0.592	0.172	0.146	0.014	1.913	0.112	0.117	0.015	0.358
before-after (1999) difference	-0.020	-0.003	0.009	2.024	-0.013	0.001	0.008	1.646	0.001	-0.002	0.011	0.236

Table 23: Transition rates from out of work into work

Moment	Data	Simulated	SE data	No. SE diff
		Secondary education		
all	0.180	0.210	0.009	3.194
women with no children	0.272	0.321	0.036	1.339
lone mothers	0.114	0.133	0.016	1.223
married mothers	0.183	0.209	0.011	2.226
		High school		
all	0.255	0.236	0.016	1.132
women with no children	0.503	0.333	0.050	3.409
lone mothers	0.186	0.189	0.037	0.084
married mothers	0.210	0.224	0.017	0.814
		University		
all	0.276	0.221	0.031	1.771
women with no children	0.585	0.326	0.059	4.381
lone mothers	0.294	0.167	0.082	1.545
married mothers	0.188	0.191	0.029	0.120

Table 24: Mean transition rates from employment to out of work

Moment	Data	Simulated	SE data	No. SE diff
		Secondary education		
all	0.064	0.071	0.004	1.914
women with no children	0.032	0.042	0.004	2.552
lone mothers	0.146	0.164	0.019	0.920
married mothers	0.085	0.085	0.006	0.137
past wage in bottom decile ($w_{t-1} < Q10$)	0.111	0.121	0.011	0.903
$w_{t-1} < Q50$	0.072	0.083	0.005	2.205
$w_{t-1} < Q90$	0.063	0.072	0.004	2.420
		High school		
all	0.056	0.052	0.004	1.027
women with no children	0.030	0.025	0.004	1.538
lone mothers	0.092	0.103	0.019	0.574
married mothers	0.086	0.078	0.008	0.999
$w_{t-1} < Q10$	0.135	0.111	0.018	1.397
$w_{t-1} < Q50$	0.079	0.074	0.007	0.730
$w_{t-1} < Q90$	0.056	0.055	0.004	0.089
		University		
all	0.040	0.035	0.005	0.995
women with no children	0.026	0.020	0.005	1.202
lone mothers	0.037	0.072	0.022	1.598
married mothers	0.061	0.056	0.009	0.500
$w_{t-1} < Q10$	0.077	0.114	0.036	1.004
$w_{t-1} < Q50$	0.079	0.071	0.014	0.590
$w_{t-1} < Q90$	0.044	0.043	0.006	0.213

Table 25: Log wages ($\ln w$) at entrance in working life

Moment	Data	Simulated	SE data	No. SE diff
		Secondary education		
mean	1.806	1.764	0.019	2.153
variance	0.072	0.077	0.007	0.694
mean: high factor 1	1.840	1.764	0.023	3.298
mean: high factor 2	1.823	1.767	0.033	1.733
wage: bottom quartile ($w_t < Q25$))	0.249	0.271	0.031	0.715
$w_t < Q50$	0.503	0.585	0.037	2.237
$w_t < Q75$	0.751	0.782	0.031	1.008
		High school		
mean	1.825	1.862	0.018	2.023
variance	0.094	0.110	0.007	2.401
mean: high factor 1	1.825	1.875	0.022	2.321
mean: high factor 2	1.816	1.889	0.030	2.410
wage: bottom quartile ($w_t < Q25$))	0.250	0.213	0.025	1.480
$w_t < Q50$	0.500	0.456	0.029	1.506
$w_t < Q75$	0.750	0.704	0.026	1.783
		University		
mean	2.095	2.068	0.025	1.039
variance	0.118	0.128	0.011	0.884
mean: high factor 1	2.088	2.059	0.027	1.091
mean: high factor 2	2.121	2.049	0.034	2.123
wage: bottom quartile ($w_t < Q25$))	0.247	0.290	0.032	1.351
$w_t < Q50$	0.500	0.492	0.038	0.226
$w_t < Q75$	0.753	0.775	0.032	0.685

Notes: Statistics in this table are for 19 to 22 years old women in the two lowest education levels, or 22 to 25 years old university graduates.

Table 26: Log wage ($\ln w$) regressions on cumulated experience and lagged wages

Moment	Data	Simulated	SE data	No. SE diff
		Secondary education		
constant	0.433	0.444	0.039	0.290
family bkg: factor 1	0.029	0.029	0.007	0.116
family bkg: factor 2	-0.006	0.001	0.007	1.067
$\ln w_{t-1}$	0.745	0.742	0.015	0.186
log cumulated working years	0.073	0.145	0.073	0.986
lagged log cumulated working years	-0.040	-0.117	0.064	1.212
Variance of residuals	0.050	0.053	0.002	1.294
1st order autocorrelation of residuals	-0.010	-0.010	0.001	0.389
		High school		
constant	0.374	0.345	0.032	0.907
family bkg: factor 1	0.010	0.011	0.007	0.155
family bkg: factor 2	0.002	0.008	0.006	0.946
$\ln w$	0.799	0.810	0.011	1.006
log cumulated working years	0.188	0.191	0.059	0.062
lagged log cumulated working years	-0.151	-0.162	0.050	0.225
Variance of residuals	0.050	0.053	0.002	1.401
1st order autocorrelation of residuals	-0.010	-0.010	0.001	0.570
		University		
constant	0.606	0.565	0.056	0.736
family bkg: factor 1	-0.009	0.006	0.011	1.429
family bkg: factor 2	0.001	-0.006	0.009	0.722
$\ln w_{t-1}$	0.760	0.754	0.020	0.340
log cumulated working years	0.088	0.185	0.066	1.461
lagged log cumulated working years	-0.069	-0.156	0.056	1.561
Variance of residuals	0.043	0.046	0.002	1.162
1st order autocorrelation of residuals	-0.007	-0.008	0.001	0.914

Table 27: Log wage ($\ln w$) regressions on age

Moment	Data	Simulated	SE data	No. SE diff
		Secondary education		
constant	1.819	1.818	0.035	0.038
family bkg: factor 1	0.090	0.079	0.019	0.597
family bkg: factor 2	-0.020	0.003	0.019	1.204
age	0.051	0.049	0.008	0.249
		High school		
constant	1.721	1.834	0.042	2.694
family bkg: factor 1	0.052	0.043	0.023	0.366
family bkg: factor 2	0.016	0.026	0.021	0.497
age	0.149	0.110	0.011	3.669
		University		
constant	2.078	2.072	0.074	0.079
family bkg: factor 1	-0.022	0.009	0.036	0.881
family bkg: factor 2	-0.010	-0.034	0.028	0.859
age	0.145	0.144	0.017	0.036

Table 28: Distribution of log wages during working life

	Secondary				High school				University			
Moment	Data	Sim	SE data	SE diff	Data	Sim	SE data	SE diff	Data	Sim	SE data	SE diff
Full-time workers												
Mean	2.084	2.065	0.011	1.757	2.298	2.280	0.011	1.666	2.555	2.575	0.014	1.433
wage: bottom dec ($w_t < Q10$)	0.100	0.125	0.006	4.460	0.100	0.111	0.006	1.886	0.100	0.088	0.009	1.310
$w_t < Q25$	0.250	0.254	0.010	0.340	0.250	0.274	0.011	2.312	0.250	0.239	0.014	0.816
$w_t < Q50$	0.500	0.508	0.014	0.600	0.500	0.524	0.013	1.840	0.500	0.490	0.018	0.570
$w_t < Q75$	0.750	0.760	0.013	0.736	0.750	0.766	0.012	1.322	0.750	0.747	0.015	0.232
$w_t < Q90$	0.900	0.910	0.009	1.085	0.900	0.899	0.008	0.187	0.900	0.881	0.010	2.018
Part-time workers												
Mean	1.902	1.905	0.011	0.341	2.089	2.104	0.020	0.796	2.474	2.408	0.038	1.726
$y_t < Q10$	0.100	0.113	0.007	1.954	0.100	0.062	0.010	3.879	0.099	0.028	0.019	3.684
$w_t < Q25$	0.250	0.229	0.012	1.774	0.250	0.177	0.017	4.348	0.250	0.224	0.033	0.801
$w_t < Q50$	0.500	0.408	0.016	5.873	0.500	0.435	0.023	2.862	0.500	0.656	0.039	4.021
$w_t < Q75$	0.750	0.719	0.014	2.184	0.750	0.764	0.020	0.667	0.750	0.890	0.035	3.957
$w_t < Q90$	0.900	0.934	0.010	3.496	0.900	0.954	0.013	4.047	0.901	0.973	0.025	2.865

Table 29: Other moments in log wages

Moment	Data	Simulated	SE data	No. SE diff
Mean earnings by family background				
Secondary education, high factor 1	2.073	2.069	0.014	0.261
Secondary education, high factor 2	2.020	2.018	0.013	0.152
High school, high factor 1	2.251	2.247	0.014	0.315
High school, high factor 2	2.278	2.272	0.015	0.373
University, high factor 1	2.525	2.539	0.015	0.910
University, high factor 2	2.530	2.543	0.018	0.748
Coefficients from regression of log wages on log experience, 1st differences				
Secondary education	0.111	0.166	0.021	2.602
High school	0.197	0.226	0.016	1.810
University	0.230	0.267	0.021	1.743
Mean yearly change in log wages if working full-time at $t-1$				
Secondary education	0.024	0.016	0.002	3.603
High school	0.036	0.022	0.002	5.725
University	0.040	0.028	0.003	3.869
Mean yearly change in log wages if working part-time time at $t-1$				
Secondary education	-0.003	0.012	0.005	3.042
High school	-0.011	0.013	0.006	3.767
University	0.011	0.014	0.011	0.255
Mean yearly change in log wages if not working at $t-1$				
Secondary education	0.001	-0.002	0.010	0.349
High school	-0.003	-0.002	0.012	0.047
University	-0.019	0.001	0.023	0.908

Notes: Experience in the second panel from top is number of years worked in the past.

Table 30: Positive childcare costs costs among working mothers of children 10 or younger

Moment	Data	Simulated	SE data	No. SE diff
Secondary education	0.250	0.325	0.014	5.262
High school	0.396	0.403	0.017	0.355
University	0.631	0.462	0.025	6.760

Web Appendix E: Marshallian elasticities in models with and without savings

In Table 31 we show the Marshallian elasticities obtained when the model excludes all savings (except student loans) and compares them to those obtained by the main model, which allows people to save. The model is re-estimated by imposing the constraint that consumption is equal to income in each period.

Table 31: Marshallian elasticities of labor supply - model with and without savings

	Model with savings		Model without savings	
	extensive	intensive	extensive	intensive
All women	.475	.210	.587	.254
		By family composition		
Single women with no children	.419	.055	.304	.199
Lone mothers	1.362	.378	2.315	.374
Women in couples, no children	.220	.167	.266	.200
Women in couples with children	.553	.304	.641	.309

Web Appendix F: Tax and benefit reforms

Here we provide a brief description of the UK tax and transfer system.[53] We focus on reforms between four systems – April 1995, April 1999, April 2002 and April 2004 – that represent four different regimes in terms of the generosity and structure of taxes and transfers. These systems are the ones we use in estimation.

Table 32 sets out the most important tax rates and thresholds for the two main personal taxes on earnings: income tax and National Insurance. Both are individual-based and operate through a system of tax-free allowances and income bands that are subject to different rates of tax.

Table 32: Tax rates and thresholds under different tax and transfer systems

	April 1995	April 1999	April 2002	April 2004
Income tax				
Personal allowance	95.45	105.87	105.97	103.09
Allowance for couples	6.99	4.81	0.00	0.00
Starting rate	20%	10%	10%	10%
Starting rate limit	86.65	36.63	44.09	43.89
Basic rate	25%	23%	22%	22%
Basic rate limit	657.99	683.83	686.6	682.21
Higher rate	40%	40%	40%	40%
National insurance				
Lower earnings limit/primary threshold	81.67	83.82	106.27	102.81
Entry fee	2%	0%	0%	0%
Main rate	10%	10%	10%	11%
Upper earnings limit	619.54	634.99	698.54	689.17
Rate above upper earnings limit	0%	0%	0%	1%

Notes: Amounts expressed in weekly terms and uprated to January 2008 prices using RPI. Allowance for couples is the married couple allowance and additional personal allowance.

Between April 1995 and April 1999, the main income tax and National Insurance reforms were as follows. For income tax, the personal allowance and basic rate limit rose in real terms by 11% and 4% respectively. The starting rate was cut from 20% to 10% but the starting rate limit reduced substantially (58%). Also, the basic rate was cut from 25% to 23%. For National Insurance, the 2% ‘entry fee’ (cliff edge) payable as soon as earnings exceeded the lower earnings limit was abolished.

Between April 1999 and April 2002, the basic rate of income tax was further reduced from 23% to 22% and the additional allowance for couples was abolished. In addition, in National Insurance, the lower earnings limit/primary threshold and upper earnings limit rose by 27% and 10% respectively.

Between April 2002 and April 2004, the income tax personal allowance and National Insurance

[53] For a more comprehensive discussion of UK taxes and transfers, see Browne and Roantree (2012) and Browne and Hood (2012).

primary threshold both declined by 3% in real terms. Also, in National Insurance, the main rate and the rate above upper earnings limit both rose by 1%.

The system of transfers in the UK is more complex. Most transfers are strongly contingent on family circumstances and are means-tested at the family level. The main transfer programs for working-age individuals in existence at some point across the four systems of interest are as follows. Child Benefit is a universal (non-means-tested) benefit available for families with children. Income Support (together with Income-Based Jobseeker's Allowance) is an out-of-work means-tested benefit that tops net family income up to a specified level based on family needs. Children's Tax Credit is a tax rebate available to families with children. (It actually part of the tax system but is included here because of the way it was reformed, discussed below). Family Credit and Working Families' Tax Credit are means-tested benefits for working families with children. They are structurally very similar to each other. Working Tax Credit is a means-tested benefit for working families that is more generous for families with children but also available to childless families. Child Tax Credit is a means-tested benefit for families with children that is not contingent on working. Working Tax Credit and Child Tax Credit are subject to a joint taper. Finally, Housing Benefit and Council Tax Benefits are means-tested benefits that help low-income families meet, respectively, rent payments and council tax bills.

Table 33 sets out maximum entitlements and taper rates for transfers that were reformed across our four systems of interest. It considers six example low-wage family types to demonstrate who were the main gainers and losers from each reform. Housing Benefit and Council Tax Benefit are not included because changes to these transfer programs were relatively minor.

Between April 1995 and April 1999, the main change was the abolition of the lone parent rate of Child Benefit, affecting lone parents. There were also some modest increases in generosity in Family Credit across all low-wage families with children.

Between April 1999 and April 2002, Family Credit was replaced by the considerably more generous Working Families' Tax Credit, affecting working families with children. The increase in generosity was particularly large for families with childcare costs. For example, maximum entitlement for a lone parent with one child aged 4 and no childcare costs grew by 21% compared with 93% for the same lone parent but with childcare costs of £98.80 (38 hours at pounds 2.60 per hour). This is because Family Credit included a childcare income disregard whereas Working Families' Tax Credit had a childcare element that contributed to the maximum award.

Between April 2002 and April 2004, Child Tax Credit replaced Children's Tax Credit and child elements of other benefits including in Working Families' Tax Credit. This also coincided with a modest increase in generosity. In addition, Working Tax Credit replaced Working Families' Tax Credit and extended entitlement to families without children.

Differences in eligibility and interactions across transfer programs make it hard to use Table 33

Table 33: Maximum entitlements and taper rates for example families for selected benefits and tax credits under different tax and transfer systems

	April 1995	April 1999	April 2002	April 2004
Childless single				
Child benefit	0.00	0.00	0.00	0.00
Income support	65.47	65.28	64.42	62.87
Children's tax credit	–	–	0.00	–
Tax credits	0.00	0.00	0.00	48.02
Lone parent with one child aged 4 and no childcare costs				
Child benefit	23.51	18.29	18.81	18.64
Income support	109.69	108.58	122.04	62.87
Children's tax credit	–	–	12.15	–
Tax credits	93.64	96.52	117.14	162.84
Lone parent with one child aged 4 and with childcare costs				
Child benefit	23.51	18.29	18.81	18.64
Income support	109.69	108.58	122.04	62.87
Children's tax credit	–	–	12.15	–
Tax credits	93.64	96.52	186.30	232.00
Childless couple				
Child benefit	0.00	0.00	0.00	0.00
Income support	0.00	0.00	0.00	0.00
Children's tax credit	–	–	0.00	–
Tax credits	0.00	0.00	0.00	115.69
Couple parents with one child aged 4 and no childcare costs				
Child benefit	14.64	18.29	18.81	18.64
Income support	0.00	0.00	0.00	0.00
Children's tax credit	–	–	12.15	–
Tax credits	93.64	96.52	117.14	162.84
Couple parents with one child aged 4 and with childcare costs				
Child benefit	14.64	18.29	18.81	18.64
Income support	0.00	0.00	0.00	0.00
Children's tax credit	–	–	12.15	–
Tax credits	93.64	96.52	186.30	232.00
Taper rates (all family types)				
Income support	100%	100%	100%	100%
Children's tax credit	–	–	6.67%	–
Tax credits	70%	70%	55%	37%

Notes: Amounts expressed in weekly terms and uprated to January 2008 prices using RPI. Amounts ignore disability-related supplements and transition rules. Note that it doesn't make sense to sum across maximum entitlements for all benefits and tax credits because some cannot be received together. April 1995 child benefit amount includes one parent benefit (later combined with child benefit). Income support calculated assuming adults are aged 25+. Child-related components of income support became part of tax credits in April 2004 system. Couples are not entitled to income support because the partner is assumed to be working full-time. The children's tax credit is an income tax rebate so is only received if income tax is paid. It became part of tax credits in the April 2004 system. Tax credits include family credit, working families' tax credit, working tax credit and child tax credit. Tax credit maximum amounts calculated assuming entitlement to full-time premium and, where relevant, childcare support for 38 hours per week at 2.60 per hour. Tax credit maximum amount in April 1995 includes full-time premium that was introduced in July 1995. The way childcare was treated for tax credits changed between the April 1999 and April 2002 systems so the maximum tax credit awards are not directly comparable before and after these dates. Tax credits under the April 2004 system additionally incorporate child-related support previously delivered through income support and the children's tax credit. The 37% tax credit taper rate in April 2004 is roughly equivalent to the 55% taper rate in April 2002 because the former operates against gross income and the latter against net income. Also note that under the April 2004 system there was a second taper of 6.67%.

to deduce the size of the overall gain or loss across years. Therefore, Table 34 sets out the net family income for the same six low-wage family types across the four tax and transfer systems. In each case, results are shown for three different hours of work: zero, part-time (18 hours per week) and full-time (38 hours per week). In each case, the wage is assumed to be equal to the April 2004 minimum wage, uprated for inflation. In cases involving childcare costs, childcare is assumed to be required to cover every hour of work at a rate of £2.60 per hour. A partner, if present, is assumed to work 40 hours per week, also at the April 2004 minimum wage.

Table 34: Net income for example families under different tax and transfer systems

Hours of work	April 1995	April 1999	April 2002	April 2004
Childless single				
0 (not working)	65.47	65.28	64.42	62.87
18 (part-time)	85.62	86.92	87.29	86.91
38 (full-time)	148.16	152.51	154.01	167.15
Lone parent with one child aged 4 and no childcare costs				
0 (not working)	109.69	108.58	122.04	128.66
18 (part-time)	184.32	181.28	201.22	213.83
38 (full-time)	227.14	223.61	263.65	266.51
Lone parent with one child aged 4 and with childcare costs				
0 (not working)	109.69	108.58	122.04	128.66
18 (part-time)	191.96	190.64	236.78	249.39
38 (full-time)	267.80	275.35	332.81	337.14
Childless couple				
0 (not working)	162.49	165.87	164.62	202.47
18 (part-time)	246.60	250.08	246.90	255.17
38 (full-time)	318.01	326.27	325.99	319.20
Couple parents with one child aged 4 and no childcare costs				
0 (not working)	219.49	226.55	263.60	268.25
18 (part-time)	261.24	268.36	302.41	320.96
38 (full-time)	332.65	344.55	356.95	360.52
Couple parents with one child aged 4 and with childcare costs				
0 (not working)	219.49	226.55	263.60	268.25
18 (part-time)	276.39	283.58	335.17	353.72
38 (full-time)	332.65	344.55	407.16	429.68

Notes: Amounts expressed in weekly terms and uprated to January 2008 prices using RPI. Amounts ignore disability-related supplements and transition rules. Calculated assuming a wage equal to the April 2004 minimum wage uprated in line with RPI. A partner, if present, is assumed to work 40 hours per week at the April 2004 minimum wage. Childcare costs calculated as £2.60 per hour for the number of hours worked listed in the table.

Childless singles and childless couples were largely unaffected by the reforms, except for the changes between April 2002 and April 2004. Childless singles working full time and childless couples with one working partner saw substantial increases in generosity (9% and 23% respectively). This was due to the Working Tax Credit reforms, which extended entitlement to families without children.

Lone parents with no childcare costs saw the largest gains between April 1999 and April 2002, particularly if they worked full time. This is a consequence of the Working Families Tax Credit reform. There were smaller gains across all hours of work between April 2002 and April 2004, due to the Working Tax Credit and Child Tax Credit reforms. Lone parents with childcare costs were affected in much the same way, though many of the gains were larger. There was also an increase in generosity for full-time work between April 1995 and April 1999.

Turning to couple parents, the patterns are similar: the biggest gains were felt between April 1999 and April 2002, coinciding with the Working Families' Tax Credit reform. There were also gains between April 1995 and April 1999 particularly for full-time workers and between April 2002 and April 2004 for part- and full-time workers.