

UKMOD Indirect Taxation (TCO) Extension

technical note

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1 Background

This document describes the TCO extension, which is designed to project indirect taxes using UKMOD, for systems from 2016. Indirect levies on household expenditure are important sources of government revenue in many countries, including the United Kingdom. Three associated tax instruments are imposed in the UK – Value Added Taxes, excises rates, and ad valorem taxes – and the TCO extension is designed to reflect each of these.

Value Added Tax (VAT) is an indirect tax that imposes a charge on the value added to each stage of the production and distribution process. Businesses pay VAT on their purchases and collect VAT on their sales, remitting the difference to the government. As a consequence, consumers pay VAT on the ultimate sales price of a good or service, with government revenue collected incrementally through the production process. In the UK, VAT is applied to most goods and services, with key exemptions being financial services, health services, education¹, charitable activities and postal services. Furthermore, some categories of expenditure are subject to a zero VAT rate, including most food and drink, children's clothing, printed materials and public transport services.

Ad valorem excise is similar to VAT in that it is a tax levied as a percentage of the product price. The main distinction between the two is that, whereas ad valorem excises are levied on consumer prices, VAT is charged on the aggregate of producer prices, ad valorem and specific excises. In the UK, ad valorem excise is limited principally to cigarettes.

Specific excises differ from both VAT and ad valorem excise by being charged with respect to product quantities rather than associated expenditure measures. Specific excises in the UK are levied on alcoholic drinks, tobacco products, and road fuel.

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¹ Tax exemption for private schools will end from January 2025.

The current analysis is inspired by a project to implement Indirect Tax and Transfer (ITT) payments in EUROMOD, as reported in Cansu Akoguz *et al.* (2020). The current implementation does, however, depart from Cansu Akoguz *et al.* (2020) in several respects. The most important distinction is that the input data and analytical framework have been adjusted to omit the possibility of inconsistencies arising where data observed in one year are analysed using a policy system designed for a different year. Associated adjustments also have the advantage that they economise definition of model parameters.

This note begins by describing the analytical background to the simulation of indirect taxes in UKMOD, paying attention to differences relative to the approach reported in Cansu Akoguz *et al.* (2020). A detailed description of the approach's practical implementation is then provided, before finishing with a brief practical example.

1.1 Analytical background

Following Cansu Akoguz *et al.* (2020), define the following:

- $x_{k,h}$ the number of units consumed of commodity k by tax unit h
- q_k the unit price paid by consumers for commodity k
- $e_{k,h} = q_k \cdot x_{k,h}$ the consumer expenditure on commodity k by tax unit h
- p_k the unit price received by producers for commodity k
- v_k the *ad valorem* excise rate applied to consumer prices, q_k , of commodity k
- a_k the specific excise applied to units of commodity k , $x_{k,h}$
- t_k the Value Added Tax rate applied to producer prices plus *ad valorem* and specific excise taxes for commodity k

Then we can also define:

$$T_{k,h}^v = v_k q_k x_{k,h} = v_k e_{k,h} \quad (1)$$

$$T_{k,h}^s = a_k x_{k,h} = \frac{a_k}{q_k} e_{k,h} \quad (2)$$

$$T_{k,h}^t = t_k (p_k x_k + T_{k,h}^v + T_{k,h}^s) = t_k (p_k + v_k q_k + a_k) x_k \quad (3)$$

$$T_{k,h} = T_{k,h}^t + T_{k,h}^v + T_{k,h}^s = (q_k - p_k) x_k \quad (4)$$

where $T_{k,h}^v$ denotes *ad valorem* excise, $T_{k,h}^s$ specific excise, $T_{k,h}^t$ VAT, and $T_{k,h}$ total indirect taxes paid on commodity k by tax unit h . From equation (4), we also have:

$$q_k = (1 + t_k)(p_k + a_k + v_k q_k) \quad (5)$$

which can be used to solve for producer prices. Equations (1) to (4) consequently permit evaluation of indirect taxes, given assumed tax parameters (t_k, v_k, a_k), tax unit expenditure ($e_{k,h}$), and – in the case of specific excises – consumer prices (q_k). VAT is given by:

$$T_{k,h}^t = \frac{t_k}{1+t_k} e_{k,h} \quad (6)$$

Cansu Akoguz *et al.* (2020) propose modelling assumptions to facilitate these evaluations. The first is that producer prices (p_k) are invariant to tax and benefit policy reform. This assumption permits consumer prices to be evaluated for changes in indirect tax parameters via equation (5). Furthermore, Cansu Akoguz *et al.* consider three alternative assumptions to define the impact that changes to tax and benefit policy have on expenditure, which they describe as “constant income shares”, “constant expenditure shares”, and “constant quantities”.

Constant income shares assumes that the ratio of expenditure by tax unit h on any commodity k to disposable income (gross of indirect taxes) is invariant to simulated policy. This assumption implies that the income elasticity of all commodities is +1 and the own price elasticity is -1.

The assumption of constant expenditure shares is identical to constant income shares other than that it holds nominal savings to be policy invariant. Hence, these two assumptions will only differ if disposable income (gross of indirect taxes) changes. If disposable income does vary, then the constant expenditure shares assumption will allocate the entire change to expenditure, whereas constant income shares will allocate the change across both expenditure and savings.

The assumption of constant quantities holds per unit expenditures, $x_{k,h}$, fixed. In contrast to the two alternatives noted above, the constant quantities assumption consequently implies 0 own price and income elasticities.

1.1.1 Practical application

Cansu Akoguz *et al.* (2020) propose augmenting input data to describe disposable income shares of targeted commodities for each observation, and dedicated model parameters describing consumer prices, q_k , and indirect taxes (t_k, v_k, a_k). Two sets of parameters are suggested: one set representing the parameters of interest and another set representing “base” parameters applicable to the respective system. The idea is that the base parameters permit identification of features that are considered invariant to the policy environment, and which can be used to evaluate the effects of alternative policy scenarios.

Specifically, producer prices for the base set of model parameters should be recovered from consumer prices by inverting equation (5). This permits consumer prices to be evaluated for the parameters of interest (via equation 5), given the assumption that producer prices are invariant to the policy environment. These consumer prices are required to evaluate specific excises via equation (2). Given tax parameters of interest, leaves only expenditure for targeted commodities needed to evaluate the indirect taxes described by equations (1) to (5).

Under the assumption of constant income shares, the augmentation of input data noted above permits expenditure for targeted commodities to be evaluated directly from

associated projections for disposable income. This is complicated under the assumption of constant expenditure shares by the need to identify nominal savings, which are assumed to remain unchanged to the policy environment. To address this issue, Cansu Akoguz *et al.* (2020) recommend running EUROMOD twice. The first simulation, evaluated under the “base” set of model parameters, is to identify nominal savings and base disposable income, which are added to the model input data. These data permit expenditure for targeted commodities to be evaluated in the second simulation based on the tax parameters of interest.

The assumption of constant quantities, like constant expenditure shares, requires two simulations to gather the information necessary to evaluate the necessary measures of expenditure under the parameters of interest. The first simulation identifies expenditure for targeted commodities under the “base” set of model parameters. This permits identification of “base” quantities, by dividing through by the “base” consumer prices that are supplied as model parameters. These base quantities are added to the model input data. The second simulation then involves evaluating new consumer prices associated with the targeted tax parameters², which allows expenditures to be obtained by interaction with the saved “base quantities”.

1.2 Approach adopted for UKMOD

The modelling approach outlined above suffers from a potential inconsistency to the extent that the “base” parameters assumed for the model fail to describe the policy context that applied to the sample population adopted as the model’s input data. Furthermore, multiple simulation runs to populate required input variables, and replication of input parameters in “base” and “target” sets introduce sources of potential simulation error. We adopt a slightly stylised simulation approach to the one outlined above that is designed to cut through these complications.

The approach implemented in UKMOD is based on an **expanded input dataset**, which includes household-specific measures of expenditure on targeted goods categories. In the case of UKMOD, the legacy specification of survey data includes survey measures of disposable income, so that the addition of measures of expenditure permit “base” savings to be identified by differencing. These data, along with dedicated **model parameters** describing tax rates, producer and consumer prices relevant for the input population, provide all the information needed to evaluate indirect transfer payments by the **TCO extension**. The “Default” and “Baseline/Reform” templates of **Statistics Presenter** are also adapted to make use of projections for indirect taxes where these are reported in simulated output.

² By identifying producer prices under the base parameters, via an inversion of equation (5), and then application of equation (5) using the targeted tax parameters and the assumption of fixed producer prices.

Consider, for example, a projection based on the assumption of “constant income shares”. In this case, commodity specific expenditure can be evaluated for any prevailing transfer system as:

$$e_{k,h} = y_h \cdot \hat{e}_{k,h} / \hat{y}_h \quad (7)$$

where y_h denotes disposable income of tax unit h and “hats” indicate variables described by the input data. Given the assumption that producer prices are insensitive to changes in tax and benefits policy, consumer prices for any policy scenario can then be calculated from equation (5). These details provide all that is necessary to evaluate indirect taxes as described by equations (1) to (4).

Extension of the above to the assumption of “constant expenditure shares” is obtained, subject to a slight modification in the way that commodity specific expenditures are imputed:

$$\hat{s}_h = \hat{y}_h - \sum_k \hat{e}_{k,h} \quad (8)$$

$$e_{k,h} = (y_h - \hat{s}_h) \cdot \hat{e}_{k,h} / \sum_j \hat{e}_{j,h} \quad (9)$$

Similarly, extension to the assumption of “constant quantities”, involves first evaluating consumer prices under tax parameters of interest, given assumed producer prices, via equation (5). Commodity specific expenditure measures can then be populated as:

$$e_{k,h} = \frac{q_k}{\hat{q}_k} \cdot \hat{e}_{k,h} \quad (10)$$

2 Expanding Input Data to Include Expenditure

The Family Resources Survey (FRS), which serves as the primary database for the UKMOD input data, does not include information on household spending. Therefore, expenditure data are imputed into the FRS from the Living Costs and Food Survey (LCF), which collects detailed information on spending patterns and the cost of living, reflecting household budgets. The LCF is conducted throughout the year across the entire UK and is considered the most significant survey on household spending in the country³.

The imputation of expenditure variables from the LCF to the FRS is carried out in two steps.

Step 1: Predictive Mean Matching (PMM)

³ It is worth noting that the sample size of the LCF is considerably smaller than that of the FRS, and the LCF income variables available through the End User Licence are top-coded. Therefore, replacing the FRS input data for UKMOD entirely with the LCF data was not considered feasible.

This method imputes missing data by identifying observed values in a donor dataset that are closest (in terms of predicted values) to the missing data points, with the aim of minimising the difference between predicted and observed data.

The imputation process begins by reading the relevant datasets (LCF and FRS) and generating common explanatory household-level variables for matching. The data is cleaned by removing missing values, negative numbers, N/A values, and outliers. Income shares for various consumption categories are then calculated by dividing the expenditure on each category by the household's income.

A probit model is estimated to calculate the probability of a household having positive expenditure on certain consumption categories, using common variables from both datasets, such as income and household socio-demographic characteristics. Fitted values are computed for both datasets to facilitate the matching of LCF and FRS data.

An ordinary least squares (OLS) regression is then used to estimate the income share of household expenditure on different categories, such as food and housing, by modelling the relationship between these shares and household characteristics, including income and socio-demographic variables. The regression produces fitted values for the income share, which are then transformed back to the original scale using an exponential function.

The fitted values from both the probit and OLS regression models are multiplied to create predicted expenditure shares for households. Mahalanobis distance is employed to measure the similarity between households in the LCF and FRS datasets. This distance is calculated based on the income shares of expenditure categories.

The final step involves matching each household from the recipient dataset (FRS) with the closest household in the source dataset (LCF) based on the smallest Mahalanobis distance. Matching is performed with replacement, meaning one LCF household can serve as a donor for multiple FRS households. The income shares of expenditures and other expenditure variables from the matched LCF household are then imputed into the FRS household, resulting in a combined dataset with variables from both sources.

However, due to the removal of outliers in both the LCF and FRS data, as well as the top-coding of income variables in the LCF, some FRS households did not receive a donor in the first round of matching. For instance, in the 2018/19 dataset, around 10% of households had missing total consumption expenditure, and approximately 4% had zero total consumption expenditure.

Step 2: Propensity Score Matching (PSM)

For the second round of matching, households with missing or zero values for total consumption expenditure are assumed to require additional imputation. For that purpose, Propensity Score Matching (PSM) with replacement is used within the FRS data to fill in the

missing expenditure values. PSM works by matching units in a treatment group with similar units in a control group based on their characteristics. The goal is to create a comparison group that resembles the treatment group as closely as possible in terms of observed covariates, so that differences in outcomes between the groups can be attributed to the treatment rather than other confounding factors. In this case, the treatment is having missing or zero total consumption expenditure. Households were matched based on a range of socio-demographic characteristics and deciles of HBAI equivalised income. Then those with missing expenditure data had their expenditure imputed from the closest match in the FRS.

Household consumption expenditure variables are initially recorded in the LCF at a 5-digit COICOP⁴ classification level. In the final step of the imputation process, these detailed expenditure categories are aggregated into 4-digit COICOP classification categories, which are then used by the TCO extension.

3 UKMOD Integrations

3.1 Indirect tax parameters

Most of the parameters used to model indirect taxes are defined in the TCO extension, as described in Section 2.3. A subset of these parameters is, however, defined in the policy spine toward the end of policy *ConstDef_uk*.⁵ The parameters included in the policy spine are those that change from year to year, and which are most likely to be of interest when conducting policy experiments. They have been included in the policy spine to facilitate maintenance and updating.

Parameters defined in the policy spine include standard, reduced, and zero VAT rates, and excises and unit prices for alcohol and tobacco products. The policy begins by defining baseline parameters that are

3.2 The TCO extension

The TCO extension is comprised of the following 7 policies:

1. `tco_paraminit_uk`: initialises excise rates and prices,
2. `tco_calcprelim_uk`: creates working income lists and evaluates consumer prices,
3. `tco_cy_uk`: projects expenditure based on “constant income shares” assumption,
4. `tco_ce_uk`: projects expenditure based on “constant expenditure shares” assumption,
5. `tco_cq_uk`: projects expenditure based on “constant quantities” assumption,

⁴ COICOP (Classification of Individual Consumption According to Purpose) is an international system used to categorize household consumption expenditures. It divides spending into broad categories, such as food, housing, and transportation, with further subcategories for detailed items.

⁵ See model comment “Indirect tax parameters”.

6. `tco_calcbase_uk`: projects VAT, ad valorem and specific excise values,
7. `tco_calcbase_uk`: inflates indirect tax values to reflect figures reported by the national accounts.

Each of these policies is described in turn.

3.2.1 Policy: `tco_paraminit`

`tco_paraminit` sets a series of model parameters used by the TCO add-on. Default values for all excise rates are set to zero. Consumer and producer prices are also defined, which are specific for each supported input dataset.

3.2.2 Policy: `tco_calcprelim`

Evaluation of indirect taxes is structured around a large number of consumer categories. The associated calculations are facilitated by a special EUROMOD function, `ilArithOp`. This function, which is based on income lists, permits a common function to be applied over terms that share a common naming format. The `tco_calcprelim` policy defines the income lists used to manage the indirect tax computations. The last function of the policy also evaluates consumer prices for each commodity associated with the respective policy form, by rearranging equation (5) as:

$$q_k = (1 + t_k)(p_k + a_k) / [1 - (1 + t_k)v_k] \quad (11)$$

3.2.3 Policies: `tco_cy`, `tco_ce` and `tco_cq`

Each of these policies implements an alternative behavioural assumption for projection good-specific expenditure under alternative policy scenarios. Only one of these functions should be implemented at a time.

3.2.4 Policy: `tco_calcbase`

Implements functions to evaluate ad valorem excises, specific excises, and value added taxes, and defines an income list for reporting.

3.2.5 Policy: `tco_calcadjusted`

Applies proportional adjustments to all projected indirect taxes to match to figures reported by the National Accounts.

3.3 Statistics Presenter

The “UKMOD Statistics – Default” and “UKMOD Statistics – Baseline/Reform” templates of Statistics Presenter have report summary statistics for indirect taxes if the associated variables are found in simulated output. The “Fiscal Overview” tab of each template

includes a panel of data for “Government revenue through indirect taxes”. Furthermore, the “Indirect Taxes” tab of each template indicates the incidence of indirect taxes on various population subgroups.

4 Practical Use of the TCO Extension

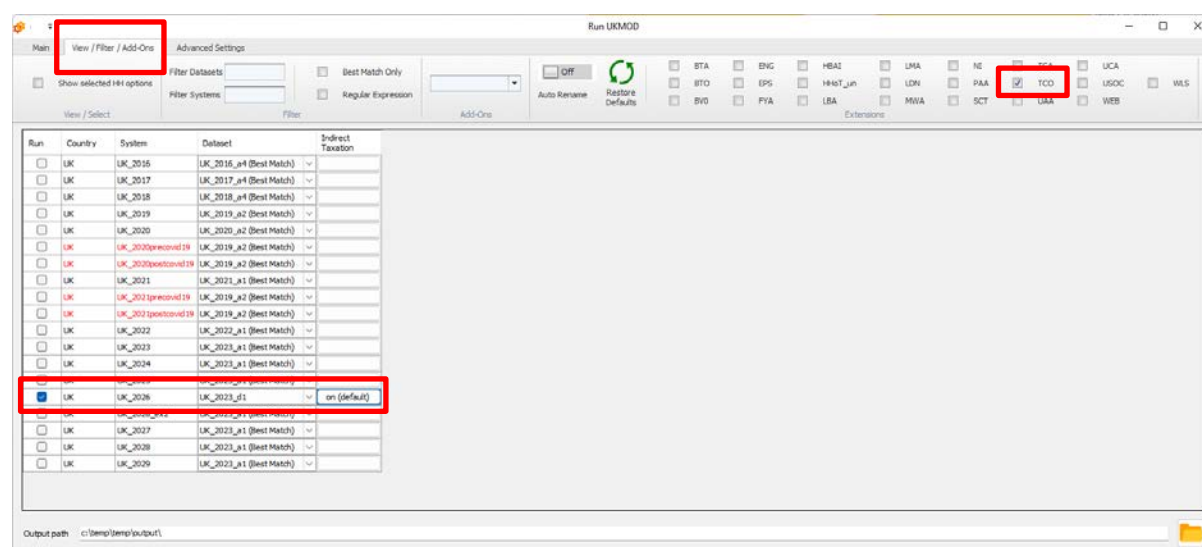
This section describes how to use the TCO add-on with the aid of a practical example.

Suppose we are interested in analysing a 5-percentage point increase in the standard rate of VAT in the UK for 2026. We begin by generating results for the default combination of system and input data.

4.1 Set-up base simulation for comparison

Open the model for the UK and press the “Run UKMOD” button of the main EUROMOD window to open the “Run UKMOD” window.

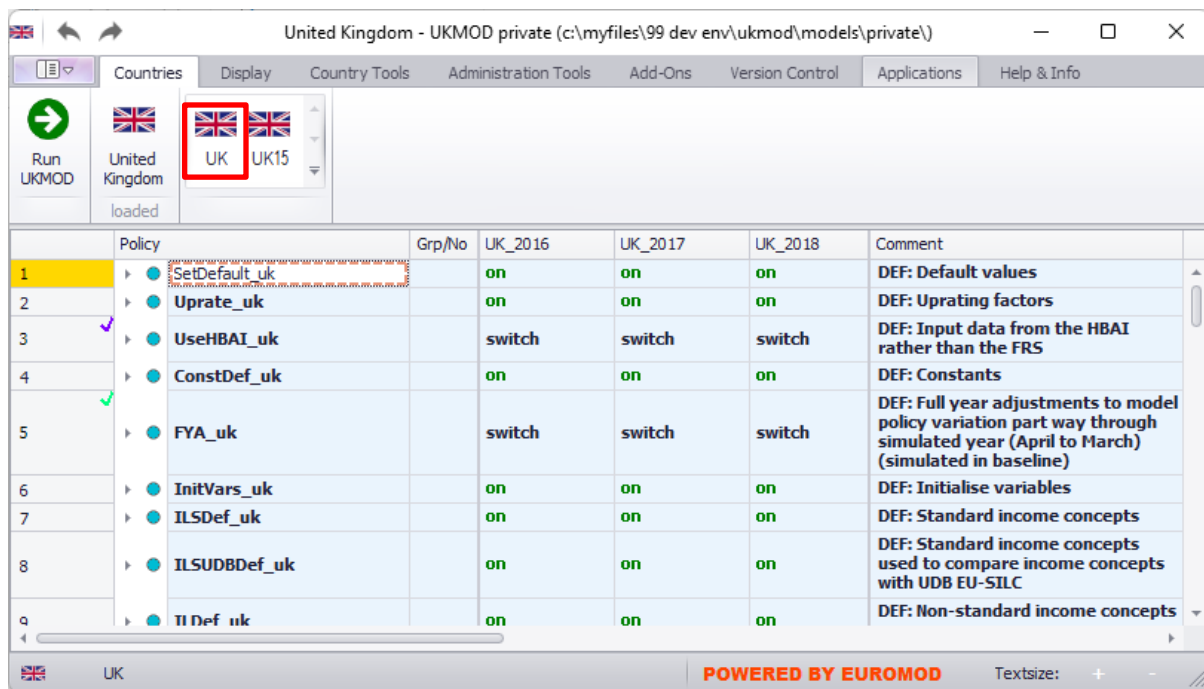
Select the “View / Filter / Add-Ons” tab, and choose the TCO Extension.



As indicated in the above, the TCO extension is designed to run by default whenever a “d” series input data is supplied. Return to the “Main” tab, and press the “Run” button. The model should then run through and complete without errors or warnings.

4.2 Define counterfactual simulation

Return to UKMOD to define our policy reform of interest. Open the UK model of UKMOD.



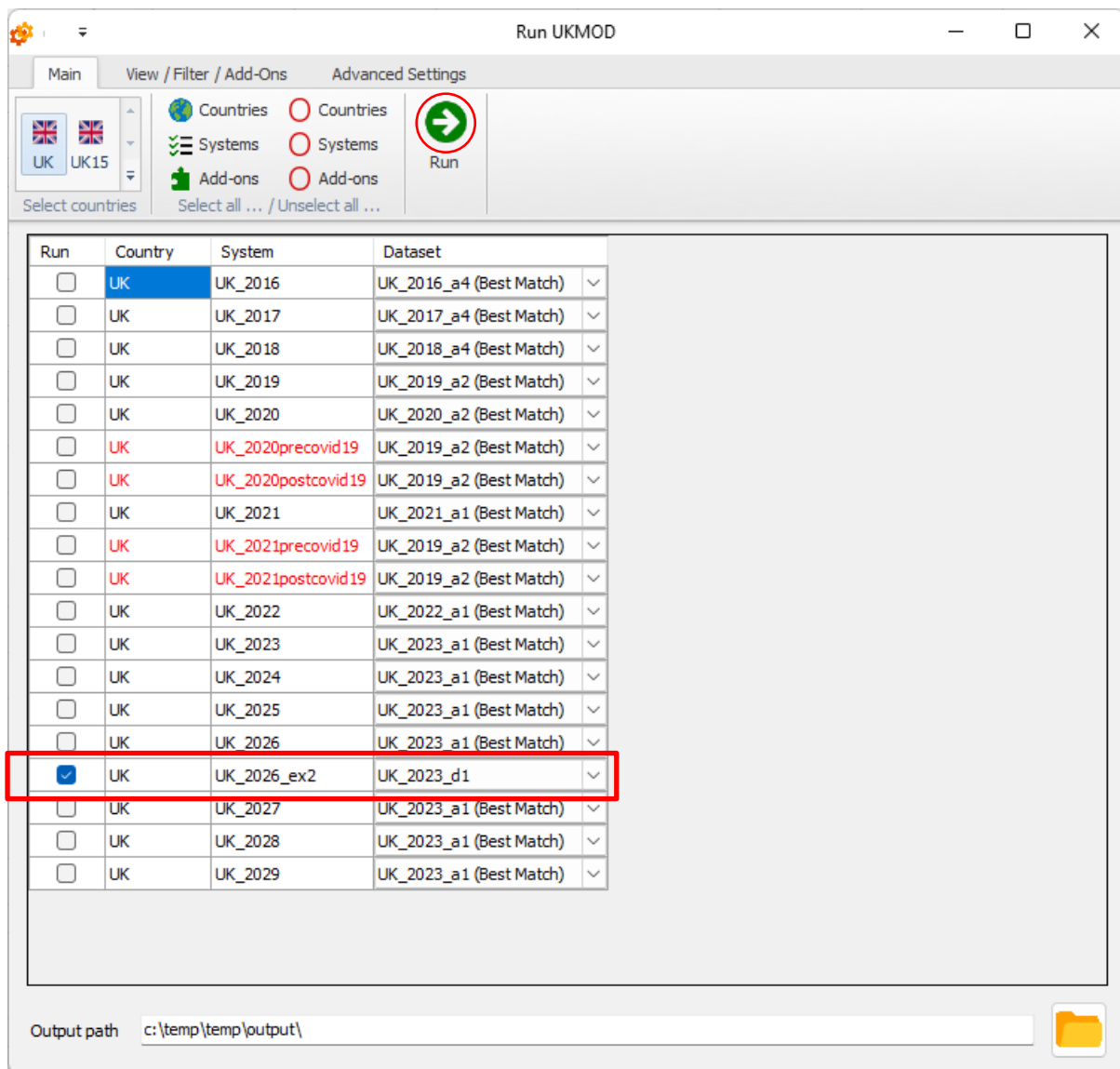
Create a copy of the 2026 system (by right-clicking “UK_2026” at the top of the display window and selecting copy/paste system). Call this copy “UK_2026_ex2”.

Navigate to the indirect tax parameters of the UK_2026_ex2 system and increase the value of parameter \$tco_t_std from 0.2 to 0.25 (as shown).

United Kingdom - UKMOD ukmod-public-b2024.14 (c:\temp\ukmod-public-b2024.14\)					
<div> <div> <div>Open Output File</div> <div>Policy Effects</div> <div>Macrovalidation</div> <div>EUROMOD Statistics</div> <div>Hypothetical Household</div> <div>Income List Components</div> </div> <div>Tools</div> <div>UKMOD plugins</div> </div>					
	Policy	Grp/No	UK_2026	UK_2026_ex2	Comment
4.20	fx DefConst		on	on	Indirect tax parameters
4.20.1	\$tco_t_std		0.2	0.25	vat standard rate
4.20.2	\$tco_t_red		0.05	0.05	vat reduced rate
4.20.3	\$tco_t_zero		0	0	vat zero rate
4.20.4	\$tco_a_02111		9.15	9.15	specific excise - 02111 Spirits and liqueurs (per 70cl bottle, 40% abv)
4.20.5	\$tco_a_02121		2.65	2.65	specific excise - 02121 Still wine (per 75cl bottle, 12% abv)
4.20.6	\$tco_a_02122		2.65	2.65	specific excise - 02122 Sparkling wine (per 75cl bottle, 12% abv)
4.20.7	\$tco_a_02131		0.62	0.62	specific excise - 02122 Beer (per pint 5% abv)
4.20.8	\$tco_a_02211		6.94	6.94	specific excise - 02211 Cigarettes (per packet of 20)
4.20.9	\$tco_a_02212		4.49	4.49	specific excise - 02212 Cigars (per 10g)
4.20.10	\$tco_a_02213		13.97	13.97	specific excise - 02213 Other tobacco (per 30g package)
4.20.11	\$tco_a_04531		0.1	0.1	specific excise - 04530 Liquid fuels for domestic use (including fuel oil) (per litre)
4.20.12	\$tco_a_07221		0.55	0.55	specific excise - 07221 Fuels and lubricants for transport (per litre)
4.20.13	\$tco_v_02211		0.165	0.165	ad valorem excise - 02211 Cigarettes (per packet of 20)
4.21	fx DefConst		on	on	Define constants: Scottish Child Payment

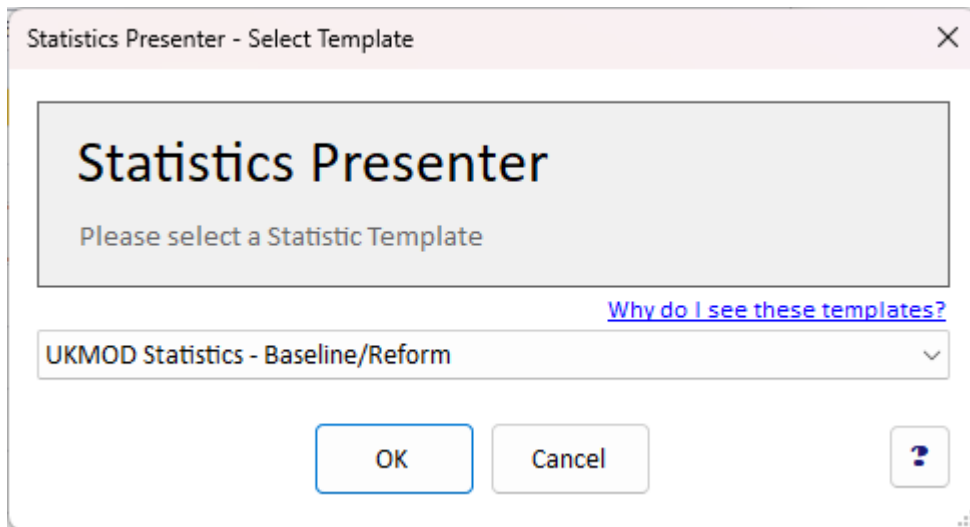
4.3 Run the counterfactual and analyse output

Save the model (CNTRL + s), and re-run the TCO add-on for the new system "UK_2026_ex2".

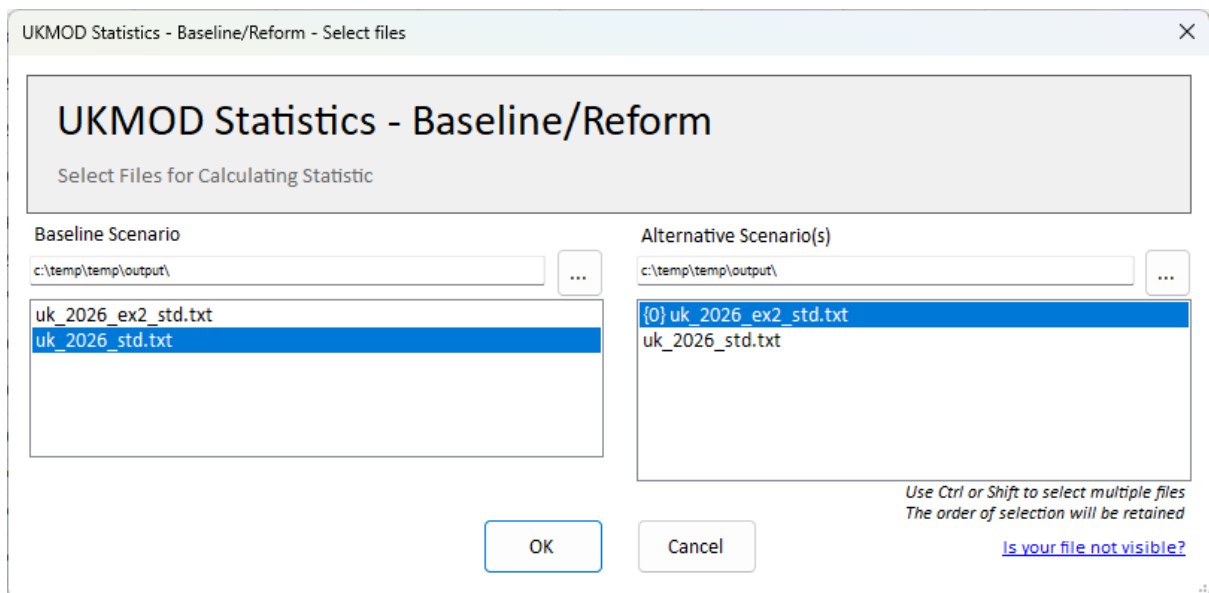


The add-on should run through, this time evaluating behavioural responses to the reform. When the model is complete, we can analyse results using Statistics Presenter.

Open the “Statistics Presenter” selection window, and select “UKMOD Statistics – Baseline/Reform” from the drop-down menu.



Under the Baseline Scenario, select the “uk_2026_std.txt” output, under the Alternative Scenario select the “uk_2026_ex2_std.txt” output, and press “OK”.



When the statistics presenter window is populated you can inspect associated results
(NOTE: results below are for test data only)

UKMOD Statistics - Baseline vs Reforms

Results for United Kingdom 2026 vs UK_2026_ex2



Fiscal Overview Poverty (fixed) Poverty (floating) Inequality Mean HH income (equ) Mean BU income (equ) Income Shares

Gainers/Losers Cut Offs Indirect Taxes Tax Incentives **Metadata**

	UK_2026 Amounts (base)	UK_2026_ex2 Amounts	Difference to base	Recipi UK_
Total market incomes	1,587,953.17	1,587,953.17	0.00	
... employment and self-employment income	1,148,598.37	1,148,598.37	0.00	
... other sources of market income	439,354.80	439,354.80	0.00	
Government revenue through direct taxes and national insurance contributions	523,568.97	523,568.97	0.00	
... direct taxes	368,203.84	368,203.84	0.00	
..... personal income tax (simulated)	325,304.93	325,304.93	0.00	
..... devolved taxes in Scotland	32,215.08	32,215.08	0.00	
..... devolved taxes in Wales	3,107.88	3,107.88	0.00	
..... non-devolved taxes	289,981.96	289,981.96	0.00	
..... non-saving non-dividend taxes	0.00	0.00	0.00	
..... saving income taxes	0.00	0.00	0.00	
..... dividend income taxes	0.00	0.00	0.00	
..... council tax (non-simulated)	42,898.92	42,898.92	0.00	
... all national insurance contributions (simulated)	155,365.13	155,365.13	0.00	
..... national insurance contributions (personal)	47,703.81	47,703.81	0.00	
..... employee national insurance contributions	43,499.00	43,499.00	0.00	
..... self-employed national insurance contributions	4,204.81	4,204.81	0.00	
..... other national insurance contributions	0.00	0.00	0.00	
..... national insurance contributions (employer)	107,661.32	107,661.32	0.00	
Government revenue through indirect taxes	96,646.92	108,460.83	11,813.90	
... all ad valorem excise	927.27	927.27	0.00	
... all specific excise	30,373.44	29,133.23	-1,240.21	
... all value added tax	65,346.23	78,400.34	13,054.11	
Credited national insurance contributions	0.00	0.00	0.00	
Government expenditure on benefits and tax credits	282,821.58	282,821.58	0.00	

UKMOD Statistics - Baseline/Reform

UKMOD Statistics - Baseline vs Reforms
Results for United Kingdom 2026 vs UK_2026_ex2

Fiscal Overview
Poverty (fixed)
Poverty (floating)
Inequality
Mean HH income (equ)
Mean BU income (equ)
Income Shares
Gainers/Losers
Cut Offs
Indirect Taxes
Tax Incentives
Metadata

10.2 Average specific excise by population decile (£ per annum per household member)

	UK_2026 (base)	UK_2026_ex2	Difference to base
Decile 1	423.57	406.25	-17.32
Decile 2	435.38	417.59	-17.79
Decile 3	484.90	465.19	-19.72
Decile 4	503.27	482.72	-20.55
Decile 5	519.54	498.31	-21.24
Decile 6	535.30	513.55	-21.75
Decile 7	509.31	488.48	-20.83
Decile 8	493.13	472.95	-20.19
Decile 9	430.51	412.85	-17.67
Decile 10	403.69	387.24	-16.44
All	473.86	454.51	-19.35
Poor	430.25	412.65	-17.60

10.3 Average value added tax by population decile (£ per annum per household member)

	UK_2026 (base)	UK_2026_ex2	Difference to base
Decile 1	917.62	1,101.01	183.39
Decile 2	938.82	1,126.43	187.61
Decile 3	1,063.71	1,276.13	212.42
Decile 4	1,097.51	1,316.81	219.30
Decile 5	1,100.39	1,320.25	219.86
Decile 6	1,164.86	1,397.53	232.67
Decile 7	1,086.12	1,302.90	216.78
Decile 8	1,026.39	1,231.46	205.07
Decile 9	933.90	1,120.49	186.59
Decile 10	865.42	1,038.32	172.90

References

Cansu Akoguz, E., Capéau, B., Decoster, A., De Sadeleer, L., Güner, D., Manios, K., Paulus, A. and Vanheukelom, T. (2020), “A new indirect tax tool for EUROMOD”, *JRC Project no. JRC/SVQ/2018/B.2/0021/OC*.