CHAPTER 3
GENERAL ISSUES IN MANAGEMENT

Multi-Sectoral Multi-Household General Equilibrium Tax Model: An Application[1]

Keshab R. Bhattarai[2]

Abstract

We present a general equilibrium tax model with four production sectors and three households with a government that collects taxes on capital income, household income and commodities and redistributes income by transferring tax revenue to households. Labour supply is assumed to be exogenous in the first model but endogenous in the second one. We show how tax reforms can create efficiency gains as well as re-allocation and redistribution impacts on an economy. Numerical example shows that economy-wide efficiency gains up to 2.4% of the base year GDP, gains of up to 29% to household 1 who pays higher taxes in the base year and loss of up to 22% to household 2 who loses transfers after the reform and re-allocation of labour and capital input across all sectors.

Key words: general equilibrium, economic welfare, tax model.
JEL classifications: D5, D6, H2, H3

A Prototype of a General Equilibrium Tax Model

Applied general equilibrium models have been used increasingly to evaluate the resource reallocation and redistribution impacts of tax reforms in an economy[3]. We here present two versions and simple numerical examples of a GE tax model for expository purposes. We begin with a four sector three household model with three tax instruments (sales, income and VAT taxes), similar to that considered earlier by Piggott and Whalley (1985). We then report on a version with a labour-leisure choice component added to the basic model. For these two platform models we briefly discuss the specification of preferences and technology, and then describe the construction of the micro-consistent data sets required for model implementation.

We also discuss the methods used for model calibration and choice of the elasticity parameters in preferences and production functions. Once the model replicates the base year economy, we can then solve for a counterfactual equilibrium without taxes in order to evaluate the welfare costs of tax distortions. The tax experiments executed with the platform model and reported here are illustrative.

I. A Specification for a Standard Static General Equilibrium Tax Model

In this section we present a platform version of a standard general equilibrium tax model, to illustrate the basic structure and use of GE model for tax policy analyses. Basic ingredients of

[1] Research reported in this paper was undertaken under an ESRC project on General Equilibrium and Dynamic Modelling for the Analysis of UK Policy Issues in the University of Warwick. I am grateful to Professor John Whalley for guidance in this research. The model developed here was also discussed in a workshop on applied general equilibrium analysis at the economics department of the University of Hull during July 2-6, 2001. I appreciate comments and suggestions from Carlo Perroni, T.F. Rutherford and Mike Ryan in the earlier version of the paper. Earlier version of this paper has appeared as Working Paper 9 in the series of Hull Advances in Policy Economics. Author is solely responsible for any errors and omissions in the paper.

[2] Lecturer in Economics, Centre for Economic Policy, Business School, University of Hull, UK.

[3] Harberger (1962), Shoven and Whalley (1984), King and Fullerton (1984), Whalley (1985), Piggott and Whalley (1985), Scarf (1986), Auerbach and Kotlikoff (1987), Goulder and Summers (1989), Taylor (1990), Kehoe (1991) Robinson (1991), Dixon et al. (1992), Fullerton and Rogers (1993), Mercenier and Srinivasan (1994), Rutherford (1995), Ginsburgh and Keyzer (1997), Bhattarai and Whalley (2000), Harrison et al. (2000), Lau, Pahlke and Rutherford (2002).

these models are found in the standard Arrow-Debreu economy (Arrow and Debreu, 1954). Households maximise utility subject to their budget constraints, and producers maximise profits subject to technology constraints. Both the utility of households and production by firms are given by standard CES (concave, monotonic, homothetic and continuous) functions. The equilibrium conditions imply that markets for goods, labour and capital are clear, firms receive zero profits in equilibrium, and income is equal to expenditure for all households. The role of the government in these platform models is to affect the distribution of income through tax revenue financed transfer programs, by taxing households and corporations on their income and collecting value added taxes from final purchases. Labour supply decisions of the households are in the platform model 2, in which a labour-leisure choice is explicitly included in household utility functions, and labour market clearing takes account of leisure consumed by households. The current model incorporates all standard equilibrium conditions that are characteristics of the computable general equilibrium literature. This class of models is used in both static and dynamic studies of tax reform policies (Ballard, Fullerton, Shoven and Whalley, 1985).

Demands

The household maximises utility which is described by a CES function defined over commodities (i=1 ..N) and leisure, subject to a budget constraint. This utility function can be written as

$$U_h = \left(\sum_i \alpha_{i,h} C_{i,h}^{\rho_h} + \beta_h L_h^{\rho_h} \right)^{\frac{1}{\rho_h}}, \tag{1}$$

where U_h is the utility of household h, $C_{i,h}$ is the consumption of good i by household h, L_h is the leisure taken by household h, $\alpha_{i,h}$ is the share of the full income of household h spent on consumption of good i, β_h is the share of full income spent on leisure, and ρ_h is the elasticity parameter in the utility function, the elasticity of substitution between goods (and leisure) being equal to $\sigma_h = \frac{1}{1-\rho_h}$ (Varian, 1992). In versions of the model in which leisure does not appear β_h=0 and $\sum_{i=1}^{N} \alpha_{i,h} = 1$.

Households receive income from capital and labour endowments, and transfers from the government. They pay taxes on household and capital income. The disposable income of a household is given by

$$I_h = r(1-t_k)\overline{K}_h + (1-t_l^h)w\overline{L}_h + TR_h, \tag{2}$$

where I_h is the full income of the household, $\overline{K}_h$ is its endowment of capital, $\overline{L}_h$ is its endowment of labour, TR_h are the transfers received by household h, r is the rental rate of capital, w is the wage rate, t_l^h is the tax rate on household h's labour income[1], and t_k is the tax rate on capital income.

The demand functions for goods and leisure are obtained by maximising (1) with respect to (2), and take the following form

[1] The effect of tax distortions on the labour leisure choice can be captured through a subsidy to the consumption of leisure at rate t_l^h.

$$C_{i,h} = \left(\frac{\alpha_{i,h} I_h}{\left(P_i(1+t_i^v)\right)^{\sigma_h} \left(\sum_i \alpha_{i,h} \left(P_i\left(1+t_i^v\right)\right)^{\sigma_h} + \beta_h \left(w\left(1-t_l^h\right)\right)^{\sigma_h} \right)} \right), \tag{3}$$

where t_i^v is value added tax rate and t_l^h is tax rate on labour income, and P_i is the price of commodity *i*.

Consumption of leisure is given by

$$L_h = \left(\frac{\beta_h . I_h}{\left(w\left(1-t_l^h\right)\right)^{\sigma_h} \left(\sum_i \alpha_{i,h} \left(P_i\left(1+t_t^v\right)\right)^{\sigma_h} + \beta_h \left(w\left(1-t_t^h\right)\right)^{\sigma_h} \right)} \right). \tag{4}$$

In versions of the model where there is no demand for leisure households have demand functions only for goods. In that case equation (4) does not exist, and equation (3) is modified by setting β_h=0.

In the one household case, the labour supply of the household LS_h is given by the difference between the household labour endowment, and the demand for leisure, L_h.

$$LS_h = \overline{L}_h - L_h . \tag{5}$$

In equilibrium, this labour supply by the household must be consistent with the total demand for labour derived from the profit maximisation behaviour of firms as set out in the following section.

Production

Producers use labour and capital in each of *N* sectors to yield value added. This also is given by CES functions.

$$Y_i = \Omega_i((1-\delta_i)(K_i)^{\gamma_i} + \delta_i(L_i)^{\gamma_i})^{\frac{1}{\gamma_i}}, \ (i = 1..N) \tag{6}$$

where Y_i is the value added of sector *i*, Ω_i is a shift parameter in the production function, K_i and L_i are the amounts of capital and labour used in sector *i*, δ_i is the share parameter of labour in the CES function, and γ_i is the CES factor substitution parameter.

The gross output of each sector reflects the use of value added, Y_i, and intermediate inputs. We assume fixed coefficients both among intermediate inputs, and between value added and intermediate inputs; $M_{i,j}$ is the intermediate use of good *i* in the production of good *j* and X_i is the gross output of sector *i*. At any set of prices, producers in each sector maximise profits subject to their technology constraint

$$\max \Pi_i = P_i X_i - wL_i - rK_i - \sum_j P_j M_{j,i} \tag{7}$$

where Π_i is the profit of sector *i*. In equilibrium, factor demands by sectors are determined where the value marginal product of factors is equal to factor prices, and there are no positive profits for producers.

Government Budget

The government collects revenue from taxes on capital and labour income and value-added taxes. All the tax revenues collected are transferred to households in lump sum form; ie.

$$\sum_h TR_h = \sum_i t_k r K_i + \sum_h t_i^v P_i C_{i,h} + \sum_h t_l^h w LS_h \, , \tag{8}$$

where t_k is the tax rate on capital income, t_i^v is the *ad valorem* tax rate on final sales, t_l^h is the tax rate on labour income of the household.

These taxes, particularly when they are levied at different rates on different sectors and households, have distortionary impacts on the allocation of resources in the economy. These are captured by the model. Government budget balance is a property of an equilibrium.

Model Equilibrium Conditions

In this model a competitive equilibrium is given by prices of consumption goods, P_i; the rental rate of capital r; a wage rate for labour, w; and levels of gross output, Y_i; capital use, K_i; and sectoral use of labour, L_i; such that,

i) markets for goods and services, labour and capital are clear; and
ii) the government budget constraint is satisfied.

More specifically, the market clearing condition for the goods market is given by

$$X_i = C_i + \sum_{j=1}^{N} a_{ij} X_j \, , \tag{9}$$

where $C_i = \sum_h C_{i,h}$ is household final consumption, and $\sum_j a_{ij} X_j$ the intermediate demand.

The capital market clearing condition implies

$$\sum_h \overline{K}_h = \sum_i K_i \tag{10}$$

and labour market clearing implies:

$$\sum_h LS_h = \sum_i LS_i \, . \tag{11}$$

Government budget balance is given by (8). When there are *n* different markets in the economy, relative prices that clear *n*-1 markets clear the *n*th market as well.

II. A Simple Micro-Consistent Data set for a Platform GE Tax Model

We can illustrate the operation of this platform model by using a simple example of a micro-consistent data set taken from Piggott and Whalley (1985). This data set meets the equilibrium conditions for a competitive economy: demand equals supply for all goods and factors, non-positive profits are made in all industries and the government budget constraint in the presence of taxes is satisfied (Mansur and Whalley, 1984; and St- Hilaire and Whalley, 1983). The input-output data on firms in Tables 1-3 are illustrative, but they are separately available for the UK economy in National Accounts and related sources as the starting point for base year model calibration. If the required balance conditions do not hold in the raw data, various adjustments become necessary. The construction of such a data set, based on UK national accounts and other data sources, is discussed in Section 4 and Appendix 1.

Table 1

Illustrative Input-output value transactions matrix for the platform model

Sectors	Sector 1	Sector 2	Sector 3	Sector 4
Sector 1	2	1	2	3
Sector 2	4	3	1	2
Sector 3	2	1	1	1
Sector 4	2	1	1	0

Our simple example of a data set for use in the platform model includes four sectors, three households, a government sector, and three types of tax instruments: taxes on capital income, household income and value added. These are displayed in Tables 1-3, where data reported are in transactions (or value) terms[1]. This platform model is a closed economy model with an implicit assumption that foreign trade balances in general.

Table 2

Illustrative Data on consumption, income, output and taxes for the platform model

Sectors	Sector 1	Sector 2	Sector 3	Sector 4
Consumption 1	4	2	4	1
Consumption 2	2	3	1	3
Consumption 3	1	1	3	4
Capital Income	1	2	3	1
Labour Income	2	4	3	1
Indirect Taxes	1	2	1	1
VAT	1	2	1	3
Base year price	1	1	1	1
Total Output	15	16	13	12

Table 3

Illustrative Data on Sources of Income to the households for the platform model

	Household 1	Household 2	Household 3
Interest income	5	1	1
Wage income	3	3	4
Transfer income	6	7	6
Household taxes	3	2	2

Tables 1-3 provide the basic data required for the implementation of the first platform model. The input-output transactions for this illustrative economy are given in Table 1, where rows represent purchases of intermediate goods by other sectors and columns represent purchases of intermediate goods by a particular sector. For instance, the first column represents the purchase

[1] This particular example is discussed in more detail in Shoven and Whalley (1992), and earlier in Piggot and Whalley (1985).

of intermediate inputs by sector 1, and the first row represents the sale of intermediate goods by sector 1 to other sectors. Input-output coefficients, which give the input requirements from sector *i* per unit of output in sector *j*, provide forward and backward linkages in the production sectors of the economy.

Information on consumption of each of three households and value added payments to capital and labour, indirect business taxes, VAT on final consumption and base-year prices are given in Table 2. The economy wide balance requires that total output be equal to the total of intermediate demand and final consumption.

Sectoral payments of wages and salaries and interest accrue to households, which provide these labour and capital services to producers. The allocation of wage and interest income among various households is as described in Table 3. From this table, it is evident that household 1 owns more capital and receives a larger amount of capital income compared to other households. It also pays more taxes when compared to other households, and receives less in transfers than household 2.

III. Calibration of Parameters and elasticities used in the platform model

The computer code used in implementing these platform models, MPSGE/GAMS programmes[1], proto.gms and leisure.gms are presented in appendices[2].

We use the data presented in Tables 1-3 to calibrate the share parameters in the CES functions used in the platform version of the model, as specified in the previous section. The calibrated share parameters in consumption and production presented below are consistent with the replication of the benchmark data by the model equilibrium solutions.

Table 4

Calibrated share parameters in consumption in illustrative example of a platform economy

Sectors	Sector 1	Sector 2	Sector 3	Sector 4
Household 1	0.429	0.167	0.338	0.078
Household 2	0.245	0.286	0.125	0.268
Household 3	0.122	0.100	0.375	0.357

The figures in Table 4 show that households differ in preferences over consumption goods. For instance, household 1 spends more on commodities 1 and 3 than on commodities 2 and 4. Household 3 spends more on commodities 3 and 4 than on commodities 1 and 2. Consumption preferences of household 2 lies between those of households 1 and 3.

Capital and labour are the only two primary factors of production for each sector considered in the platform model 1 (equation 6). With constant returns to scale in production, the value of output at factor cost will equal the remuneration of capital and labour. The production side calibrated share parameters are given in Table 5, which shows that sector 1 and 2 are labour intensive while sectors 3 and 4 use equal shares of labour and capital.

To calibrate share parameters to base year data, we also need numerical values of elasticities of substitution in utility and production. Numerical values of these estimates can be crucial in deriving model results. Following a standard practice common to applied general equilibrium modellers, we select elasticity parameters close to literature based estimates as presented in Table 6 (see appendix for various estimates of elasticity of substitution).

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[1] See Rutherford T. F. (1997) for details.

[2] We use the GAMS (Generalised Algebraic Modelling Software) software (Brooke, Drud, & Kendrick ((1980)) to implement these models. This is optimization software which is used in GE model format by introducing all required model equilibrium conditions into constraints on nonlinear optimization. The GAMS format has convenient and transparent syntax, and good display and diagnostic features, explaining its use. While widely used by general equilibrium modellers, GAUSS, MATLAB, and MATHEMATICA play a similar role.

Table 5

Calibrated shares of capital and labour in production in illustrative example of a platform economy

Sectors	Share of capital income	Share of labour income
Sector 1	0.333	0.667
Sector 2	0.333	0.667
Sector 3	0.500	0.500
Sector 4	0.500	0.500

Table 6

Elasticity of substitution in consumption and production

	Elasticity of substitution
Among consumption goods	1.5
Capital and labour	0.75

Table 7

Capital and Value added Tax rates in the base year in illustrative example of a platform economy

Sectors	Tax Rate on Capital Income	Value-added Tax Rates
S1	1.00	0.17
S2	1.00	0.50
S3	0.33	0.14
S4	1.00	0.60

The above discussion implies that we are now able to use the platform version of this model for general equilibrium analysis of tax policy. The basic platform model has three different tax instruments: taxes on capital income, value-added taxes on sales of final goods, and taxes on household income. Tax rates on capital and household income are given in Tables 7 and 8. Tax rates on household income are given in Table 8, which also shows net transfer as fraction of household income.

Table 8

Household tax rates in illustrative example of a platform economy

Households	Household income tax rates	Net transfers as fraction of household income
H1	0.27	0.27
H2	0.22	0.55
H3	0.22	0.44

A standard test of the code of an applied general equilibrium model lies in the replication of the benchmark equilibrium with the use of calibrated parameters and selected values of elasticities. Unless the model reproduces the base year data as a solution to the specified model, the calibration process is not complete. This puts limitations on the admissible set of parameters in a calibrated model. Only parameters that are consistent with the replication of the base year equilibrium are meaningful for policy analysis.

After checking the replication of the benchmark economy, we solve the base case of platform model 1 with existing taxes on production and consumption as given by the tax rates in Tables 7-8. Basic economic theory suggests that these taxes distort the allocation of resources in the economy, causing inefficiency in consumption and production, and affecting the distribution of income among households (Varian, 1992). We now turn to defining measures of the welfare cost from tax distortions in the platform economy.

IV. Welfare and Distributional Impacts of Tax changes in the Platform Model

We use comparative static analysis to measure the welfare costs of tax distortions by comparing an equilibrium with taxes and an equilibrium without taxes. Traditionally, equivalent and compensating variation measures are used to compute the welfare costs of tax distortions. Hicksian equivalent variation measures changes in money metric utility between tax and no-tax equilibria. Compensating variation measures the amount of money required to bring a household back to the same level of utility as in the benchmark equilibrium following changes in prices in counterfactual equilibrium. In the linear homogenous utility case, implied by the CES functions, the equivalent and compensating variation can be defined as[1]:

$$EV^h = \left(\frac{U_C^h - U_B^h}{U_B^h}\right) I_C^h, \tag{12}$$

$$CV^h = \left(\frac{U_B^h - U_C^h}{U_C^h}\right) I_B^h, \tag{13}$$

where subscripts C and B stand for counterfactual and benchmark equilibria, EV^h and CV^h are the equivalent and compensating variation due to tax changes, U_C^h and U_B^h are utility levels in counterfactual and benchmark scenarios, and I_C^h and I_B^h are levels of income in counterfactual and benchmark equilibria. Equations (12) and (13) provide the basis for an economy wide calculation of the distorting welfare cost of any given set of sales and/or labour income taxes. The total welfare cost is computed by taking the arithmetic sums of *EV*s and *CV*s across households, *h*. We then express these sums as a fraction (or percentage) of the relevant sum of economy wide income measures:

$$TEV = \frac{\sum_h EV^h}{\sum_h I_o^h}, \tag{14}$$

$$TCV = \frac{\sum_h CV^h}{\sum_h I_n^h}, \tag{15}$$

where TEV and TCV are the economy-wide total equivalent and compensating variation from the tax changes.

The welfare costs (gains from removal) of tax distortions in the platform model are reported in Table 9.

[1] See Shoven and Whalley (1992, chapter 4).

Table 9

Welfare gains from removing tax distortions in the platform model (EV, CV as a fraction of income)

Households	Equivalent Variation	Compensating Variation
H1	0.299	-0.230
H2	-0.226	0.291
H3	-0.119	0.135

The welfare costs presented here show significant effects on the distribution of income among households. Household one gains by 29% of its benchmark income. Before tax reform, this household was paying the highest rate of income tax, and received a lower share of transfers compared to other households. Tax reform reduces their tax burden and they lose their transfer component of income, but this is less than that of other households. Meanwhile households 2 and 3 are worse off because of the tax change. This is mainly due to the loss of the transfer component of their income.

It should be noted that money metric gains occurring for household 1 are sufficient to compensate the money metric losses to households 2 and 3. The overall economy wide impact of tax distortions, measured through Equivalent Variation is 0.00703 (and the corresponding compensating variation is -0.00716). Though this economy-wide tax reform has only a small gain in comparison to the magnitudes of tax rates existing in the platform economy, model results show the redistribution of income among households which take place due to the change. However, we would expect a larger net overall gain to the economy after the removal of distortions caused by the taxes to the allocation of resources under a further refinement to the platform model, to include the labour-leisure choices made by households. This is discussed in the next section.

V. Labour-Leisure choice in the platform model

The implicit assumption in implementing the platform version of the model so far has been that households only value commodities, and they supply all of their labour endowment as labour services to producers. However, households care for leisure as well as their labour income when maximizing utility, given their time endowments. There is a trade off between labour and leisure, and a labour-leisure choice can be incorporated in the model by including leisure in the utility function. The choice of leisure, given the time and budget constraints of the households, implies a labour supply decision consistent with maximization of utility by households. An explicit consideration of a labour leisure choice is central to any consideration of the labour supply impacts of tax reforms.

The data presented earlier in Tables 1-3 have been modified in order to incorporate a labour-leisure choice in the platform general equilibrium tax model. These modified data are presented in Tables 10-12.

Table 10

Input-output table for platform model 2

Sectors	Sector 1	Sector 2	Sector 3
Sector 1	2	1	5
Sector 2	4	3	3
Sector 3	4	2	3

Table 11

Data on consumption, income, output and taxes for platform model 2

Sectors	Sector 1	Sector 2	Sector 3
Consumption 1	4	2	4
Consumption 2	2	3	2
Consumption 3	1	1	5
Capital Income	1	2	3
Labour Income	1	3	1
Indirect Taxes	1	3	1
VAT	1	2	4
Base year price	1	1	1
Total Output	14	14	16

Table 12

Income source data for platform model 2

	Household 1	Household 2	Household 3
Interest income	5	1	1
Transfer income	6	6	7
Household taxes	3	2	2
Leisure	1	1	3
Labour Supply	2	2	1
Labour supply to s1	1	0	0
Labour supply to s2	1	2	0
Labour supply to s3	0	0	1
Price of leisure	1	1	1

Calibrated parameters used in the GE tax model with a labour-leisure choice are presented in Tables 13-15. The utility function contains two nests. First a composite good is constructed by using the elasticity of substitution among commodities, as shown in Table 16. Then households choose between leisure and the composite good. The budget shares spent on composite good and consumption of leisure by household are given in Table 13.

Table 13

Shares of consumption and leisure in the leisure utility function in platform model 2

Households	Share of full income spent on consumption	Share of full income spent on leisure
H1	0.913	0.087
H2	0.831	0.169
H3	0.588	0.412

Poor households (i.e. type H2 and H3) take more leisure compared to rich households of type H1 whereas the share of consumption in full income is higher for the high income households. This indicates that the richer households supply more labour than the poor households as the opportunity cost of labour is higher for them.

Table 14

Calibrated shares in consumption in platform model 2

Households	Sector 1	Sector 2	Sector 3
H1	0.429	0.167	0.318
H2	0.286	0.333	0.212
H3	0.107	0.083	0.398

Figures in Table 14 show the pattern of preference for consumption by the three households. Household 1 spends more on sector 1 good, while household 3 likes more sector 3 goods.

Table 15

Calibrated shares of capital and labour in production

Sectors	Share of capital income	Share of labour income
S1	0.333	0.667
S2	0.600	0.400
S3	0.250	0.750

The factor intensity differs among sectors in a multisectoral model. Some sectors are capital intensive and others are labour intensive in the production process. Figures in Table 15 show that sector 1 and sector 3 are labour intensive ones while sector 2 is a capital intensive sector.

Table 16

Elasticities of substitution in consumption and production in platform model 2

	Elasticity of substitution
Leisure and consumption	0.75
Among consumption goods	2.0
Capital and labour	2.0

As with platform model 1, we use platform model 2 to evaluate the distortionary cost of taxes for this illustrative economy. This is done by comparative static analysis of tax and non tax equilibria.

The tax rates on capital and labour income and value added taxes similar to Table 7 are presented in Table 17.

Table 17

Tax rates used in the base case in the platform 2 model.

Sectors	Tax Rate on Capital Income	Value-added Tax Rates
S1	0.5	0.17
S2	1.5	0.50
S3	0.33	0.571

This prototype model includes household tax rates, which are reported in Table 18.

Table 18

Household tax rates in the platform 2 model

Households	Household income tax rates	Net transfers as fraction of household income
H1	0.27	0.27
H2	0.22	0.56
H3	0.22	0.44

To measure the distortionary cost of taxes in this case we compute equivalent and compensating variations for each household, comparing money-metric utility measures of households before and after the tax changes, as given by equations 12-15.

Table 19

Welfare gains from removal of tax distortions in platform model 2

Households	Equivalent Variation	Compensating Variation
H1	-0.31	0.31
H2	0.44	-0.44
H3	0.57	-0.57

The redistributive impacts of these tax changes are again significant. On the contrary to platform model 1, household 1 is worse off after the change, while households 2 and 3 gain. This result is due to differences in the valuation of leisure by these households. Because household 1 values leisure is less than households 2 and 3, a reduction in the cost of leisure after the tax change is more favourable to households 2 and 3 than to household 1. Thus we show that taking account of leisure significantly changes the model outcome.

The economy-wide impacts of these tax changes are positive. The overall EV is equal to 2.4% of the total income of the economy (the corresponding CV was equal to -2.5%). This result is strikingly different from the small but positive effect of tax reforms reported in the case of version 1 of the platform model.

Another useful way of measuring the cost of tax distortions is to find the welfare cost of each additional pound of tax revenue raised by extra taxation. Economists have used the marginal excess burden of taxes (MEB) concept to measure these additional welfare costs. This measure gives the loss of welfare (money metric utility) in an incremental tax equilibrium compared to the before (base case tax) tax equilibrium. In version 2 of the platform model, an extra pound raised by means of incremental taxes (i.e. scaling all existing tax rates proportionately) has an excess burden equal to 21 pence. This MEB figure is comparable to those found in earlier general equilibrium analysis of tax policies (e.g. Ballard, Fullerton, Shoven and Whalley, 1985; and Piggott and Whalley, 1985; Goulder and Summers, 1989; see the appendix for an elaborated list).

VI. Conclusion

We use two prototypes of closed economy multi-sector multi-household static general equilibrium tax model with the government collecting taxes on capital income, value-added taxes on commodities and taxes on household income and redistributing income by means of transfers to households. Labour supply is exogenous in the first model, while labour-leisure choice is endogenous in the second one.

The value-added tax influences the composition of final demand, income tax and accompanying transfers influence the labour supply decisions of the households. Differential rates of capital income across sectors distort the allocation of capital resources across sectors. Production subsidies reduce the selling price of commodities below the cost of production.

When taxes eliminated household 1, which was paying the highest rate of income tax and received a lower share of transfers compared to household 2 and 3 gains, by 29% of its benchmark income. Tax reform reduces its tax burden. Meanwhile households 2 and 3 are worse off by 22 and 11% of their base income because of the tax change. This is mainly due to the loss of the transfer component of their income. Money metric gains occurring for household 1 are sufficient to compensate the money metric losses to households 2 and 3. The overall economy wide impact of tax distortions, measured through Equivalent Variation is 0.00703 (and the corresponding compensating variation is -0.00716). Though this economy-wide tax reform has only a small gain in comparison with the magnitudes of tax rates existing in the platform economy, model results show the redistribution of income among households which take place due to the change.

The redistributive impacts of these tax changes are significant even in the second model, where we consider labour leisure choice endogenously. On the contrary to platform model 1, household 1 is worse off after the change, while households 2 and 3 gain. This result is due to differences in the valuation of leisure by these households. Because household 1 values leisure is less than households 2 and 3, a reduction in the cost of leisure after the tax change is more favourable to households 2 and 3 than to household 1. Thus we show that taking account of leisure significantly changes the model outcome.

The economy-wide impacts of these tax changes are positive. The overall EV is equal to 2.4% of the total income of the economy (the corresponding CV was equal to -2.5%). This result is strikingly different from the small but positive effect of tax reforms reported in the case of version 1 of the platform model. In version 2 of the platform model, an extra pound raised by means of incremental taxes (i.e. scaling all existing tax rates proportionately) has an excess burden equal to 21 pence.

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APPENDIX

GAMS/MPSGE code for the Prototype General Equilibrium Tax Model

A1.*Prototype Multisectoral General Equilibrium Model**

```
$OFFLISTING
Option decimals=5;

SET

      I       Sectors  /
      S1      Sector 1
      S2      Sector 2
      S3      Sector 3
      S4      sector 4
      /

      HH      Households and labor categories  /
            H1      Household 1
            H2      Household 2
            H3      Household 3
      /;

ALIAS (I,J), (LC,HH), (H,HH);


TABLE IOF(I,J) Input-output flows
      S1      S2      S3      s4
S1      2       1       2       3
S2      4       3       1       2
S3      2       1       1       1
s4      2       1       1       0


TABLE ZZ(*,I) MISCELLANEOUS PARAMETERS AND INITIAL DATA
      S1      S2      s3      S4
Cons1   4       2       4       1
cons2   2       3       1       3
cons3   1       1       3       4
Tax     1       2       1       1
Ka      1       2       3       1
Lb      2       4       3       1
vat     1       2       1       3
XD      14      14      12      9
p0      1       1       1       1

Table income(*,hh) Sources of Income to the households
      h1      h2      h3
intr    5       1       1
wage    3       3       4
trns    6       7       6
hhtx    3       2       2
;
```

```
PARAMETER
            C0(hh,I)  gross of VAT consumption
            D0(HH,I)  net of VAT consumption
            GREV      government revenue
            HIT(HH)   taxes on household income
        HIT0(HH)     taxes on household income
        HTX(HH)     revenue of taxes on household income
            IN0(I,J)   input of sector i good to sector j output
            I0(HH)     gross income of househods
            INTR(HH)   interest income
            K0(I)      capital services used per sector
            L0(I)      labor used in each sector
            p0(I)      benchmark prices of commodities
            rk0(i)
            tk(i)      tax rates on capital services
            TL(I)      tax rates on labor
            TR(HH)     transfer to households
            NTR(HH)    net transfer to households
            ntrr(hh)   net transfer rate to households
            VA0(I)     value added in benchmark
            vAt(I)     value added tax revenue in the benchmark
            WAG(HH)    labor endowment of households
            Y0(I)      output per-sector
            tk0(i)     base year capital tax rate
            vt(i)      value-added tax rate
            vt0(i)     base year value-added tax rate
             ;

*       Extract some data:

y0(I) = ZZ("XD",I);
C0("H1",I) = ZZ("CONS1",I);
C0("H2",I) = ZZ("CONS2",I);
C0("H3",I) = ZZ("CONS3",I);
D0(HH,I) =C0(HH,I);
IN0(I,J) = IOF(I,J);
K0(I) = ZZ("KA",I);
L0(I) = ZZ("LB",I);
P0(I) =  ZZ("P0",I);
VAT(I) = ZZ("VAT",I);

WAG(hh) =INCOME("WAGE",HH);

INTR(HH) =INCOME("INTR",HH);
TR(HH) = INCOME("TRNS",HH);
HTX(HH) =INCOME("HHTX",HH);

NTR(HH) =TR(HH)-HTX(HH);

I0(HH) =WAG(HH)+INTR(HH)+NTR(HH);

*       Impose a marginal income

HIT(HH) =HTX(HH)/I0(HH);
ntrr(hh) =ntr(hh)/i0(hh);
```

```
*       Calibrate capital tax rates to the data:

tk(i) =ZZ("Tax",I)/k0(i);
rk0(i) = 1 + tk(i);
display tk;

*       calibrate the value-added tax from the data:
VT(I) =VAT(I)/(SUM(HH,C0(HH,i))-VAT(i));
p0(i) =  1 + vt(i);
D0(HH,I) =C0(HH,I)/(1+VT(I));

GREV = SUM(I,VAT(I)+ZZ("Tax",I))+SUM(HH,HTX(HH));

DISPLAY Y0,VT,I0, TK,D0,IN0,K0,L0,TR,HTX,GREV;

*Check the zero profit condition in the base year

PARAMETER prf(i), MKT(*), IB(HH), PL0, RK0;

PL0=1;

*       Zero profit:

prf(i) = y0(i) - sum(j, iof(j,i)) - l0(i) - k0(i)*rk0(i);
display prf;

*       Market clearance:
mkt(i) = y0(i) - sum(j,iof(i,j)) - sum(hh,d0(hh,i));
mkt("l") = sum(hh, wag(hh)) - sum(i, l0(i));
mkt("k") = sum(i, k0(i)) - sum(hh,intr(hh));
display mkt;

*check income balance condition for households

IB(HH) =SUM(I,(D0(HH,I)*P0(I))) -WAG(HH)*PL0 -INTR(HH) -NTR(HH);

DISPLAY IB,hit,ntrr;

$ONTEXT

$MODEL:pjw

$COMMODITIES:
      P(I)    ! SUPPLY PRICE
      RK   ! CAPITAL RENTAL RATE
      PL  ! WAGE RATE
      PT  ! value of transfers
      PU(HH) ! unit expenditure cost index

$SECTORS:
      Y(I)    ! PRODUCTION
      U(HH)   ! consumpion
$CONSUMERS:
      RA(HH)   ! PRIVATE HOUSEHOLDS
```

```
      govt     ! tax income account

$PROD:Y(I)  s:0   VA:1.5
      O:P(I)          Q:Y0(I)
      I:P(J)          Q:IOF(J,I)
      I:PL            Q:L0(I) VA:
      I:RK            Q:K0(I) VA:  A:GOVT  T:TK(I) P:rk0(i)

$PROD:U(HH)     S:0.75
      O:PU(HH)        Q:I0(HH)
      I:P(I)          Q:D0(HH,I)    A:GOVT  T:VT(I) P:P0(I)

$DEMAND:GOVT
      D:PT     Q:grev

$DEMAND:RA(HH)
      E:PL            Q:WAG(HH)
      E:RK            Q:INTR(HH)
      E:PT            Q:NTR(HH)
      D:PU(HH)

$REPORT:
      V:Y1(I)    O:P(I)    PROD:Y(I)
      V:U1(HH)    O:PU(HH)  PROD:U(HH)
      V:L1(I)    I:PL      PROD:Y(I)
      V:K1(I)    I:RK      PROD:Y(I)
      V:W(HH)    W:RA(HH)

$OFFTEXT

*OPTION SYSOUT =ON;
$SYSINCLUDE mpsgeset PJW

PJW.ITERLIM = 0;
$INCLUDE PJW.GEN
SOLVE PJW USING MCP;

***Retrieving parameters consistent with the equilibrium *****

parameter va(i), betak(i),betal(i),netinc(h),alpha(h,i);

va(i) =PL.L*L1.L(I) +RK.L*K1.L(I);
netinc(h) =ra.L(H)-HTX(H);
betal(i) =(PL.L*L1.L(I))/va(i) ;
betak(i) =  (rk.L*K1.L(I))/va(i);
*alpha(h,i) =p.l(I)*d0(H,I)/NETINC(H);
alpha(h,i) =p.l(i)*d0(H,I)/netinc(H);
display va,betak,betal,netinc,alpha;

*       Assign base year taxes:
vt0(i) = vt(i);
hit0(hh) = hit(hh);
tk0(i) = tk(i);

DISPLAY "FIRST", P.L,PL.L,RK.L,PU.L;
```

```
PARAMETER WA(HH),EV0(HH),CV0(HH),EV,CV;
WA(HH) =W.L(HH);

*tax reform: elimination of all taxes

VT(I) =0.01;
TK(I) =0.01;
hIt(hh) =0.0;

PJW.ITERLIM = 1000;
$INCLUDE PJW.GEN
SOLVE PJW USING MCP;

DISPLAY P.L,PL.L,RK.L,PU.L;

CV0(HH) =(W.L(HH)-WA(HH))/WA(HH);
EV0(HH) =(WA(HH)-W.L(HH))/W.L(HH);
EV =SUM(HH,EV0(HH))/SUM(HH,WA(HH));
CV =SUM(HH,CV0(HH))/SUM(HH,W.L(HH));

DISPLAY WA,W.L,EV0,CV0,EV,CV;
```

A2. * Labour Leisure choice Model**

```
$OFFLISTING
$offsymlist offsymxref
SET

      I       Sectors  /
      S1      Sector 1
      S2      Sector 2
      S3      Sector 3
      /

      HH      Households and labor categories  /
            H1      Household 1
            H2      Household 2
            H3      Household 3
      /;

ALIAS (I,J), (LC,HH), (H,HH);

TABLE IOF(I,J) Input-output flows
      S1      S2      S3
S1      2       1       5
S2      4       3       3
S3      4       2       3

TABLE ZZ(*,I) MISCELLANEOUS PARAMETERS AND INITIAL DATA
      S1      S2      s3
Cons1   4       2       4
cons2   2       3       2
cons3   1       1       5
Tax     1       3       1
```

```
      Ka      2       2       3
      Lb      1       3       1
      vat     1       2       4
      XD      14      14      16
      p0      1       1       1

      TABLE ZZ1(HH,*) Leisure accounts of the households
      Le     la     ls1    ls2    ls3    intr   trns    hhtx  PLE0
h1    1      2      1      1      0      5      6       3      1
h2    1      2      0      2      0      1      6       2      1
h3    3      1      0      0      1      1      7       2      1
;

      PARAMETER
                 C0(hh,I)
                 D0(HH,I)
                 LE0(HH,I)
                 LA0(HH,I)
                 GREV
                 HTX(HH)
                 HIT(HH)
                 hit1(hh)
                 IN0(I,J)
                 I0(HH)
                 INTR(HH)
                 K0(I)
                 L0(I)
                 p0(I)
                 PLE0(HH)

                 tk(i)
                 tk1(i)
                 TR(HH)
                 NTR(HH)
                 Tx(I)
                 VA0(I)
                 vAt(I)
                 VT(I)
                 vt1(i)
                 WAG(HH)
                 WLE(HH)
                 Y0(I)
                  ;

      y0(I) = ZZ("XD",I);
      C0("H1",I) = ZZ("CONS1",I);
      C0("H2",I) = ZZ("CONS2",I);
      C0("H3",I) = ZZ("CONS3",I);
      D0(HH,I) =C0(HH,I);
      IN0(I,J) = IOF(I,J);
      K0(I) = ZZ("KA",I);
      L0(I) = ZZ("LB",I);
      P0(I) =  ZZ("P0",I);
      VAT(I) = ZZ("VAT",I);
```

```
PLE0(HH) =  ZZ1(HH,"PLE0");
WAG(HH) = ZZ1(HH,"LA");
WLE(HH) = ZZ1(HH,"LE");

INTR(HH) =ZZ1(HH,"INTR");
TR(HH) = ZZ1(HH,"TRNS");
HTX(HH) =ZZ1(HH,"HHTX");

NTR(HH) =TR(HH)-HTX(HH);

I0(HH) =WAG(HH)+INTR(HH)+NTR(HH);

HIT(HH) = HTX(HH)/I0(HH);

I0(HH) =WAG(HH)+INTR(HH)+NTR(HH);

HIT(HH) =HTX(HH)/I0(HH);
tk(i) =ZZ("Tax",I)/k0(i);

VT(I) =VAT(I)/(SUM(HH,C0(HH,i))-VAT(i));

D0(HH,I) =C0(HH,I)/(1+VT(I));

GREV = SUM(I,VAT(I)+ZZ("Tax",I))+SUM(HH,HTX(HH));


DISPLAY Y0,D0,HTX,I0,IN0,K0,L0,VAT,INTR,TR,GREV,TK,VT,HIT;

PARAMETER MKT(I), IB(HH), PL0, RK0;


PL0=1; RK0=1;
MKT(I) =Y0(I)-SUM(J,IN0(I,J))-SUM(HH,D0(HH,I));
IB(HH) =SUM(I,(1+VT(i))*(D0(HH,I)*P0(I))) -WAG(HH)*PL0 -
INTR(HH)*RK0 -TR(HH)+HTX(HH);

DISPLAY MKT, IB;
tk1(i) =tk(i);
vt1(i) =vt(i);
hit1(hh)=hit(hh);

$ONTEXT

$MODEL:pjw

*$PEPS: 1.0E-6
*$echOP:.TRUE
*$FUNLOG:.TRUE

$COMMODITIES:
      P(I)    ! SUPPLY PRICE
      RK   ! CAPITAL RENTAL RATE
      PL  ! WAGE RATE
      PT
      PLE(HH)
```

```
        PU(HH)

  $SECTORS:
        Y(I)     ! PRODUCTION
        LS(HH)
        U(HH)

  $CONSUMERS:
        RA(HH)    ! PRIVATE HOUSEHOLDS
        govt


  $PROD:Y(I)  s:0   VA:2
        O:P(I)          Q:Y0(I)
        I:P(J)          Q:IOF(J,I)
        I:PL            Q:L0(I) VA:
        I:RK            Q:K0(I) VA:A:GOVTT:TK(I)P:(rk0*(1+TK1(I)))

  $PROD:LS(HH)
        O:PL            Q:WAG(HH)
        I:PLE(HH)       Q:WAG(HH)

  $PROD:U(HH)      s:0.75    a:2.0
        O:PU(HH)        Q:(I0(HH)+WLE(HH))
        I:P(I)          Q:D0(HH,I)A:GOVT T:VT(I)P:(P0(I)*(1+VT1(I)))
  a:
        I:PLE(HH)       Q:WLE(HH)

  $DEMAND:GOVT
        D:PT
Q:(SUM(I,(VT(I)*p0(i)*SUM(HH,D0(HH,I)))+(TK(I)*rk0*K0(I)))+(SUM(HH,HIT(HH)*
I0(HH))))

  $DEMAND:RA(HH)  s:1.5
        E:PLE(HH)       Q:(WAG(HH)+WLE(HH))
        E:RK            Q:INTR(HH)
        E:PT            Q:(TR(HH)-HIT1(hh)*I0(HH))
        D:PU(HH)        Q:(I0(HH)+WLE(HH))


  $REPORT:
        V:Y1(I)     O:P(I)     PROD:Y(I)
        V:IO(I,J)   I:P(J)     PROD:Y(I)
        V:L1(I)     I:PL       PROD:Y(I)
        V:K1(I)     I:RK       PROD:Y(I)
        V:LS1(HH)   I:PLE(HH)  PROD:LS(HH)
        V:U1(HH)    O:PU(HH)   PROD:U(HH)
        V:C1(HH,I)  I:P(I)     PROD:U(HH)
        V:LE(HH)    I:PLE(HH)  PROD:U(HH)
        V:W1(hh)    D:PU(HH)   DEMAND:RA(HH)
        V:PT1       D:PT       DEMAND:GOVT
        V:W(HH)     W:RA(HH)

  $OFFTEXT
```

```
*OPTION SYSOUT =ON;
$SYSINCLUDE mpsgeset PJW

pl.fx =1;

PJW.ITERLIM = 0;
$INCLUDE PJW.GEN
SOLVE PJW USING MCP;
DISPLAY HTX;

***Retrieving parameters consistent with the equilibrium *****

parameter va(i),
betak(i),betal(i),netinc(h),alpha(h),alphal(H),alphac(h,i);

va(i) =PL.L*L1.L(I) +RK.L*K1.L(I);
netinc(h) =ra.L(H)-HTX(H);
betak(i) =(PL.L*L1.L(I))/va(i) ;
betal(i) =  (rk.L*K1.L(I))/va(i);
alpha(h) =SUM(I,p.l(I)*C1.l(H,I))/NETINC(H);
alphaL(H) = 1-alpha(h);
alphac(h,i) = p.l(I)*C1.l(H,I)/NETINC(H);
display va,betak,betal,netinc,alpha,alphal, alphac;

*$ontext
PARAMETER WA(HH),UA(HH),REVA, REPORT,REPHH, REPORT1,REPHH1,
REPORT2,REPHH2;
UA(HH) =U.L(HH);
WA(HH) =W1.L(HH);

REPORT("OUTPUT", I) =Y1.L(I);
REPORT("PRICES", I) =P.L(I);
REPORT("CAPITAL", I) =K1.L(I);
REPORT("LUSE", I) =L1.L(I);
REPORT("SALES TAX",I) =VT(I);
REPORT("KI-TAX",I) =TK(I);

REPHH("LSUPPLY", HH) =LS1.L(HH);
REPHH("UTILITY", HH) =U1.L(HH);
REPHH("INCOME", HH) =W1.L(HH);
REPHH("INCTAX",HH) =HIT(HH);
REVA =govt.L;

PARAMETER LMD,MEB,EV0(HH), CV0(HH),EV1,CV1,EV2,CV2;

PJW.ITERLIM =5000;

VT(I) =0.01;
TK(I) =0;
HIT(HH) =0;

$INCLUDE PJW.GEN
SOLVE PJW USING MCP;
```

```
VT(I) =0.7;
TK(I) =0.5;
HIT(HH) =0.6;

$INCLUDE PJW.GEN
SOLVE PJW USING MCP;

EV0(HH) =((U.L(HH)-UA(HH))/U.L(HH))*W1.L(HH);
CV0(HH) =((UA(HH)-U.L(HH))/UA(HH))*WA(hh);
EV1 =SUM(HH,EV0(HH))/SUM(HH,W1.L(HH));
CV1 =SUM(HH,CV0(HH))/SUM(HH,WA(HH));

REPORT1("OUTPUT", I) =Y1.L(I);
REPORT1("PRICES", I) =P.L(I);
REPORT1("CAPITAL", I) =K1.L(I);
REPORT1("LUSE", I) =L1.L(I);
REPHH1("LSUPPLY", HH) =LS1.L(HH);
REPHH1("UTILITY", HH) =U1.L(HH);
REPHH1("INCOME", HH) =W1.L(HH);
REPORT1("SALES TAX",I) =VT(I);
REPORT1("KI-TAX",I) =TK(I);
REPHH1("INCTAX",HH) =HIT(HH);

REPHH1("EV-HH", HH) =EV0(HH);
REPHH1("CV-HH", HH) =CV0(HH);

DISPLAY EV1;

LMD =1.001;

VT(I) =VT(I)*LMD;
TK(I) =TK(I)*LMD;
HIT(HH) =HIT(HH)*LMD;

$INCLUDE PJW.GEN
SOLVE PJW USING MCP;

EV0(HH) =((U.L(HH)-UA(HH))/U.L(HH))*W1.L(HH);

MEB =SUM(HH,EV0(HH))/(REVA-govt.L);

DISPLAY MEB;

*$ONTEXT
VT(I) =0.3;
TK(I) =0.4;
HIT(HH) =0.3;

$INCLUDE PJW.GEN
SOLVE PJW USING MCP;

REPORT2("OUTPUT", I) =Y1.L(I);
REPORT2("PRICES", I) =P.L(I);
REPORT2("CAPITAL", I) =K1.L(I);
REPORT2("LUSE", I) =L1.L(I);
```

```
REPHH2("LSUPPLY", HH) =LS1.L(HH);
REPHH2("UTILITY", HH) =U1.L(HH);
REPHH2("INCOME", HH) =W.L(HH);
REPORT2("SALES TAX",I) =VT(I);
REPORT2("KI-TAX",I) =TK(I);
REPHH2("INCTAX",HH) =HIT(HH);
REPHH2("EV-HH", HH) =EV0(HH);
REPHH2("CV-HH", HH) =CV0(HH);

EV0(HH) =(PU.L(HH)-UA(HH))/UA(HH);
CV0(HH) =(UA(HH)-PU.L(HH))/PU.L(HH);
EV2 =SUM(HH,EV0(HH))/SUM(HH,W.L(HH));
CV2 =SUM(HH,CV0(HH))/SUM(HH,WA(HH));

*DISPLAY RE-
PORT,REPHH,REPORT1,REPHH1,REPORT2,REPHH2,EV1,CV1,EV2,CV2;
DISPLAY REPORT,REPHH,REPORT1,REPHH1,EV1;
*$offtext
```