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Exploring the Importance of Incentive Responses for Policy Projections
APPENDIX

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A MODEL PARAMETERISATION

This appendix provides an overview of the model parameterisation, which is designed to complement the analytical description of the model provided in Section 2.2 of the main text. For an extended description of how the model parameters have been set, please see van de Ven (2017).

In common with the existing dynamic programming literature, a two stage procedure was used to identify parameters that match LINDA to survey data. The first stage identified a subset of parameters exogenously from the model structure, using methods that have changed little since the advent in the 1960s. Most of the parameters identified in the first stage are directly observable, and were evaluated from publicly available data sources. Given the model parameters evaluated in the first stage, remaining model parameters were adjusted in a second stage so that selected 'simulated moments' implied by the structural model matched to 'sample moments' estimated from survey data. Conceptually, the second stage of the procedure involves adjusting unobserved model parameters to ensure that observable endogenous characteristics implied by the assumed theoretical framework best reflect a selected set of moments estimated from survey data.

This appendix begins by describing evaluation of the parameters identified exogenously from the model structure, before discussing the endogenously defined parameters.

A.1 Simulated transfer policy

The policy structure implemented for parameterising the model broadly reflects the UK policy context as it applied in April 2011. This policy environment was used to project the population cross-section forward from 2011 to 2016. From 2016, the policy environment assumed for the base simulation reflects

reforms introduced as part of the 2015 Budget Statement. This section describes the 2011 policy environment; details of how reforms introduced by the 2015 Budget Statement were captured are available from the author upon request.

A.1.1 Income taxes

Income taxes are calculated separately for each simulated adult. The 'taxable income' of an adult is evaluated by aggregating their income from employment, retirement pensions, and investment returns on assets held outside of pensions, and deducting their respective personal allowance. In contrast to practice, this definition of taxable income omits Jobseekers Allowance, a stylisation that is likely to have a negligible bearing on simulations as individual employment circumstances are assumed to be stable within each year (so that individuals in receipt of Jobseekers Allowance do not typically pay income tax).

The personal allowance for individuals under state pension age is set equal to £7475 per year in 2011, and is withdrawn by 50p for each £1 of income in excess of £100,000 per year. The personal allowance for individuals in excess of state pension age is set equal to £10,015 per year, and is withdrawn in stages, at the rate of 50p for each £1 of private income between £24,000 and £29,080 per year, and then again at the rate of 50p for each £1 of private income in excess of £100,000 per year.

Income taxes are paid at the rate of 20% on taxable income up to the basic rate limit of £35,000 per year, at the rate of 40% on income between £35,001 and the higher rate limit of £150,000, and at the additional rate of 50% on all taxable income in excess of £150,000 per year. All thresholds and personal allowances are assumed to grow in line with wages.

A.1.2 National insurance contributions

Class 1 (employee) National Insurance contributions are calculated on the earnings of each adult under state pension age. Contributions are paid at the rate of 12% on earnings in excess of the Primary Threshold (worth £139 per week in 2011) and under the Upper Earnings Limit (£817 per week), and at the rate of 2% on earnings in excess of the Upper Earnings Limit. All thresholds are assumed to grow in line with wages.

A.1.3 Taxes on consumption

Simulating taxes on consumption for the UK is complicated by the different rates of Value Added Tax and excise duties that are payable on different goods and services, which contrasts with the aggregate measure of non-durable consumption projected by LINDA. To accommodate this variation, a series of reduced-form regressions were estimated that describe the fraction of total non-durable expenditure on each of six consumption categories: goods liable to the full rate of VAT, goods liable to the reduced

rate of VAT, alcohol, tobacco, fuel, and insurance premia distinguishing those liable to the standard and higher rates of tax. These reduced-form models are used to approximate benefit unit consumption of each of the six expenditure categories during each year, and the associated tax burden is evaluated by multiplying by the relevant tax or duty rate.

In the case of VAT and taxes on insurance premia, the relevant rates are unambiguously defined: the full-rate of VAT in 2011 was 20% and the reduced rate was 5%; the standard rate of tax applied to insurance premia was 6% and the higher rate was 20%. In contrast, the duties levied on alcohol, tobacco and fuel vary substantially across individual products. Averages were consequently calculated for the rates applied to individual products within these three broad consumption categories, weighting by expenditure share (data supplied by HM Treasury). These calculations yielded indirect tax rates (inclusive of VAT) of 50% for alcohol, 66% for fuel, and 80% for tobacco.

The reduced-form models for consumption shares were calculated using data drawn from the Living Cost and Food Survey, pooled over the years 2001 to 2010 (115,827 observations). Each of the six categories of consumption were evaluated following coding used for the IGOTM effective as at 31 August 2012. After testing a number of alternatives, we selected a linear regression specification for all six consumption categories, defining the respective consumption share as a function of age, relationship status, numbers of children, education status, disposable income, and consumption.

A.1.4 Council Tax

Council tax is assumed to depend on relationship status, and the number and age of dependent children. It is modelled based on imputed bedrooms, consistent with the definition of the "bedroom entitlement" applied for housing benefit (see below). One bedroom is imputed for each single adult / cohabitating couple, another for each child aged 13 or over, and another for every 2 children aged under 13 years, subject to a maximum of four bedrooms. Furthermore, higher rates of council tax are assumed to apply to couples than to singles. The rates assumed for 2011 are: £14.17 per week for single adults and £19.23 for couples in a one bedroom house; £16.19 for singles and £22.26 for couples in a two bedroom house; £18.22 for singles and £27.32 for couples in a three bedroom house, and £20.24 for singles and £32.38 for couples in a four bedroom house. These rates are all indexed to wage growth.

All benefits values and thresholds, unless otherwise stated, are assumed to be frozen (in nominal terms) from 2016 to 2020, and to be indexed to prices thereafter.

A.1.5 Income support prior to state pension age

Support to benefit units with low incomes who do not satisfy the age requirements of the pension credit (see below) is modelled on income support. The maximum benefit payable under income support is comprised of a number of components. Single adults are eligible for income support worth £71

per week in 2011, and couples for £111.45 per week. Benefit units with dependent children under age 6 are assumed to be eligible for healthy start vouchers worth £6.20 per week for new-borns, decreasing to £3.10 per week for children aged 1 to 5. Free school meals are also included, worth £5.52 for each child aged 5 to 10.

Furthermore, benefit units that are identified as home owners with a mortgage are eligible for assistance with mortgage interest payments, worth up to 3.85% per annum (nominal, 1.85% real) on a mortgage of up to £200,000.

The benefits referred to here are means-tested, withdrawn at the rate of £1 for each £1 of private income, and at the rate of £1 per week for every £250 of non-housing capital in excess of a £6,000 disregard for those on income support.

A.1.6 Pension credit

The pension credit is comprised of two elements, both of which are modelled explicitly. The guarantee credit is payable from age 60 in all years prior to 2010, rising to age 61 in 2010, 62 in 2012, 63 in 2014, 64 in 2016, and from simulated state pension age thereafter. Simulated state pension age is projected to remain at 65 years until 2018, increasing to 66 in 2019, to 67 in 2026, and to 68 in 2034.

The age of eligibility for the guarantee credit is defined with respect to planned variation of state pension age for women, taking into consideration the division of time into discrete annual intervals that is a feature of the model. Specifically, state pension age for women increased to 60 years and 1 month in May 2010, 61 years and 1 month in May 2012, 62 years and 1 month in May 2014, and is projected to rise to 63 years and 3 months by July 2016, 64 years and 1 month by November 2017, and 65 years by November 2018 at which time the state pension age of men and women will be equalised. Thereafter, existing legislation that will see state pension age of both men and women increase to 65 years and 1 month by January 2019, 66 years and 1 month by May 2026, and the government has announced its intention to increase state pension in line with longevity thereafter.

The guarantee credit provides a maximum benefit worth £137.35 per week to a single adult in 2011, and £209.70 to a couple. Furthermore, benefit units that are identified as home owners with a mortgage are eligible for assistance with mortgage interest payments, worth up to 3.85% per annum on a mortgage of up to £200,000. These payments are subject to a means-test on total benefit unit private income and non-housing capital, with benefits reduced £1 for every £1 of private income, and by £1 for every £500 of non-housing wealth in excess of a £10,000 disregard.

The savings credit provides additional income to benefit units that have private income in excess of a minimum threshold and are above state pension age. Savings credit increases at the rate of 60p for every £1 of private income in excess of £103.15 per week for singles in 2011, and £164.55 per week for couples, up to a maximum benefit worth £20.52 per week for singles in 2011 and £27.09 per week for

couples. Any private income earned beyond the sum required to obtain the maximum savings credit benefit, reduces the benefit at the rate of 40p in the £1.

The maximum benefits payable under the guarantee credit are assumed to increase with real wages. In contrast, the maximum value of the savings credit is assumed to be indexed to prices. This implies that the savings credit threshold grows faster than earnings.

A.1.7 Working tax credit

Working tax credit is payable to any benefit unit over age 24, with at least one adult in full-time employment, or with at least one adult in some employment and with a dependent child. The maximum benefit payable is comprised of a basic element worth £1920 per year in 2011, plus an additional element worth £1950 per year for single-parents and couples, plus an element worth £790 per year for benefit units with at least one adult working at least 30 hours per week. Furthermore, benefit units in which all adult members work at least 16 hours per week are eligible to subsidised child care for children aged 14 and under, equal to 70% of qualifying child care costs up to a maximum of £175 per week for a single child, and £300 per week for two or more children.

The benefits payable under the working tax credit are means-tested in conjunction with benefits payable under the child tax credit described below.

A.1.8 Child tax credit

The child tax credit is payable to benefit units with dependent children under 20 years of age. The maximum benefit payable is comprised of a family element worth £545 per year in 2011, and a child element worth £2,555 per year for each qualifying child.

Eligible benefits under the child tax credit are aggregated with those of the working tax credit and subject to a common means test. Any benefit unit income in excess of a minimum threshold reduces the total tax credits payable, at the rate of 41p per £1. The minimum threshold is £6,420 per year in 2011 for benefit units eligible to both the working tax credit and the child tax credit, and £15,860 per year for those eligible to only the child tax credit.

A.1.9 Child benefit

Benefit units with dependent children receive Child Benefit. The benefit is worth £20.30 per week in 2011 for the first child and £13.40 per week for each subsequent child. Child benefits are not means-tested.

A.1.10 Housing benefit

Housing benefit is paid in respect of simulated rent payments to benefit units that have sufficiently low incomes. The maximum benefit payable under housing benefit is equal to rent expenditure capped at the respective local housing allowance. The local housing allowance is determined by rates graded by the bedroom entitlement of the benefit unit. The bedroom entitlement allows one bedroom for each single adult / cohabitating couple, another for each child aged 13 or over, and another for every 2 children aged under 13 years, subject to a maximum of four bedrooms. The local housing allowance is £162.50 per week in 2011 for one bedroom, £188.50 per week for two bedrooms, £221 per week for three bedrooms, and £260 per week for four bedrooms.

Housing benefit is means-tested with respect to a broad measure of income that is net of child care costs eligible to subsidies via the working tax credit (see above), and most taxes and benefits. The measure of income also includes imputed returns on non-housing wealth, calculated as £1 per week for every £250 of wealth in excess of a £6,000 disregard for individuals under the age of eligibility the Guarantee Credit, and £1 per week for every £500 of non-housing wealth in excess of a £10,000 disregard otherwise. This measure of income is then reduced by an earnings disregard, worth £5 per week for single people, £10 per week for couples, and £25 per week for lone-parents, with an additional £17.10 disregard applied for benefit units with at least one adult working full-time, or at least one adult working and with dependent children.

Any excess of this measure of income above the benefit unit's relevant applicable amount reduces housing benefit at the rate of 65p in every £1. The applicable amount is equal to £67.50 per week for single adults, £72.30 for lone-parents, and £105.95 for couples, increasing by £62.33 for each dependent child (aged 18 and under). Couples and lone-parents are also eligible to an additional family premium worth 17.40 per week.

A.1.11 Council tax benefit

Council tax benefit is provided to subsidise the costs to households of council taxes (see above). Although council tax benefit was available in 2011, it has been amended to a localised benefit from 2013/14. Nevertheless, council tax benefit is modelled by default in the form that it took prior to localisation of the benefit. This structure assumes that council tax benefit is subject to the same means-testing rates and thresholds as housing benefit described above, with the exception that the benefit is withdrawn the rate of 20p in every £1. As council tax benefit and housing benefit are withdrawn simultaneously, this implies 85p of aggregate (council tax and housing) benefit is withdrawn for every £1 of income above the benefit unit's relevant applicable amount so long as both benefits are received.

A.1.12 Universal credit

Universal credit is designed to replace income support (including income based Jobseekers Allowance), housing benefit, the working tax credit, and child tax credit. Although universal credit was not available in 2011, it has been in planning since the conservative party annual conference in 2010. The scheme has been rolled-out progressively since April 2013, and is scheduled to have replaced the existing benefit schemes by 2017/18. This policy shift is consequently built into the model.

The maximum payment under universal credit is simulated by aggregating the maximum sums payable under income support, child tax credit, and housing benefit, and then adding the maximum child care component payable under the working tax credit. This maximum benefit is then withdrawn at the rate of 65p for each £1 of earned income net of taxes and national insurance contributions earned above the benefit unit's relevant "work allowance". Furthermore, any pension income received is deducted from the universal credit payable, and each £250 of non-housing wealth in excess of a £6,000 disregard reduces the universal credit by £1 per week (in 2011 prices).

The work allowance depends upon whether housing related support would have been received through either income support (off-setting mortgage interest) or housing benefit (off-setting rent). If so, then so-called "lower work allowances" apply, worth £25.21 per week to single adults in 2011, £59.72 to lone parents, £25.21 to couples, and £50.41 to couples with children. Otherwise, "higher work allowances" apply, which are identical to the lower allowances for benefit units without children, but are worth £166.67 per week to lone parents, and £121.71 to couples with children.

A.1.13 State pensions

State pensions are assumed to be paid to qualifying benefit units from state pension age. State pension age is specified to increase in line with official guidelines for men, current as of the 2014 Pensions Act. The maximum value of the single tier pension is set equal to the guarantee credit, worth £137.35 per week to a single adult in 2011, and £209.70 to a couple. This benefit is indexed to assumed wage growth.

Rights to the single tier pension are accrued through accreditation for national insurance contributions. An adult is accredited with national insurance contributions in any given year, if they pay class 1 contributions, if they are identified as involuntarily unemployed (receive a low wage offer in the model), or if they have a dependent child under age 12 in the household. At least 10 years' of national insurance contributions are required to receive any income under the single tier pension, and 35 years' contributions are required for the full single tier pension.

The above description is applied when simulating the population through time. An alternative approach is, however adopted when solving the lifetime decision problem. To limit computational burden when solving the lifetime decision problem, all benefit units are assumed to be eligible to a flat rate pension worth 90% of the maximum defined above.

A.1.14 Allowance for imperfect benefits take-up

Take-up of benefits by a benefit unit in any year is modelled as a random event. Each benefit unit in each year is assigned a number drawn from a uniform [0,1] distribution. This number is compared against the "take-up rate" associated with the benefit unit's circumstances in the respective year. If the number is less than the take-up rate, then the benefit unit is assumed to take-up their benefits; otherwise they do not.

Take-up rates distinguish between benefit units, based on labour supply, family demographics, and age, and are based on statistics reported for 2013/14 in "Income-related benefits: Estimates of take-up", Department for Work and Pensions (2015).

A.2 Non-discretionary costs

The model distinguishes between three classes of committed expenditure: housing, child care, and other necessities. The first two of these are distinguished separately, as they have a bearing on the benefits that individuals are eligible for. Each consumption class is discussed in a separate subsection below.

A.2.1 Housing

A stylised approach has been adopted to identify the following housing related features within the model: gross housing equity, gross mortgage debt, realised return on gross housing equity, unrealised return on gross housing equity, mortgage interest costs, and rent. These factors are identified using the following procedure.

Logit regression models are used to describe the incidence of home ownership and mortgage holding in the model, with reference to the simulated year, and each benefit unit's age, relationship status, and aggregate non-pension wealth. The logit regressions were estimated on data reported by the Wealth and Assets Survey (WAS) for 2011.

Net housing equity is defined as a ratio of net non-pension wealth. Given the stylised approach taken to model housing, and the compelling nature of this relationship, net housing equity in the model is imputed as a simple age specific ratio, also evaluated from the WAS.

Mortgage debt, for home owners who are also identified as mortgage holders in the model, is imputed on the basis of a Tobit regression equation for the ratio of gross mortgage debt to net housing equity. The regression model describes the ratio of mortgage debt to housing equity as a function of age, time, relationship status, and net non-pension wealth, and was estimated on the same WAS data as considered for other aspects of housing.

Algorithm A.1: Computing housing-related variables.

```
1: Identify home-owners.
2: if home owner then
3:     go to step 7
4: else
5:     go to step 18
6: end if
7: Compute net housing equity.
8: Identify mortgage holders.
9: if mortgage holder then
10:    go to step 14
11: else
12:    go to step 16
13: end if
14: Compute mortgage debt.
15: Compute annual interest charge on mortgage debt.
16: Compute returns to gross housing equity.
17: Go to step 19.
18: Compute rent paid.
19: Evaluate council tax payment.
```

Housing has an impact on family budgets in three ways in the model: returns to gross housing wealth, interest charges on outstanding mortgages, and rent payable. Each of these is described in turn.

Returns to gross housing wealth were calculated from the ONS mix adjusted house price index, and discounted to real terms by the National Accounts final consumption deflator. The calibration assumes that the return to housing wealth in forward projections is equal to the mean return observed between 1970 and 2010.

Interest on outstanding mortgages has a direct impact on our measure of committed expenditure, and can affect the benefits to which a benefit unit is eligible. This rate is set to the maximum interest rate eligible for subsidy through Income Support; 3.85% per annum nominal – which is taken to be 1.85% real (assuming that target inflation is achieved).

Rents in 2011 are set equal to the Local Housing Allowance rates averaged over all Local Authorities, reported for June 2011 by the Valuation Office Agency. Rents are assumed to grow in line with wages. The rental rates are defined in terms of numbers of bedrooms, which are simulated in the model as defined for the Housing Benefit. The only exception is in relation to single adults aged 30 and under without children, who are assumed to share their accommodation, and who consequently incur the lower rental charge associated with shared accommodation by the LHA.

Two sets of rents are supplied to the model: Local Housing Allowance (LHA) rates for low income people, and "market rent" for high income people. Both sets of rents are defined in terms of numbers

of bedrooms, which are simulated in the model as defined for the Housing Benefit. The only exception is in relation to single adults aged 30 and under without children, who are assumed to share their accommodation, and who consequently incur the lower rental charges.

A.2.2 Child care

A linear regression model was estimated for the average aggregate child care costs, distinguished by child age, parental labour supply, and survey year. This equation was estimated on data reported by the LCF.

Child care costs are assumed to be incurred only by benefit units with children under age 14, and in which all adults supply some labour. Child care costs are assumed to vary between children aged 0-4 and those aged 5-13. Child care costs are also assumed to vary between benefit units in which all adults are full-time employed and those working less than full-time.

A.2.3 Other basic necessities

Consumption on "other basic necessities" in the model is parameterised based on data reported for the 5% of benefit units with the lowest aggregate consumption. Data for calibrating this aspect of the model were evaluated from the LCF (and its predecessors) between 1971 and 2012.

The LCFs were used to identify age, year, equivalised total consumption (in 2011 prices), and equivalised consumption net of child care and rental charges for the full reported sample of benefit units. The equivalence scale used for analysis is the revised OECD scale, which is also assumed for the model's preference relation. The 5% of benefit units with the lowest equivalised total consumption, distinguished by year and across 7 age bands (18-24; 25-34; 35-44;…; 65-74; 75+) were selected from the full sample population. Averages for equivalised consumption net of child care and rental charges, by age band and year, were then evaluated. These averages of equivalised consumption are loaded into the model to define consumption on "other basic necessities".

A.3 Returns to non-housing wealth

The rate of return to non-housing, non-pension wealth is given by:

$$r^{nh} = \begin{cases} r^I & \text{if } w^{nh} \geq 0 \\ r_l + (r_u - r_l) \min\left\{\frac{-w^s}{g^{ft}}, 1\right\}, r_l < r_u & \text{if } w^{nh} < 0 \end{cases} \tag{A.1}$$

Specifying $r_l^D < r_u^D$ reflects a so-called 'soft' credit constraint in which interest charges increase with loan size. $r_I$is set equal to the average real return on long-term treasury bills reported between 1970 and 2010. r_l is set equal to annual averages of the monthly interest rates on sterling personal loans

up to £10,000 to households reported by the Bank of England (code IUMHPTL) between 1995 and 2010. r_u is set equal to annual averages of the monthly interest rates for sterling credit card lending to households reported by the Bank of England (code IUMCCTL) between 1995 and 2010.

The (real) return assumed to pension wealth during the accrual phase, was set to 3.5% per annum, based on a benchmark allocation of a 60:40 split between equities and bonds, a 5% real return to equities, and a 1.2% return to Gilts. The capital return assumed for calculating the price of pension annuities was set equal to 1.5%, reflecting the assumed (real) rate of wage growth, and the associated capital charge was set to 4.7% based on "typical" pricing margins reported in the pension buy-outs market.

A.4 Mortality rates

The age and year specific mortality rates assumed for the model are set to observed rates between 1951 and 1980, and to mortality rates assumed for the Office for National Statistics (ONS) principal population projection between 1981 and 2062.

All dates prior to and following the time series reported by the ONS (1951 to 2062) are imputed by employing a geometric convergence rate of 2.5 per cent per annum from the last age-specific statistic loaded into the model (1951 if back in time, 2062 if forward in time) and a series assumed to represent the "very long-run". This "very long-run" projection is obtained by amplifying the year-to-year variation in the two nearest years loaded into the model by a factor of 15.

The sex specific mortality rates published by the ONS are aggregated into a gender neutral series by weighting each series by the relative likelihood that the respective sex survives to each age, given the assumption that sexes are equally weighted at birth.

A.5 Relationship status

The model requires rates of marriage formation, divorce, and widowhood. The last of these three states is projected on the basis of projections of individual specific mortality. This section describes derivation of the model parameters for marriage formation and divorce.

At the time of writing, the ONS reports historical data for the number of marriages in England and Wales by age, sex and calendar year at annual intervals between 1851 and 2011. The ONS also makes available for modelling purposes the component factors that underlie its population projections, which describe official estimates for the number of marriages by age and sex at annual intervals between 2008 and 2033. Furthermore, ONS population estimates by age, sex and marital status are available for England and Wales at annual intervals between 1971 and 2033. These statistics permit age and gender specific marital rates to be calculated for England and Wales at annual intervals between 1971 and 2033

inclusive. Furthermore, the ONS reports age and sex specific divorce rates for England and Wales at annual intervals between 1950 and 2010, which can be extended to 2032 by the component factors of the ONS population projections that are noted above.

The rates of marriage formation and divorce that are described above are imperfect for modelling purposes in (at least) three important respects. First, the transition rates for marriage and marital dissolution that are described above are not distinguished by education status. Second, marriage rates calculated on historical data do not account for marriages that are performed abroad. Thirdly, the majority of the statistics that are reported by the ONS focus on legal marital status, and do not extend to include civil partnerships or cohabitation.

The focus of ONS statistics on legal marriage is problematic for modelling purposes due to the rise of civil partnerships and cohabitation, and the fact that couples who share the same address often engage in some pooling of consumption and income. This pooling of financial resources is recognised by the system of social security in the UK, which treats cohabitating couples in the same way as registered married couples when determining eligibility for most benefits (excluding state pensions and bereavement allowances).

The rates of marriage and divorce described above were consequently adjusted to match the implied proportion of the population married, by age and year, to marriage rates described by the Living Costs and Food Survey (LCF, and its predecessor surveys) reported between 1978 and 2012. Details for these adjustments can be obtained from the author upon request.

A.6 Fertility

The model requires fertility rates by age, year, relationship status, and number of previous births to simulate dependent children. Unfortunately these rates are not readily available for the UK, and so were constructed based on a set of identifying assumptions and a selected set of publicly available data sources.

The ONS reports the number of births by age of mother and registered marital status at annual intervals between 1938 and 2010 for England and Wales. It also reports the number of births within marriage/civil partnerships by age of mother and number of previous live-born children, at annual intervals between 1938 and 2010 for England and Wales. As noted previously, ONS population estimates/projections by age, sex and marital status are available for England and Wales at annual intervals between 1971 and 2033. Furthermore, the proportions of women by age, year, and marital status, recorded as having 0, 1, 2, 3, and 4+ dependent children can be estimated on the sample reported by the LCF (and its predecessor surveys) for the period between 1971 and 2012.

We assume that the data reported by the ONS for England and Wales, and by the LCF, are representative for the United Kingdom. Assume also, that the number of children reported by the LCF for

women to age 45 is equivalent to the total number of live-born children. Then, combining the ONS population estimates with the proportions estimated on LCF data, we can calculate the number of married women with 0, 1, 2, 3, and 4+ dependent children by age and year. Ignoring the distinction between marriage and civil partnerships, we then combined the 'number of births' data reported by the ONS with our population estimates to obtain birth rates for married women that distinguish between the mother's age, year, and the number of previous births. These birth rates were extended to single women by applying a proportional adjustment equal to the age and year specific ratio of the average birth rate of single women to married women, described by the ONS population estimates that are cited above.

The fertility rates that were obtained as outlined above can be treated as approximate only. To improve the ability of the model to capture the evolving population structure in the UK, we adjusted the statistics that were obtained as described above to align the model to ONS estimates for England and Wales of the percentage distribution of women of childbearing age by number of live-born children, age and year of birth of woman between 1920 and 1991. Details of how this was done can be obtained from the author upon request.

A.7 Parameters identified endogenous to LINDA

The parameters of the assumed preference relation, simulated rental charges, and a selected set of parameters governing intertemporal evolution of latent wages were all adjusted endogenously to the model structure. Preference parameters are unobservable, and are consequently prime candidates for identifying endogenously to the model. Although rental charges are observable, distributional considerations complicate identification of appropriate charges to assume for the model. Similarly, although wages are observable, a subset of wage parameters were identified endogenously to the model to account of associated selection effects.

Adjustment of the parameters to match the simulated moments implied by a dynamic programming model to associated sample moments is commonly conducted either by manual calibration or optimisation of a loss function using an econometric criterion. The current parameterisation was obtained via a series of manual adjustments of model parameters, guided by graphical representations and sums of squared errors for a set of age specific population moments, following the approach described by Sefton, van de Ven, and Weale (2008).

A.7.1 Calibrated parameters

The assumed preference relation (see Section 2.1.1 of the main text) includes five parameters: relative risk aversion, γ; an exponential discount factor, δ; a parameter for the warm-glow model of bequests, ζ; the intra-temporal elasticity, ε; and the utility price of leisure, α. There are 12 rental rates included

with the model, which distinguish benefit units by income, demographic size, and age. Finally, the specification adopted for wages (see Section 2.1.2) includes a very large number of parameters, governing wage growth $m(.)$, earnings volatility $\sigma_{\omega}^{2}(.)$, and the factor effects of pension take-up λ^{ret}.

A.7.2 Calibration procedure

Following extensive experimentation, a step-wise procedure was adopted, based on concentric cycling over three sets of model parameters; A, B, and C. Parameters in a higher set were re-adjusted each time the parameters in a lower set were altered, so that those in set C were subject to the most frequent adjustment, and those in set A the least frequent. Set A comprises simulated rental rates, set B the parameters governing wage growth and earnings volatility (of employees), and set C all other endogenously calibrated parameters. We began by setting rental charges to average market rates, all wage growth parameters $m(.) = 1$, and made initial guesses for earnings volatility, $\sigma_{\omega}^{2}(.)$. Given these assumptions for parameter sets A and B, and the model parameters identified exogenously from the model structure, the calibration procedure began by adjusting parameters in set C. It was not necessary to pass through a large number of cycles to obtain convergence, due to the invariance of the cross-sectional population characteristics upon which the calibration was based, as is discussed further below.

A.7.3 Identification of parameter set C

All five preference parameters of the model and the factor effects of pension take-up λ^{ret}, were identified by matching the model to moments evaluated on survey data reported for a single (reference) population cross-section. This is notable, given that preference parameters are often a central focus of interest in the related literature. It is also extremely useful because it simplifies specification of the policy context underlying the behaviour considered for identification, and omits the feed-back effects that can otherwise complicate parameter adjustments. Parameterisation then proceeded in four concentric 'loops'.

(1) The inner-most loop, which was repeated most frequently, focussed on adjusting α and λ^{ret}. Increasing the utility price of leisure α tends to decrease labour supply throughout the working lifetime. Exaggerating the wage discount for benefit units that have previously accessed their private pensions tends to decrease labour supply late in the working lifetime. These two model parameters provide a high degree of control over the employment profile throughout the life-course, and were jointly adjusted to match the model to age and relationship-specific means for employment participation.

(2) The second loop jointly adjusted δ and ζ to reflect age and relationship specific geometric means for consumption. Increasing the discount factor δ makes benefit units more patient, and consequently tends to decrease consumption throughout the working lifetime. Increasing ζ exaggerates the bequest motive, which tends to lower consumption late in the life course when the probability of imminent

mortality becomes appreciable. Taken together δ and ζ provide a high degree of control over the age profile of consumption implied by the structural model.

(3) The third loop of the calibration strategy adjusted γ, by focussing on the associated influence on savings incentives. Raising γ *ceteris paribus* exaggerates precautionary savings motives, implying lower consumption and *lower* pension scheme participation (due to the illiquidity of pension wealth). In contrast, raising δ tends to imply lower consumption and *higher* pension scheme participation as benefit units are made more patient. Hence, if the rates of pension scheme participation implied by the model following the second loop of the calibration were too low (high), we reduced (increased) γ and returned to the inner-most loop. Otherwise we proceeded to the outer-most loop.

(4) ε was adjusted to match the model to distributional variation described by data for the ratio between equivalised consumption and leisure. Increasing ε will tend to shift period specific expenditure in favour of (equivalised) consumption, relative to leisure, for benefit units with relatively high (equivalised) wage rates.

Identification of parameter set B

The drift parameters, $m\left(.\right)$, and the dispersion parameters, $\sigma_{\omega}^{2}\left(.\right)$, were calibrated against historical data by projecting the reference population cross-section backward through time. The drift parameters were adjusted to reflect geometric means of employment income, distinguished by age, year, relationship status, and education status. The model includes a separate drift parameter for each age, year, education, and relationship combination, so that a close match could be obtained to the associated sample moments.

Similarly, the variance parameters were adjusted to reflect age, year, and relationship specific variances of log employment income calculated from survey data. Unlike the drift parameters, however, only four parameters – distinguish singles from couples, and graduates from non-graduates – were adjusted to reflect the dispersion of employment income. These model parameters were adjusted manually.

Identification of parameter set A

Two sets of rents $\left(rent\right)$ are supplied to the model: Local Housing Allowance (LHA) rates are assumed for benefit units with equivalised incomes below 60% of median gross full-time earnings in 2011, and "market rents" for those with equivalised incomes above 120% of median earnings. Between these two income thresholds, rental charges are assumed to vary linearly between the LHA and market rents. Both sets of rents are described in terms of numbers of bedrooms, where one bedroom is allowed for each single adult / cohabitating couple, another for each child aged 13 or over, and another for every 2 children aged under 13 years, subject to a maximum of four bedrooms. The only exception is in relation to single adults aged 30 or under without children, who are assumed to share their

accommodation, and who consequently incur lower rental charges.

The simulated benefits system includes a scheme to subsidise rental charges. Furthermore, rents in the model are disproportionately incurred by individuals toward the bottom of the income/wealth distribution. Increasing rents consequently tends to increase disposable incomes toward the lower end of the distribution on a before housing costs basis, and to reduce disposable incomes on an after housing costs basis, with associated implications for simulated poverty rates. Rental charges were consequently adjusted to match poverty rates generated by the model to survey data.

B PROJECTIONS UNDER NAÏVE REDUCED-FORM SPECIFICATIONS

This appendix reports sensitivity of simulated results to the assumed method for identifying the reduced-form descriptions for behaviour. Specifically, the behavioural descriptions used to project reduced-form decisions are taken directory from the structural solutions evaluated under the base policy environment (reflecting UK policy prevailing in 2016), without the adjusting those descriptions as discussed in Section 2.3 of the main text. The current appendix replicates statistics reported in Section 3.1 of the main text for the effects of policy counterfactuals on aggregates for the evolving population cross-section.

Discussion here focusses on the projected effects of the rise in income tax rates, which indicate substantive differences in projected decision making associated with alternative behavioural assumptions. Under the non-response scenario, the rise in income tax rates is projected to have no immediate effect on labour supply, but does result in increasing employment as the time horizon is extended. By 2046, almost one million additional (equivalent) full-time workers are projected under the higher tax rate counterfactual when behavioural responses to altered incentives are suppressed. This increase in simulated labour supply with the projected time horizon is a product of the coincident decline in (non-pension) wealth. The rise in income tax rates from 2016 is projected under the non-response scenario to result in a decline in aggregate net wealth by 2046 of £775 billion (885 - 110).

The increase in private income associated with the projected rise in labour supply is more than sufficient to off-set the coincident decline in investment income associated with falling net assets, so that private income is projected to increase by £30 billion in 2046 under the high tax rate counterfactual when behavioural responses are suppressed. This increase in private income amplifies the increase in income tax revenue associated with the higher tax rates that are imposed. It also mitigates the projected impact on disposable incomes, thereby supporting a higher consumption stream. Furthermore, the increase in employment rates permits the accrual of higher pension wealth, off-setting the overall decline in total net worth associated with the higher tax rate counterfactual.

Interpreted from a utility maximising perspective, the projections that omit behavioural responses to altered incentives assume that the population spends and supplies labour under the counterfac-

Table B.1: Projected effects of policy counterfactuals on annual government budget, distinguished by year and accommodated behavioural response (£2016, billions).

	income tax rates rise 10%			retirement benefits fall 20%			income tax rates rise 10%			retirement benefits fall 20%		
	response*						response*					
	none	emp	full	none	emp	full	none	emp	full	none	emp	full
	net government revenue						benefits expenditure					
2016	52.4	45.8	41.8	17.5	17.9	17.2	0.1	0.6	0.6	-19.6	-19.6	-19.7
	(0.4)	(0.4)	(0.4)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
2021	56.5	50.7	44.4	19.3	19.8	19.3	0.4	0.8	0.6	-22.0	-22.1	-22.3
	(0.5)	(0.5)	(0.4)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
2026	59.4	53.1	45.2	21.8	22.4	22.2	0.6	1.0	0.7	-25.1	-25.2	-25.5
	(0.7)	(0.7)	(0.6)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
2036	58.1	50.2	39.3	30.8	31.7	32.1	9.3	9.7	9.0	-35.4	-35.5	-36.2
	(0.8)	(0.8)	(0.6)	(0.2)	(0.2)	(0.2)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)
2046	81.2	70.1	55.4	42.0	43.4	44.3	1.6	1.9	0.8	-47.6	-47.7	-48.8
	(0.9)	(0.8)	(0.7)	(0.2)	(0.2)	(0.3)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)
	income tax revenue						consumption tax revenue					
2016	52.3	46.3	45.1	-2.1	-1.7	-1.4	0.1	0.1	-2.7	0.0	0.0	-1.1
	(0.4)	(0.4)	(0.4)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2021	58.0	52.9	48.7	-2.5	-2.2	-1.9	-1.1	-1.3	-3.6	-0.1	-0.1	-1.1
	(0.5)	(0.5)	(0.5)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2026	61.8	56.3	50.1	-3.0	-2.5	-2.2	-1.8	-2.2	-4.2	-0.3	-0.3	-1.1
	(0.7)	(0.7)	(0.6)	(0.0)	(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2036	70.1	63.2	53.7	-4.0	-3.3	-2.8	-2.7	-3.3	-5.4	-0.6	-0.5	-1.3
	(0.7)	(0.7)	(0.5)	(0.0)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2046	85.7	75.7	62.5	-4.8	-3.6	-3.1	-2.9	-3.8	-6.4	-0.8	-0.7	-1.4
	(1.0)	(0.8)	(0.7)	(0.0)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

Notes: * "none" = projections omitting behavioural responses to policy incentives; "emp" = projections allowing for labour supply responses to policy incentives; "full" = projections allowing for labour and savings responses to policy incentives. Standard errors reported in parentheses. "income tax rates rise 10%" denotes counterfactual in which the marginal rates on all taxable income are increased by 10 percentage points. "retirement benefits fall 20%" denotes counterfactual in which all state retirement benefits are reduced in value by 20 percentage points.
Source: Author's calculations on simulated data generated using 30 separate sets of random draws.

Table B.2: Projected effects of policy counterfactuals on aggregate domestic sector finances, distinguished by year and accommodated behavioural response (£2016 billion, unless otherwise stated).

	income tax rates rise 10%			retirement benefits fall 20%			income tax rates rise 10%			retirement benefits fall 20%		
	response*						response*					
	none	emp	full	none	emp	full	none	emp	full	none	emp	full
	equivalent full time employees ('000)						consumption expenditure					
2016	-0.1	-515.3	-573.4	0.0	90.6	154.8	0.0	-0.1	-18.7	0.0	-0.2	-7.4
	(0.0)	(9.1)	(9.6)	(0.0)	(5.1)	(6.4)	(0.0)	(0.0)	(0.2)	(0.0)	(0.0)	(0.0)
2021	298.1	-137.0	-343.0	10.3	96.4	141.2	-8.2	-9.7	-24.8	-1.3	-1.3	-7.6
	(6.4)	(14.1)	(13.4)	(1.2)	(7.0)	(7.3)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)
2026	506.5	82.5	-214.9	14.4	107.5	148.1	-13.0	-15.4	-29.0	-2.5	-2.3	-8.0
	(10.6)	(13.1)	(12.3)	(1.8)	(6.9)	(7.1)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)
2036	825.9	351.6	-106.3	11.3	133.2	171.6	-18.9	-23.2	-36.9	-4.8	-4.4	-9.2
	(13.9)	(16.3)	(15.0)	(1.5)	(6.7)	(7.9)	(0.2)	(0.2)	(0.3)	(0.1)	(0.1)	(0.1)
2046	940.6	433.1	-147.6	10.7	167.0	185.2	-20.7	-27.2	-44.4	-7.1	-6.1	-10.4
	(14.1)	(17.2)	(15.8)	(0.8)	(9.4)	(12.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)
	private income						disposable income					
2016	0.0	-15.1	-17.1	0.0	1.5	3.2	-52.3	-59.8	-61.8	-17.5	-16.6	-16.0
	(0.0)	(0.4)	(0.4)	(0.0)	(0.1)	(0.1)	(0.4)	(0.5)	(0.5)	(0.1)	(0.1)	(0.2)
2021	7.2	-6.3	-12.8	-1.1	0.3	2.8	-50.9	-57.9	-61.2	-20.7	-19.8	-18.5
	(0.4)	(0.6)	(0.6)	(0.0)	(0.1)	(0.2)	(0.6)	(0.6)	(0.6)	(0.2)	(0.2)	(0.3)
2026	12.3	-3.0	-12.3	-2.2	-0.2	3.3	-50.0	-58.2	-62.5	-24.3	-23.1	-20.9
	(0.6)	(0.7)	(0.6)	(0.0)	(0.2)	(0.3)	(0.5)	(0.7)	(0.9)	(0.3)	(0.3)	(0.3)
2036	22.7	1.7	-14.2	-4.5	-1.0	4.8	-40.4	-52.5	-60.2	-36.0	-33.5	-29.8
	(0.9)	(1.1)	(0.8)	(0.1)	(0.2)	(0.3)	(0.7)	(0.8)	(0.8)	(0.4)	(0.5)	(0.4)
2046	30.4	-0.2	-23.4	-7.1	-1.1	6.4	-56.2	-74.5	-85.9	-50.0	-45.7	-40.6
	(1.2)	(1.1)	(1.1)	(0.1)	(0.3)	(0.5)	(1.6)	(1.5)	(1.7)	(0.4)	(0.5)	(0.6)
	pension wealth						non-pension wealth					
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2021	1.7	-21.6	-7.5	0.1	3.8	17.4	-233.2	-259.3	-175.6	-83.7	-81.0	-39.3
	(0.7)	(1.8)	(1.9)	(0.1)	(0.8)	(1.1)	(2.4)	(3.1)	(2.5)	(0.7)	(1.0)	(1.5)
2026	11.1	-33.1	-5.4	0.2	7.0	32.4	-420.3	-473.5	-326.7	-171.7	-165.0	-79.9
	(1.3)	(2.1)	(2.2)	(0.2)	(1.1)	(2.2)	(4.2)	(4.3)	(3.5)	(1.7)	(1.7)	(2.2)
2036	53.9	-39.0	27.8	0.4	13.3	72.4	-681.3	-799.3	-566.0	-364.4	-344.6	-173.4
	(3.3)	(4.2)	(3.6)	(0.2)	(1.2)	(2.4)	(5.3)	(6.8)	(6.2)	(3.4)	(3.8)	(4.2)
2046	110.5	-44.2	81.4	0.6	23.8	136.2	-885.0	-1108.2	-793.1	-595.2	-549.5	-286.3
	(3.9)	(4.6)	(4.0)	(0.3)	(1.7)	(4.0)	(7.8)	(9.4)	(9.7)	(4.4)	(5.3)	(4.8)

Notes: * "none" = projections omitting behavioural responses to policy incentives; "emp" = projections allowing for labour supply responses to policy incentives; "full" = projections allowing for labour and savings responses to policy incentives. Standard errors reported in parentheses. "equivalent full-time employees" evaluated as projected change in total number of labour hours per week divided by 37. "private income" denotes income net of interest charges from all private sources. "disposable income" denotes income net of government taxes and transfers.
Source: Author's calculations on simulated data generated using 30 separate sets of random draws.

tual policy environment as though they still lived under the base policy environment. This means that, in context of the 10% rise in income tax rates, people are projected to spend as though they enjoyed a higher disposable income than they actually receive for any given measure of private income. Conceptually, these individuals are repeatedly "surprised" by how little wealth they have in each succeeding period, and subsequently cut back consumption and increase labour supply to make up the ever-growing short-fall in wealth. The result is a dynamic projection for the counterfactual that reflects a run-away wealth effect. Similar effects are not associated with results reported in Section 3 of the main text, because the description assumed for behaviour is explicitly adapted to respond to the considered policy reforms.

The labour supply response to the rise in income tax rates projected for 2016 under the employment-response scenario, closely reflects that generated under the full-response scenario. Despite the coincident decline projected for disposable incomes in 2016 (due to both the reduction in labour incomes and higher tax burdens), however, projected consumption expenditure remains invariant by construction under the employment-response scenario. This combination of lower disposable incomes and fixed consumption expenditure in near-term projections following the rise in income taxes produces a rapid draw-down of assets under the employment-response scenario. The decline in asset holdings exaggerate the wealth effects of the higher tax rate counterfactual, off-setting incentives to reduce labour supply under the employment-response scenario. This is the mechanism that is responsible for the drift of the projections under the employment-response scenario toward those of the non-response scenario as the time horizon is extended.

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