WELFARE IMPACTS OF EQUAL-YIELD TAX REFORMS IN THE UK ECONOMY [1]

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Abstract

We use a multisectoral dynamic general equilibrium tax model with and without announcement effects in open and closed capital markets to evaluate efficiency gains and transitional effects from equal yield tax reforms for seven different taxes in the UK economy. We are able to distinguish empirically between more distortionary and less distortionary taxes. The impacts of an unanticipated tax reform on investment, capital accumulation, output and employment are less than those of anticipated tax reforms because producers, traders, investors and the government are more capable of adjusting their economic behaviour than the households when tax announcements are made in advance. In equal yield tax experiments welfare gains up to 1.4 percent of base year GDP can occur by removing distortions in taxes. Welfare loss of up to 2.05 percent of it can happen if a less distortionary tax, such as the labour income tax is replaced by more distortionary taxes. These simulation results are robust to whether the capital market is closed or open.

Keywords: dynamic tax model, general equilibrium, welfare, UK economy

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Introduction

Applied general equilibrium models have been in use for many years for the evaluation of short and long run impacts of fiscal policy. Depending on the specification of households, sectors of production and other economic institutions, these models provide numerical illustration of economy wide impacts of tax-transfer programmes. Plenty of studies exist in which these tools are used for analysis of policy alternatives available to a government (Harberger (1962), Ballard, Fullerton, Shoven, and Whalley (1984), Piggott and Whalley (1985) Auerbach and Kotlikoff (1987) Goulder and Summers (1989), Robinson (1991), Hutton and Kenc (1994) and Perroni (1995)). Benchmarked to a dynamic reference path, these models provide the basis for numerical analyses of economic policies designed to increase growth rates, improve income distribution and assure efficiency in inter sectoral reallocation of resources over time going beyond the single sector model as in Ramsey (1928), Solow (1956), Uzawa (1962), Cass (1965), Lucas (1988), Romer (1989) and Rebelo (1991).

Here we focus on empirical results obtained from a dynamic multisectoral tax policy model, which contains a representative household, an investor, sixteen different firms, a government as well as the international sector. Advancement in computing technology has made it possible to compute more decentralised markets in recent years (Rutherford (1995)). Micro-founded models of decentralised economies have become increasingly popular tools for evaluating macroeconomic policy issues in recent years (Rankin (1992)). The model here provides a numerical example of a decentralised market that takes a 60 years' horizon and is implemented with the micro-consistent data set for the UK economy received from the Inland Revenue (see Tables A1, A2 and A3 in the appendix).

Essential features of the model are presented in section I followed by model specification in section II. A brief discussion of the calibration technique is provided in section III. Numerical specification of parameters and benchmark tax rates are given in section IV. Results of the model are discussed in section V followed by conclusions and references.

I. Features of a dynamic multisectoral general equilibrium tax model

Every applied general equilibrium model begins with specifications for consumption, production, price and quantity adjustment process in goods and factor markets. The model behind this paper contains a single representative consumer, producers representing the sixteen different sectors, a government sector and the rest of the world. With its focus on analysis of fiscal policy it has a more elaborate specification of production sectors and the tax structure as close as possible to the UK economy. The essential features of it can be summarised in terms of the following five points.

1. We use the constant elasticity of substitution (CES) for the utility of an infinitely lived representative household, which allocates its lifetime income between consumption and savings and total time endowment between leisure and labour supply in order to maximise utility subject to its intertemporal budget constraint. The consumption, leisure and labour supply activities of households are related to each other. The representative household uses its time endowment either to supply labour to productive firms or to enjoy leisure. Its consumption level in turn depends upon labour and capital income and transfers. Besides its time endowment, the household is also endowed with the initial capital stock, which accumulates over time as savings provide for investment in each period. This household also owns production firms and acts as an investor to allocate the accumulated capital stock among various firms to maximise the rate of return from its investment activities. The government influences household decisions by means of taxes on labour and capital income and on consumption and transfers.
2. Firms use labour and capital as well as intermediate inputs to produce goods for the market while maximising their own profit over time. In this model the marginal productivity is the only investment criteria for investment across sectors. More productive sectors get more input as the investor is interested in gaining higher net of tax returns from each unit of investment. Tax distorted rates of return vary across sectors as taxes distort allocations affecting input or output prices, even shutting down investment in certain sectors that cannot promise reasonable net of tax returns.
3. Government plays a key role in the resource allocation process by means of its tax and transfer scheme. Its revenue comprises direct and indirect taxes and tariffs which is either spent on government consumption, or on provision of production subsidies to firms or to transfer income to the household. The government budget is balanced over time like that of the representative consumer or those of firms.
4. This model assumes a competitive global economy exporting and importing commodities to and from the rest of the world. We use the Armington specification of differentiated products in which imports are aggregated with domestic supply using CES function and domestic output is divided between domestic supplies and exports by a constant elasticity of transformation (CET) function. Export subsidies and import tariffs cause domestic

prices to differ from those in the rest of the world (ROW). The international payments are balanced as export earnings pay for imports over time.

5. The price mechanism plays a key role in allocating resources in this economy. Quantities and prices adjust until demands equal to supplies in goods, labour and financial markets. Tax wedges between basic and market prices distort the allocation of resources by firms and the consumer, which gives a less efficient outcome than that in a non-distorted economy.

II. Specification of the Model

II.1 Intertemporal preferences and household demand

We assume forward-looking behaviour by consumers and producers, in the sense that they have perfect foresight with regard to their income, resources and prices of commodities in the economy. In the model, infinitely-lived households allocate lifetime income to maximise lifetime utility, which is defined as

$$\sum_{t=0}^{\infty} \beta^t \frac{U_t^{1-\sigma} - 1}{1-\sigma} \tag{1}$$

where β is the discount factor, which depends on the rate of time preference; U_t is composite commodity in the instantaneous utility function as given in (2). This composite commodity is made of consumption and leisure. We choose a constant relative risk aversion (CRRA) CES functional form for this utility function in (1)[2] in which $1/\sigma$ measures the elasticity of substitution between the present and future composite commodity. The smaller is σ, the more slowly marginal utility falls as the quantity of the composite commodity rises, so households are more willing to allow changes in the composite commodity over time. Thus a smaller σ implies a higher elasticity of substitution between current and future consumption or a higher degree of consumption smoothing and substitution over time.

Instantaneous utility U is a function of composite consumption and leisure:

$$U(C_t, L_t) = \left(\alpha_c C_t^{\frac{\gamma-1}{\gamma}} + (1-\alpha_c) L_t^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}} \tag{2}$$

where C_t is composite consumption in period t, and L_t is leisure in period t. Here γ represents the elasticity of substitution between consumption and leisure; the larger the value of γ, the more responsive are consumption and labour supply to changes in commodity prices and wage rates.

[2] When $\sigma = 1$, we have $U(C_t) = \ln U_t$.

The representative household faces an intertemporal budget constraint whereby the present value of its consumption and leisure in all periods cannot exceed the present value of infinite lifetime full income (wealth constraint). Life-time income in this model includes the value the household's labour endowment and other income:

$$\sum_{t=0}^{\infty} R_t^{-1}(P_t(1+t^{vc})C_t \ +w_t(1-t_l)L_t) = W \qquad (3)$$

where, $R_t^{-1} = \prod_{s=0}^{t-1} 1/(1+r_s)$ is a discount factor; r_s represents the real interest rate on assets at time s; P_t is the price of composite consumption (which is based on goods' prices), t^{vc} is value added tax on consumption, t^l is labour income taxes, and C_t is composite consumption, which is composed of sectoral consumption goods, i.e. $P_t = \vartheta \prod_{i=1}^{n} p_{i,t}^{\alpha_i}$, and $C_t = \prod_{i=1}^{n} C_{i,t}^{\alpha_i}$ where α_i gives the share of spending on good i by the representative household, $C_{i,t}$ is a composite of domestic and foreign sector j products and $p_{i,t}$ its gross-of-tax price, and ϑ is a constant price index in the base year. W is the life time wealth of the household, defined as

$$W = \frac{J_0}{1+r_0^c} + \frac{J_1}{(1+r_0^c)(1+r_1^c)} + \ldots . + \frac{J_2}{\Pi_s^t(1+r_s^c)} + \ldots = \sum_{t=0}^{\infty} R_t^{-1} J_t \qquad (4)$$

where J_t is disposable household full income in period t, which includes the value of labour endowments and capital income plus transfers:

$$J_t = (1-t_l)w_t\overline{L}_t + (1-t_k)r_t K_t + TR_t \qquad (4')$$

where w_t is the wage rate, $\overline{L}_t$ is labour supplied, r_t is the rental rate of capital, K_t is the capital stock, TR_t is the transfer from the government to the household, t_l is the tax rate in labour and t_k is the tax rate in capital.

We combine equations (1) to (4) to form the Lagrangian for the consumer's inter-temporal allocation problem in (5).

$$\Im = \sum_{t=0}^{\infty}\left(\frac{1}{1+\rho}\right)^t \frac{\left(\left(\alpha_c C_t^{\frac{\gamma-1}{\gamma}} + (1-\alpha_c)L_t^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}\right)^{1-\sigma} - 1}{1-\sigma} + \lambda\left[\sum_{t=0}^{\infty} R_t^{-1}(P_t(1+t^{vd})C_t \ + w_t(1-t_l)L_t) - W_t \ \right] \qquad (5)$$

Here, γ is the intratemporal elasticity of substitution between consumption and leisure, λ is the shadow price of income in terms of the present value of utility, and β in (1) is replaced by $\frac{1}{1+\rho}$, where $\rho > 0$ is the rate of time preference, which indicates the degree to which the household prefers leisure and consumption in earlier rather than in later years. The larger the value of ρ, the more the household is willing to spend resources under its disposal earlier in life. This parameter is thus crucial in determining the amount of saving that the household wants to carry out in each period. Non-satiation in preferences implies that the inter-temporal budget constraint will hold with equality at an optimum.

The instantaneous utility function used to model intratemporal substitution possibilities by consumers contains three levels of nesting. At the top level, utility is a function of leisure and composite consumption, as in (1). How a single composite consumption good is made from sixteen sub-composite goods is shown in the second level of the nest. Finally each sub-composite good again represents a combination of domestic and imported goods.

Like consumption, investment and government consumption demand also comprise domestic and imported sources, but their composition depends on relative price of commodities.

II.2 Saving, investment, and labour supply

Economy wide savings, S_t, is the total of household savings (we assume that the government pursues a balanced budget policy over the model horizon). Household savings are the part of income that is not consumed:

$$S_t = J_t - P_t(1+t^{vc})C_t \tag{6}$$

For a given rate of time preference and inter-temporal rate of substitution (and if some other conditions are satisfied), individuals will save more when the rate of interest is higher than when it is lower. The lower the inter-temporal elasticity of substitution and the smaller the time preference parameter, the larger are the savings in the economy. A higher rate of interest on savings raises the cost of current consumption in terms of future consumption. At the same time, it raises lifetime wealth. The first effect tends to induce more savings, while the second tends to raise consumption. If the former effect dominates the latter, which is the case given our model parameterisation, savings will rise.

Note that, in reality, it is possible that the rate of return on saving received by households may be less than the cost of capital to the investors if financial intermediaries charge interest on the mobilisation of resources, the transaction cost of intermediation thus taking the form of a wedge between the prices faced by savers and investors. Here, we simply assume that the gross-of-intermediation cost of capital is equal to the return on savings.

Economy wide balance requires that income be equal to total expenditure. Government revenue is constrained to be equal to its expenditure. In the closed-capital market version of the model, we also assume trade balance (equality between the value of imports and the value of exports) in each period; whereas when we allow for international capital flows, trade balance must be satisfied in present value terms over the model horizon (see the next section).

Investors employ savings to purchase investment goods. The market rental rate of capital is determined by the equality of the demand for and the supply of capital. Total investment demand equals the use of investment goods from domestic and imported sources:

$$I_t = \sum_i PD_{i,t} ID_{i,t} + \sum_i PM_{i,t} IM_{i,t} \qquad (7)$$

where $ID_{i,t}$ is domestic supply of investment goods, and $IM_{i,t}$ is imported investment goods. Ideally one would need to include a capital composition matrix to specify how a unit of investment good in a particular sector is made from the capital inputs from various sectors. In the absence of information on the sectoral composition of investment by sector of origin, we simply specify a composite investment good using information on total investment demand from the input-output table. This composite good is then allocated to sector-specific investment so as to equalize the marginal productivity of capital across sectors. Investment opportunities are arbitraged when the net rate of return from each investment activity does not exceed the rate of interest, and is equal to it when investment is undertaken at a positive level in that sector, i.e.

$$R_{i,t} - \delta_i \le r_t \;;\; I_{i,t} \ge 0 \;;\; I_{i,t}(R_{i,t} - \delta_i - r_t) = 0 \qquad (8)$$

where $R_{i,t}$ is the gross-of-depreciation rate of return in sector *i* at time *t*, δ_i is the sector-specific depreciation rate, and r_t is the rate of interest at *t*. This arbitraging condition implies that sectors with higher gross return $R_{i,t}$ and lower depreciation rate δ_i generate more gross investment demand. On a balanced-growth path, investment will grow at the same rate in all sectors, and the return to capital will be equalized everywhere. However, during the transition to a balanced-growth path, it is possible for the net return in a sector to fall below the return elsewhere in the economy, and, as a result, for investment to "shut down" in that sector.

Sectoral assets are subject to economic depreciation. Thus, in every period, gross sectoral investment replenishes depleted capital, and increases the capital stock (*net* investment). Capital accumulation in sector *i* in period *t+1* then is given by the capital stock of period *t* net of depreciation and investment:

$$K_{i,t+1} = K_{i,t}(1-\delta_i) + I_{i,t} \qquad (9)$$

Growth in sectoral output depends both upon the growth of employment and the growth of the capital stock in that sector. On a balanced-growth path, where all prices are constant and all real economic variables grow at a constant rate, capital stocks must grow at a fast enough rate to sustain growth. This condition can be expressed as

$$I_{i,T} = K_{i,T}(g + \delta_i) \quad (10)$$

where the subscript T denotes the terminal period of the model.

Note that assuming a closed capital market may not be realistic for the UK economy. The representation of capital mobility in small open-economy models is not yet quite satisfactorily developed in the applied general equilibrium literature. Goulder, Shoven and Whalley (1983) model capital markets for the US by assuming that the capital endowment of the rest of the world is five times the US endowment, the implicit assumption being that the US economy constitutes about a fifth of the world economy. If we follow the same route for the UK, we may roughly assume that the rest of the world is endowed with twenty-five times more capital than UK households (considering UK GDP to be equal to 4 percent of world GDP). For simplicity, in the open capital markets version of the dynamic model we simply assume the UK to be a price taker in capital markets, and allow capital inflows and outflows to take place so as to ensure that the UK rate of interest remains constant and equal to the world rate of return. A more realistic analysis of capital asset flows would require a model structure where the UK economy is explicitly modelled as part of the global economy.

Labour supply, LS_t, for each household is given by the difference between the household labour endowment, and the demand for leisure, L_t.

$$LS_t = \overline{L}_t - L_t \quad (11)$$

In equilibrium, the wage rate must be such that the labour supplied by the household equals the total demand for labour derived from the profit maximising behaviour of firms (as set out in the following section).

II.3 Technology and trade

The structure of production in the model is shown in Figure A2 in the appendix. At the bottom of the figure one type of composite capital stock[3] combines with labour to form value added for the sixteen sectors in the model. Then this value added aggregate combines with domestic and imported intermediate inputs from sixteen sectors to produce gross output for each sector. Gross output is either sold in domestic markets or exported to the rest of the world.

Following a well-established convention in open-economy applied general equilibrium models, we adopt an "Armington (1969)" specification whereby products are differentiated according to the location of production. Thus domestic and imported goods, even in the same sector, are qualitatively different and are not perfect substitutes, and intra-industry trade can occur. The Armington aggregation function, with given shares and substitution elasticity, describes how the domestic and imported goods are combined:

$$A_{i,t} = \Phi\left(\delta_i^d D_{i,t}^{\frac{\sigma_m - 1}{\sigma_m}} + \delta_i^m M_{i,t}^{\frac{\sigma_m - 1}{\sigma_m}} \right)^{\frac{\sigma_m}{\sigma_m - 1}} \quad (12)$$

where $A_{i,t}$ is the Armington CES aggregate of domestic supplies $D_{i,t}$ and import supplies $M_{i,t}$ for each sector, δ_i^d is the share of domestically produced goods*,* δ_i^m is the share of good *i* imports, σ_m is the elasticity of substitution in the aggregate supply function, and Φ is the shift parameter of the aggregate supply function.

The aggregate value of supply in the economy must be equal to the sum of the values of domestic supplies and imports:

$$PA_{i,t} A_{i,t} = PD_{i,t} D_{i,t} + PM_{i,t} M_{i,t} \quad (13)$$

where $D_{i,t}$ and $M_{i,t}$ are domestic and import supplies respectively, $PD_{i,t}$ is gross price of domestic supplies, $PM_{i,t}$ is price of imported goods gross of tariffs, and $PA_{i,t}$ is the gross price of composite commodity *i*.

Overall market clearing in the product market implies

$$A_{i,t} = CC_{i,t} + G_{i,t} + I_{i,t} + \sum_j DI_{i,j,t} + \sum_j MI_{i,j,t} \quad (14)$$

where $CC_{i,t}$ is composite consumption, $G_{i,t}$ and $I_{i,t}$ represent composite consumption by the government and investment respectively (discussed below), $DI_{i,j}$ is the demand for domestic intermediate input and $MI_{i,j}$ is demand for imported intermediate inputs,.

Domestic supply, $D_{i,t}$, in equations (15,16), is the part of gross output sold in the domestic market. The rest of domestic output is exported. The split between domestic sales and exports is given by a constant elasticity transformation function:

$$GY_{i,t} = \Theta\left((1 - \delta_i^e) D_{i,t}^{\frac{\sigma_y - 1}{\sigma_y}} + \delta_i^e E_{i,t}^{\frac{\sigma_y - 1}{\sigma_y}} \right)^{\frac{\sigma_y}{\sigma_y - 1}} \quad (15)$$

where $GY_{i,t}$ is output (gross of intermediate inputs), $E_{i,t}$ is exports, $D_{i,t}$ is domestic supplies, σ_y is the elasticity of transformation in total supply, δ_i^e is the share of exports, and Θ is the

[3] Disaggregation of assets into five different capital assets—long-lived plant and machinery, short lived plant and machinery, vehicles, buildings and dwellings, as in our static model, is left for a future version of the model.

shift or scale parameter in the transformation function. The value of gross supplies in the economy must be equal to the sum of the gross values of domestic supplies and exports:

$$P_{i,t}GY_{i,t} = PD_{i,t}D_{i,t} + PE_{i,t}E_{i,t} \tag{16}$$

where $D_{i,t}$ and $E_{i,t}$ are domestic and export supplies respectively, $PD_{i,t}$ is gross prices of domestic supplies, $PE_{i,t}$ is price of exported goods gross of export taxes, and $P_{i,t}$ is the price of domestic supplies of commodity *i*.

The import and export prices in equations (16) and (20) will generally differ from domestic prices because of tariffs and export taxes applied considering product differentiation between domestic and foreign products. The gross-of-export-tax prices of exportable goods and the gross-of-tariff prices of importable commodities tend to get closer to world prices as the elasticity of transformation between domestic sales and exports in production and the elasticity of substitution between domestically produced goods and imports in consumption approach infinity.

On the production front, producers use labour and capital in each of *N* sectors to produce value added. The amount of each type of these inputs employed by a producer in a particular sector is based upon the sector specific production technology and input prices. We use a CES function to express this relationship:

$$Y_{i,t} = \Omega_i \left((1-\delta_i)(K_{i,t})^{\gamma_i} + \delta_i (LS_{i,t})^{\gamma_i}\right)^{\frac{1}{\gamma_i}} \tag{17}$$

where $Y_{i,t}$ is the gross value added of sector i, Ω_i is a shift or scale parameter in the production function, $K_{i,t}$ and $LS_{i,t}$ are the amounts of capital and labour used in sector *i*, δ_i is the share parameter of labour in production, and γ_i is the CES substitution elasticity parameter. This is a constant return to scale production function. Euler's product exhaustion theorem implies that total output (value added) equals payments to labour and capital and each factor receives remuneration at the rate of its marginal productivity:

$$PY_{i,t}Y_{i,t} = w_t LS_{i,t} + r_t K_{i,t} \tag{18}$$

where w_t is the gross-of-tax wage rate and r_t is the gross rental rate of capital.

The relationship between the intermediate inputs and gross output is expressed by input-output coefficients, which form a fixed physical non-price based constraint in the production system. The general form of production function is

$$GY_{i,t} = \min\left(Y_{i,t}, \left(\frac{DI_{i,j,t}}{a^d_{i,j}}\right)_{i=j}, \left(\frac{MI_{i,j,t}}{a^m_{i,j}}\right)_{i=j} \right) \tag{19}$$

where $a_{i,j}^{d}$ are input-output coefficients for domestic supply of intermediate goods; $a_{i,j}^{m}$ are input-output coefficients for imported supply of intermediate goods, $DI_{i,j}$ is the supply of domestic intermediate input and $MI_{i,j}$ is the supply of imported intermediate inputs. The presence of input-output linkages in the model enables us to assess various kinds of backward and forward impacts of policy changes. For instance a tax on agricultural output has a direct effect on demands for agricultural goods, and a backward impact that spreads to many other sectors which provide inputs to that sector. Similarly, through forward linkages, the tax affects the cost of agricultural inputs to other sectors.

The objective of a firm in the *j*th sector of the economy is to maximise the present value of profits subject to production technology constraints. Sectoral profits are given by the differences between the revenue from sales and the cost of supply. The unit revenue function is a constant elasticity transformation (CET) composite of the unit price of domestic sales and the unit price of exports. The unit costs are divided between value-added, i.e. payments to labour and capital, and domestic and imported intermediate inputs:

$$\Pi_{j,t}^{y} = [((1-\delta_{i}^{e})PD_{i,t}^{\frac{\sigma_y-1}{\sigma_y}} + \delta_{i}^{e} PE_{i,t}^{\frac{\sigma_y-1}{\sigma_y}})]^{\frac{1}{\sigma_y-1}} - \theta_{j}^{v} PY_{j,t}^{v} - \theta_{j}^{d} \sum_{i} a_{i,j}^{d} P_{i,t} - \theta_{j}^{m} \sum_{i} a_{i,j}^{m} PM_{j,t} \tag{20}$$

where: $\Pi_{j,t}^{y}$ is the unit profit of activity in sector *j;* $PE_{j,t}$ is the export price of good *j* $PD_{j,t}$ is the domestic price of good *j;* $PY_{j,t}^{v}$ is the price of value added per unit of output in activity *j;* σ_y is a transformation elasticity parameter ; $P_{i,t}$ is the price of final goods used as intermediate goods; δ_{j}^{e} is the share parameter for exports in total production; θ_{j}^{v} is the share of costs paid to labour and capital; θ_{j}^{d} is the cost share of domestic intermediate inputs; θ_{j}^{m} is the cost share of imported intermediate inputs; $a_{i,j}^{d}$ are input-output coefficients for domestic supply of intermediate goods; $a_{i,j}^{m}$ are input-output coefficients for imported supply of intermediate goods.

In equilibrium, with free entry and perfect competition, profits will be zero in each period. The zero-profit condition for sector *j* in period *t* can be written in dual form in terms of composite prices of commodities and inputs (see appendix for details):

$$\Pi_{j,t}^{y} \leq 0 \tag{21}$$

With respect to international trade, zero trade balance is a property of any general equilibrium model. In the version with no international capital flows, we have, therefore, assumed that the value of exports (gross of UK taxes and subsidies) equals the value of imports (net of UK taxes and subsidies) in equilibrium in each period:

$$\sum_i PE_{i,t} E_{i,t} = \sum_i PM_{i,t} M_{i,t} \tag{22}$$

No inter-temporal borrowing occurs in this case. In the version with international capital flows, we have that this condition must be satisfied in present value terms, i.e.

$$\sum_t (1+r^W)^{-t} \sum_i PE_{i,t} E_{i,t} = \sum_t (1+r^W)^{-t} \sum_i PM_{i,t} M_{i,t} \tag{23}$$

where r^W is the world rate of interest.

II.4 Public consumption

The government collects revenue from various taxes and spends that revenue to purchase goods and services for public consumption and to make transfers to households.

The value of government consumption is given by

$$G = \sum_i PA_i GD_i + \sum_i PA_i GM_i \tag{24}$$

where GD_i is government consumption of domestic goods, and GM_i is government consumption of imported goods. Like households, the government chooses between domestic and imported goods for its consumption on the basis of their relative prices.

Tax revenue is collected through taxes on capital and labour income and value added taxes on final demand, production taxes on intermediate inputs, and tariffs on imports:

$$REV_t = \sum_i t_i^k r_t K_{i,t} + \sum_i t_i^{vc} P_{i,t} CC_{i,t} + \sum_i t_i^{vg} P_{i,t} G_{i,t} + \sum_i t_i^{vk} P_{i,t} I_{i,t} + \sum_i t_l wLS_t + \sum_i t_i^m PM_{i,t} M_{i,t} + \sum_i t_i^p P_{i,t} GY_{i,t} \tag{25}$$

where REV_t is total government revenue and t_i^k is a composite tax rate on capital income from sector *i*. These rates are derived from the P-Tax model of capital income tax rates, originally written by King and Robson (1988) using methodology devised by King and Fullerton (1984); and used in the Inland Revenue for a number of years. t_l^{vc} is the *ad valorem* tax rate on final consumption by households, t_i^{vg} is that on public consumption and t_i^{vk} is the ad valorem tax rate on investment. t_l is the tax rate on labour income of the household, t_i^p is the tax on production, and t_i^m is the tariff on imports. All of 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.

Tax revenues are either used to finance public consumption, or to make transfers to households in lump sum form:

$$REV_t = G_t + TR_t \tag{26}$$

II.5 Definition of a dynamic competitive equilibrium

A dynamic competitive equilibrium is a combination of sequences of prices of gross output $P_{i,t}$, price of domestic supplies, $PD_{i,t}$; import prices, $PM_{i,t}$; export prices, $PE_{i,t}$; prices of value added, $PY_{i,t}$; prices of capital goods, $P^k_{j,t}$; prices of terminal capital, $PTK_{j,t}$; wage rates of labour, w_t; prices of government services, PG_t; values of transfers to households, PR_t; prices of composite of consumption and leisure, PU_t; rental rate of capital for each sector, r^k_1 : R+ →R, and sequences of gross output, $GY_{i,t}$; total supply of domestic intermediate inputs, $DI_{i,j,t}$ and imported intermediate inputs, $MI_{i,j,t}$; sectoral capital stock, $K_{i,t}$; labour demands, $LS_{i,t}$; value added, $Y_{i,t}$; sectoral investment, $I_{i,t}$; exports, $E_{i,t}$; imports, $M_{i,t}$ government revenue, REV_t; services, G_t; consumption of households, CC_t; labour supply, LS_t and leisure demand, L_t; and level of household utility from consumption, U_t, such that given these prices and quantities, the following conditions are satisfied:

1. households maximise inter-temporal utility subject to their wealth constraint;
2. investors maximise inter-temporal profits subject to arbitrage conditions in capital markets;
3. producers minimise costs subject to technology constraints;
4. unit profits are zero in all production sectors;
5. markets for goods and services clear;
6. the government account constraint is satisfied;
7. the balance of payments condition is fulfilled
8. the economy grows at a constant rate beyond a certain terminal period *T*.

In such an equilibrium, consumers have perfect foresight, capital accumulation is consistent with household's and producers' optimisation and income and expenditures balance over the life period. An agent is doing the best he or she can in light of actions taken by others, and actions taken together are feasible given technologies and resources.

III. Dynamic calibration[4]

The dynamics in this model arise from an endogenous process of capital accumulation and exogenous growth rate of the labour force. We rule out uncertainty and rely on the perfect foresight of households and firms, which means that actual and expected values of variables are the same. We have a single vintage of capital. Embodiment of technical progress through multiple vintages of capital, though important from practical point of view, has not been modelled here because of complexity in computation (Cooley, Greenwood and Yorukoglu (1997)). Consistency of this dynamic model is assured by replication of the benchmark economy (as in Lau et. al (2002) for an example).

There are essentially five steps involved in calibration of this dynamic model. The first step relates to forming a relation between the price of investment good at period t, P_t and the price of capital in period *t+1*, P_{t+1}^k. It also needs specifying a link between prices of capital stock at periods *t* and *t+1*, P_t^k and P_{t+1}^k, with due account of the rental on capital and the depreciation rate. For instance, one unit of investment made using one unit of output in period *t* produces one unit of capital stock in period *t+1*. This implies, $P_t = P_{t+1}^k$, where P_t is the price of one output in period *t* and P_{t+1}^k is the *t* period price of one unit of capital in period *t+1*.

Capital depreciates at the rate of δ. One unit of capital at the beginning of period *t* earns a rental R_t^t and delivers *1-*δ units of capital at the end of period *t* (or at the start of the *t+1* period), $(1-\delta)P_{t+1}^k$. Here R_t^t is also measured in term of P_{t+1}^K or P_t. We therefore must have:

$$P_t^k = R_t^t + (1-\delta)P_{t+1}^k \tag{27}$$

In a perfect foresight world price of capital in period *t* really reflects the sum of discounted rental over time. A sum of geometric series of declining values of investment income can be used to expand terms for P_t^K and P_{t+1}^K as following:

$$P_t^K = R_t^t + \frac{R_t^t(1-\delta)}{1+r} + .. = R_t^t\left(\frac{1+r}{r+\delta}\right) \tag{28}$$

$$P_{t+1}^K = R_t^t(1-\delta) + \frac{R_t^t(1-\delta)^2}{1+r} + .. = R_t^t\left(\frac{1+r}{r+\delta}\right)(1-\delta). \tag{29}$$

A unit of capital generates less revenue next period because of depreciation, $R_{t+1}^t = R_t^t(1-\delta)$. The second step of calibration involves setting up a link of the rental rate

[4] I appreciate very useful and extensive comments made by the editor of the Economic Issues for this section.

with the benchmark interest rate and the depreciation. The rental covers depreciation and interest payment for each unit of investment. When rental is paid at the end of the period

$$R_t^t = (r+\delta)P_t^k \qquad (30)$$

where r is the benchmark real rate of interest. If the rental rates are paid in the beginning of the period t then from intertemporal arbitrage the equation (28) changes to $\frac{R_t^t}{P_{t+1}^k} = \frac{r+\delta}{1+r}$.

Third step of calibration involves forming relation between the future and the current price of capital. Use equation (28) and (29) together to get

$$\frac{P_{t+1}^k}{P_t^k} = \frac{1}{1+r} \approx 1-\delta . \qquad (31)$$

This means that the ratio of prices of the capital at period t and $t+1$ equals to the market discount factor in the model, which is $(1-\delta)$. This discount factor can also be approximated by $\frac{1}{1+r}$. In addition, the spot price of capital stock in period $t+1$ equals ${}_{t+1}P_{t+1}^K = \frac{R_t^t(1-\delta)(1+r)}{(r+\delta)}$. When an expectation is made in period t about the period $t+1$ it needs to be discounted by factor $\frac{1}{1+r}$. That means expected price of a unit of $t+1$ capital at t is given by ${}_tP_{t+1}^K = \frac{R_t^t(1-\delta)}{(r+\delta)}$. In equation (28) above we have spot price of unit of capital defined as ${}_tP_t^K = \frac{R_t^t(1+r)}{(r+\delta)}$. Thus the ratio of price of capital in period t and $t+1$ is $\frac{{}_tP_{t+1}^k}{{}_tP_t^k} = \frac{1-\delta}{1+r}$. In this case both the discount rate δ and the benchmark interest rate r are involved in linking price of capital at periods t and $t+1$.

The fourth step of calibration involves setting up equilibrium relation between capital earning (value added from capital) and the cost of capital. We compute values for sectoral capital stocks from sectoral capital earnings in the base year. If capital income in sector i in the base year is $\overline{V}_i$, we can write $\overline{V}_i = R_iK_i$. Since the return to capital must be sufficient to cover interest and depreciation, we can also write

$\overline{V}_i = (r+\delta_i)P_{t+1}^kK_i$, or $\qquad K_i = \frac{\overline{V}_i}{(r+\delta_i)} \qquad$ Since $P_t = P_{t+1}^k = 1 \qquad (32)$

The fifth step of calibration involves setting up relation between the investment and capital earning on the balanced growth path[5]. Investment should be enough to provide for growth and depreciation, $I_i = (g_i + \delta_i)K_i$, which together with (32) implies

$$I_i = \frac{(g_i + \delta_i)}{(r + \delta_i)} \overline{V}_i \tag{33}$$

The balance between investment and earnings from capital is restored here by adjustment in the growth rate g_i that responds to changes in the marginal productivity of capital associated to changes in investment. Readjustment of capital stock and investment continues until this growth rate and the benchmark interest rates become equal.

If the growth rate in sector *i* is larger than the benchmark interest rate then more investment will be drawn to that sector. The capital stock in that sector rises as more investment takes place setting the diminishing return on capital. Eventually the declining marginal productivity of capital retards growth in that sector We also have built scenarios for closed and open capital markets and anticipated and unanticipated tax reforms. The lending and borrowing is permitted in response to trade imbalances in the open capital market case. The households and producers use announced tax rates in the base year instead of current ones in anticipated scenario while they use existing taxes until the reform occurs in the unanticipated scenario.

Thus investment per sector is tied to earnings per sector. In the benchmark equilibrium, all reference quantities grow at the rate of labour force growth, *g,* and reference prices are discounted on the basis of the benchmark rate of return as given by equation (31) above.

To solve the model, we allow for a time horizon sufficient for a balanced-growth path to be attained. In our simulations we use a sixty-five year horizon. In practice, the model's variables typically converge to an approximate balanced-growth path after about twenty to thirty years. We formulate and solve the model using the GAMS/MPSGE software (Rutherford (1995), Brook et.al. (1992)).

IV. Parameters, elasticities and tax rates

We calibrate the model following the steps outlined above using a micro consistent data set for the UK economy for the year 1995 (Siddorn (1999)). Implicitly, following a general practice in the applied equilibrium analysis, we assume that the UK economy was on a balanced-growth path in that year. Once the model is calibrated in this way, the baseline

[5].This model assumes a uniform growth path across the sectors in the steady state. There may be a set of dynamic paths in which some sectors might be expanding and some others remain contracting or even eliminated over time. Analysis of this sort of economy requires a more complicated model left as an open question for further research.

growth path shows how the economy would move forward, *ceteris paribus*, if the current economic policies were to continue (Bhattarai (2001,2000, 1999, 1997).

Table 1
Basic Parameters of the UK Model

Steady state growth rate for sectors (g)	0.02
Net interest rate in non-distorted economy (r)	0.02
Reference quantity index of output, capital and labour for each sector , Q_{rf}	$(1+g)^{t-1}$
Reference index of price of output, capital and labour for each sector, P_{rf}	$1/(1+r)^{t-1}$
Elasticity of transformation between UK's domestic supplies and exports to the Rest of the World (ROW) , σ_y	1.5
Elasticity of substitution between UK's domestic products and imports from Rest of the World (ROW), σ_m	1.5
Intertemporal elasticity of substitution, σ	0.5
Intra temporal elasticity of substitution between leisure and composite goods, γ	0.5
Elasticity of substitution in consumption goods across sectors, σ_c	0.5

Besides capital stocks for each production sector, a careful selection of other model parameters is crucial to the general equilibrium analysis of model results. The intertemporal rate of substitution in the household's utility function, the elasticity of substitution between composite consumption and leisure, the elasticity of substitution between domestic and imported commodities and the elasticity of substitution between the capital and labour inputs in production are the crucial parameters which determine the behaviour of the current model. It also needs the elasticity of transformation between domestic and foreign trade, popularly known as the Armington (1969) elasticity, the growth rate of the labour force, the benchmark rate of interest, and rates of depreciation by sector. Table 1 and Table 2 list the values assumed for these parameters in the current model.

The capital income tax rate for each sector, as given in Table 2, is derived from the asset specific tax rates obtained from the calculations of the P-TAX model received from the Inland Revenue. The P-tax calculates tax wedge using sector specific financial structure and depreciation allowances for each type of asset. The wide variation in these rates across sectors thus not only reflects statutory rates but also underlying differences in depreciation allowances and debt-equity or self-financing structure. Taxes on building type assets were higher than for plant and machinery or for the vehicles type assets for each sector in the benchmark. Further more effective tax rates were higher if the investment project were financed by debt rather than equities. Thus sectors which had a larger proportion of building asset and relied on debt financing such as the financial services, education and public administration sector and agricultural sector had higher effective rates of capital income taxes.

Table 2
Depreciation, Capital Income and Indirect Tax Rates (%)

Industry	Elasticity of substitution between labour and capital (γ_i)	Depreciation rate (annual %)	Capital income tax rate	Indirect tax on private consumption	Indirect tax on public consumption	Indirect tax on investment	Production tax rates	Tariff rates
Agric	1.2	8.3	41.4	1.6	7.7		-10.9	2.5
Extra	1.7	16.6	26.2					2.5
Minin	1.5	10.4	31.0	12.5			-0.6	2.5
Chemi	1.7	5.6	24.0	15.4	8.3		14.3	2.5
Metal	1.6	5.4	25.3			3.8	0.0	2.5
Engin	1.5	6.0	27.6		31.1	4.9	0.0	2.5
Food	1.0	5.4	28.0	17.0	3.5		12.2	2.5
Othma	0.9	6.4	26.2	26.3	19.	6.1	0.0	2.5
Power	1.5	4.1	28.9	5.7	22.1		3.4	2.5
Constr	1.0	9.4	30.3	13.3	27.8	2.5	-0.1	
Distr	1.6	5.9	33.9	4.4			5.4	
Trans	1.6	7.5	29.7	8.3	15.3	0.1	-2.2	2.5
Finan	1.6	6.9	41.9	1.0	11.0	0.3	2.0	2.5
PubAD	1.6	4.	45.8					2.5
EducA	1.6	3.8	48.1	7.5	0.6		1.9	2.5
House	1.0	2.0					-0.3	2.5

Source and notes: We have done some sensitivity analysis while choosing the values of the elasticity of substitution between labour and capital. These values are close to those used by Piggott and Whalley (1985). The aggregate depreciation rate per sector is derived from the P-tax sector-asset specific discount rates (King and Robson (1988); tax and tariff rates rely on Bhattarai (1999) and Siddorn (1998).

V. Tax policy experiments: equal-yield tax reforms

By removing distortions equal yield tax reforms aim for an efficient, fair and simple tax system holding revenue constant. However, there are several practical question relating to the tax base, information about the tax reform and the level of distortions due to one tax versus another. Should revenue be raised by direct or indirect taxes? Should it be from capital or labour income? Are the effects of tax reforms different when people have some anticipation of future taxes or when such reforms come all of a sudden? Are the impacts of reform different in closed capital markets or open capital markets? These are key issues that we would like to answer by assessing the dynamic efficiency and reallocation effects of taxes using the dynamic tax model described in the previous section. In each equal yield tax reform we ask what happens if we replace the differentiated tax rates existing in the UK in 1995 by uniform rates across all sectors. The actual benchmark tax rates as reported in Table 2 and their counterfactual rates for our analysis are as given in Table 3 below. Removing distortions with lower uniform rates of one particular tax instead of its benchmark rates may reduce or increase the overall distortions in the economy. Efficiency gains are expected to be positive if that tax has more distortionary impact on production and consumption than other taxes in the system, while efficiency losses may occur if less distortionary taxes are replaced by more distortionary taxes in order to maintain the equal yield constraint. Therefore whether aggregate welfare improves by changing one particular tax depends on its degree of relative distortions rather than in absolute tax rates.

Table 3
Counterfactual tax rates in the dynamic UK model

Tax experiment	Capital income tax rate	Indirect tax on private consumption	Indirect tax on public consumption	Indirect tax on investment	Production tax rates	Tariff rates	Household income tax rate
Counterfactual tax rates	25.0	10.0	5.0	5.0	5.0	1.0	15.0

We use overall efficiency gains to measure the impact of a tax reform. These gains are measures in terms of changes in money metric utility to the consumer relative to that in the base year, which is computed as the change in the present value of lifetime utility relative to base expressed as a percentage of base year UK GDP as:

$$UW = 100(LU - 1)\frac{C_0}{GDP_0} \tag{34}$$

here UW is a measure of the present value of welfare to the representative household for the period of the model horizon, LU is the unit of composite lifetime utility which is equal to one in the base case solution, C_0 is the composite of consumption and leisure in the base year, and GDP_0 is the base year GDP (the adjustment factor $\frac{C_0}{GDP_0}$ corrects for the fact that the value of household composite consumption in the model includes the value of leisure and excludes government consumption).

Table 4
Efficiency effects of tax reform in the dynamic UK model
Change in life time utility as a percentage of base GDP (%)

	Closed capital market with no anticipation	Closed capital market with anticipation	Open capital market with no anticipation
Capital income tax	0.699	0.633	0.768
Labour income tax	-2.054	-2.054	-2.195
Production tax	1.421	1.284	1.442
Investment tax	-0.085	-0.048	-0.106
Household consumption tax	0.112	0.557	0.693
Government consumption tax	0.297	0.256	0.317
Tariffs	0.070	0.053	0.081

The dynamic welfare gains of equal yield tax reform associated with seven different taxes for three different scenarios are as shown in Table 4. The efficiency gain from reform of five different taxes, as set out in Table 2 and 3 above, with the equal-yield constraint is positive. This indicates removal of sector specific distortions in the economy. Model results show loss in welfare with reform in investment and labour income taxes. The welfare loss in case of investment tax reflects an increase in the tax rate in the counterfactual scenarios because tax rates were lower in the benchmark case. The negative welfare gains from the labour income tax reform, when its rate is reduced from 25 to 15 percent indicates that the labour income tax is less distortionary than other taxes. As its rate declines it causes more distortions in the system as there is an equi-proportional increase in other more distortionary taxes. A reduction in revenue due to lower labour income taxes has to be compensated by higher rates of more distortionary taxes to meet the equal yield constraint.

In the "anticipated" scenario, we assume that private agents can foresee the tax change occurring five years before it is implemented, and can therefore immediately adjust their choices in anticipation of the change. People do not know about tax changes in advance in unanticipated scenario. Welfare gains, which are generally lower with anticipation than without anticipation, reflect the fact that producers, traders, government and owners of capital are more capable of adjusting their economic behaviour when they know how taxes are going to change in the future. The presence of announcement effects, however, has an ambiguous effect on the welfare impacts of tax reform. On the one hand, announcing tax changes in advance enables the private sector to better adjust to the change, immediately undoing some of the distortions associated with the taxes to be reduced. On the other hand, when new distortionary policies are introduced, announcing policy changes in advance actually raises the efficiency costs of the policy, as individuals' choices are immediately affected by the change. The model solutions show that dynamic welfare effects are generally larger when there are international capital flows.

The efficiency gains or losses signal underlying quantity and price adjustments across sectors because of the above taxes. Capital income tax reform impacts growth path of the economy. Model-based numerical simulations for the various experiments provide results that show impacts on sectoral investment, capital stocks, output and employment relative to the baseline "business as usual" reference path case. We report series of capital stock across the sectors in the appendix.

When capital income tax rates, which range from 24 percent in the chemical sector to 48 percent in the education sector in the base year, are set to a uniform twenty-five percent rate in the counterfactual scenario, it has positive impact on the growth path of investment, capital stock, employment and output across all sectors relative to their benchmark. In an unanticipated case it raises investment by more than fifteen percent in production sectors and other sectors, before it settles down between five and fifteen percent above the reference path of the economy. The agriculture, finance, distribution, mining and construction sectors, which are relatively more distorted in the benchmark, experience more expansion than other sectors. In contrast, housing investment shuts down for more than five years and remains depressed afterwards.

Capital stocks in each sector follow the growth in investment. In the long run, the capital stock in agriculture remains above fifteen percent higher than in the baseline; other sectors experience a ten percent increase compared to the reference path (see Figures A1 and A2 in the appendix for instance). This again depends on the degree of distortion in that particular sector in the benchmark. For instance, the growth path of the capital stock in the chemical sector does not deviate much from the reference path, due to the capital tax rate in that sector remaining relatively unaffected by the reform.

The general pattern of investment and capital stock effects described above is not very different in closed and open capital market except that the convergence is faster and smoother in the open capital market case than with closed capital markets.

Besides inter-sectoral asset reallocation, changes in the relative user cost of capital have a significant effect on employment across sectors. When capital inputs become relatively cheaper than the labour input, producers tend to substitute capital for labour. As outlined above, capital becomes relatively cheaper in certain sectors such as agriculture, finance, public administration, and education, and relatively expensive in some other sectors, particularly manufacturing, after a uniform tax reform.

The levels of employment and output under a uniform capital income tax reform remain within –5 and 5 percent of the reference path in this model. Growth of the agriculture sector is above the reference path across all market scenarios, while that of the engineering sector remains below the reference path in all scenarios. This reflects the fact that the capital income tax in the agriculture sector has reduced from 41 percent to 25 percent and it has a relatively lower depreciation rate compared to other sectors. The construction sector experiences a big shock after the tax change, but bounces back to above the benchmark reference path over time.

The presence of announcement effects causes investment to begin adjusting earlier, in anticipation of the new taxes. When tax changes are known in advance, there are incentives, immediately after the announcement, to postpone investment to periods where it enjoys relatively better tax treatment. As the time of the reform approaches, however, investment changes go in the same directions as the post-reform changes (with the exception of the initial spike immediately following the reform).

Looking at these numbers on investment and capital stock we may conclude that the impact of capital income tax reform varies across sectors and the size of this impact depends upon the benchmark rates of capital income tax and depreciation. Sectors subject to higher tax rates and lower depreciation rates in the benchmark realise growth paths significantly above the reference path of the economy and sectors with lower tax and depreciation rates stay on or below the reference path.

The general equilibrium impacts of capital income tax changes affect the reference paths of employment and output but the size of the employment and output effects are smaller than those on investment and capital stock by sector. Changes in the capital stock have some knock on effects on employment and then on output. Output effects are more extreme in the extraction and distribution sectors, which are more capital-intensive than service sectors such as public administration and education. Our above empirical findings on aggregate and sector specific impacts of capital income taxes for the UK economy are also close to the conclusions of some other studies on the US economy as analysed in Boskin (1978), Fullerton, Shoven, and Whalley (1983) and Auerbach and Kotlikoff (1987).

In contrast to positive impacts of capital income tax reform, a reduction in the labour income tax rate from 24 percent in the benchmark economy to 15 percent in the counterfactual depresses investment, capital stock, output and employment in all but the housing sector. Given the equal-yield constraint, the reduction in revenue due to lower labour income taxes causes equi-proportional increases in other taxes. This is the main reason for such depressing impacts of reducing labour income tax which contributes to 55 percent of the total tax revenue in the economy, with the dynamic efficiency loss of 2.05% of the base year

GDP as reported earlier. Though labour taxes may influence the labour leisure choice of individuals, given the structure of this model it is more "neutral" than any other taxes. More elaborate explanation of redistribution impacts of taxes is outside the scope of the current model, which has only a representative agent.

Besides capital and labour income taxes this model contains five other taxes: production tax, tax on investment goods, taxes on private consumption, taxes on public consumption and a tariff.

When we replace all sector-specific production tax rates in the benchmark, which vary from –11 to 14 percent in the base year, by a uniform rate of 5 percent, it has a positive impact both on growth and efficiency. Investment, capital stock, employment and output expand. The overall efficiency effect of the replacement is a sizeable 1.4 percent of the base year GDP. There is little variation between the open and closed capital markets cases.

Reform of indirect tax rates on investment goods exhibits a very different pattern of impacts on the model economy in comparison with other experiments, and we see a significant difference between the open and closed capital market scenarios, with and without announcement effects. Since investment taxes are small in the benchmark, however, all the associated impacts are relatively modest. In the long run, the growth paths of most sectors are 2 percent above or below the reference path. The efficiency loss from moving to a uniform 5 percent investment tax from the existing differentiated but lower tax rates ranges from 0.08 percent to -0.1 percent of base year GDP, suggesting that this tax is relatively more distortionary than other taxes.

In the current model tax rates on household consumption[6] vary from 1.6 percent in the agriculture sector to 26 percent in 'other manufactures' in the base year. In our experiment, these differentiated rates are replaced by a flat ten percent rate. The pattern of growth effects relative to the reference path varies significantly across sectors. Production sectors generally experience higher growth rates relative to the reference path while other sectors experience a negative impact. This pattern is very different from what we observe for other tax experiments, because consumers are less able to shift the burden of taxes in comparison to producers. Tax relieves on consumption increases demand by reducing distortions in relative prices faced by consumers and raises the effective wage rate for the household.

[6] The main excise duties on tobacco, alcohol and fuel were included in 'Production Taxes' here in line with ONS Input-Output definitions; although in a later tax aggregation provided by the Inland Revenue and used in our Static Model (Bhattarai (1999)) such excise taxes were incorporated within consumption taxes (see also Siddorn (1999)).

Taxes on public consumption vary from 0.6 percent to 32 percent in the data. Such differentiated tax rates on public consumption create distortions in public demand choices. In our counterfactual experiment, we reduce these rates to a uniform rate of 5 percent. Simulation results show that most of the sectors experience increased growth. Again, sectors with higher tax rates in the base year are above the reference path, and sectors with low taxes on public consumption do not show much variation.

Table 5
Sensitivity of lifetime utility to key elasticities in the model

Ten different configurations for key elasticities in the model (Scenarios)	Intertemporal substitution between consumption and leisure	Sensitivity of lifetime utility to elasticities of substitution in consumption and production (as percentage change of utility relative to it value in the benchmark)
S1	0.6	0.080001
S2	0.72	0.080000
S3	0.86	0.080000
S4	1.02	0.080001
S5	1.2	0.080002
S6	1.4	0.080001
S7	1.62	0.079999
S8	1.86	0.079999
S9	2.12	0.080001
S10	2.4	0.079997

Following a long process of intra-regional and international trade liberalisation over more than five decades, very little room is left for further gains from liberalisation of commodity trade alone. Still we find some mild efficiency effects and more or less uniformly positively distributed effects of tariff reform across sectors. These results show that as the UK economy is quite liberalised already, gains from such moves may be very small, even when dynamic linkages are taken into account.

The results discussed above are robust to the various specifications to the values of elasticities of substitution as shown in Table 5 below. The lifetime utilities do not vary much just by changes in these elasticities. For ten different values of these elasticities, that range form 0.6 to 2.4, we notice changes in the lifetime utility by only 0.08 percent of the benchmark scenario. This sensitivity result indicates that the model results that were discussed above, are robust enough to elasticity configurations. The welfare impacts of tax reform, reported in table 3 and 4 above, indeed reflect the cost of distortions from the tax system.

VI. Conclusion

The major advantage of the dynamic model presented here, in comparison to the static version of the models, lies in its ability to track both short- and long-run impacts of tax and trade policy measures on the growth path of the economy via their effects on capital formation. In the dynamic model, the process of capital accumulation, both in the short and in the long run, is determined endogenously through consumption-saving decisions of households and investment allocation decisions of producers. The structure of the model allows us to look at the differential impacts of tax reform on investment by sector and to capture the possibility of transitory shutdowns in sectoral investment.

The model is calibrated using 1995 micro consistent data for the UK economy. It is then used to perform a number of equal-yield tax replacement experiments, whereby a certain tax is reduced and the remaining taxes increased in order to guarantee a constant period-by-period level of government spending without any change in public borrowing. For each experiment, we assess overall dynamic efficiency impacts as well as transitional and long-run effects on sectoral output, employment, and capital formation. In each case, we investigate whether impacts differ when people can anticipate tax changes occurring in the future or when they encounter tax changes all of a sudden without any anticipation. We also investigate how results in a closed capital market specification differ from those in an open capital market setting.

The dynamic efficiency effects and the growth path impacts of tax reform vary significantly across experiments. When distortionary capital income tax rates ranging from 24 to 48 percent in the base year are replaced by a uniform capital income tax rate of 25 percent, the dynamic efficiency gains are about 0.77 percent of the base year GDP. Some sectors, such as agriculture, where the relative capital input cost has been reduced in the counterfactual scenario by lower capital income tax rates, experience an expansion. Other sectors, such as engineering, where the capital income tax has not been reduced that much in the counterfactual scenario relative to the benchmark, experience slower growth.

Reducing labour income tax from 24 percent in the benchmark year to 15 percent results in a welfare loss of up to 2.05 percent of the base year GDP, mainly because more distortionary taxes have to be increased to make up for lost revenues. Replacing differential tax rates on production by a uniform 5 percent rate across sectors results in a welfare gain of 1.4 percent of the base year GDP. Similarly replacing differentiated household consumption taxes by a uniform 5 percent rate causes a gain of 0.6 percent of GDP. We find similar gains in welfare from a reform in the taxes on government consumption and tariffs.

The private sector's ability to anticipate reform affects transitional effects as well as the dynamic efficiency effects of reform, raising them in some cases and lowering them in others. Simulation results appear to be robust with respect to changes in the degree of international openness of capital markets and a range of values for the intertemporal and entra-temporal substitution elasticities. In all cases, convergence to a new balanced-growth path occurs more quickly when private agents anticipate future tax changes and when capital markets are internationally open.

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Table A1

Aggregation of 123 sectors into 16 sectors from 1990 Input-Output Sectoral Classification

INDUSTRY/ASSET	1990 I-O Sectors	1990 sectoral code	1995 sectoral code
Agriculture	Agriculture, Forestry, Fishing	1,2,3	1-3
Extraction	Extraction – oil and gas	5	5
Other mining & quarrying	Coal extraction, stone, clay, sand, gravel, metal ores and minerals	4 ,14, 10	4,6,7
Chemicals	Coke ovens, oil proc, nuclear fuel, inorganic chemicals, organic chemicals, fertilisers, synthetic resins, paints, dyes, printing ink, special chemical for industry, pharmaceutical products, soap and toilet preparations, chemical products, man-made fibres	6, 20-29	35-46
Metals and mineral products	Iron and Steel, Aluminium, other non-ferrous metals, structural clay products, Cement, lime and plaster, concrete, asbestos, abrasive prods, glass, refractory and ceramic goods, metal casting, metal doors, windows, packaging products of metals, industrial plant and steel work, engineers small tools	11-13, 15-19, 30-34, 37	49-61
Engineering	Agricultural machinery and tractors, metal working machine tools, textile etc machinery, process machinery and contractors, mining equipment, mech power transmission equipment, other machinery, ordnance samll arms and ammunition, insulated wires and cables, basic electrical equipment, industrial electrical equipment, telecommunications etc. equipment, electronic components, electronic consumer goods, demestic electric appliances, electric lighting equipment, instrument engineering	35,36,38-52,57	62-76
Food, drinks and tobacco	Oils and fats, slaughtering and meat processing, milk and products, fruit vegetable and fish processing, grain milling and starch, bread, biscuits, sugar, confectionary, animal feeding stuffs, miscellaneous foods, alcoholic drink soft drinks, tobacco	58-70	8-20
Other manufacturing	Motor vehicles and parts, shipbuilding and repairing, aerospace etc, other vehicles, woollen and worsted, cotton spinning and weaving, hosiery and other knitted goods, textile finishing, carpets, jute, leather and leather goods, footwear, clothing furs, household and other textiles, timber and wood products, wooden furniture, pulp, paper and board, paper and board products, printing and publishing, rubber products, processing of plastics, jewellery and coins, sports goods and toys, other goods	53-56, 71-90	21-34, 47-48,77-84
Electricity, gas and water	Electricity production, gas, water supply	7,8,9	85-87
Construction	Construction	91	88
Distribution, hotels, etc.	Wholesale distribution, retail distribution, distribution and vehicles repairs, hotels catering, pubs etc.	92,93,94,95	89-92
Transport, storage, and communication	Railways, road and other inland transport, sea transport, air transport, transport services, postal services, telecoomunication	96-102	93-99
Financial sector	Banking and finance, insurance, auxiliary financial services, estate agents, legal services, accountancy services, other professional services, advertising, computing services, other business services, renting of movables, owning and dealing in real estate, research and development	103-114, 118	100-103, 105-114
Public administration	Public administration	115	115
Education, health and social work	Sanitary services, education, health services, recreation and welfare services, personal services, domestic services	116, 117 ,119-122	116-123
Housing services	Ownership of dwelling	123	104

Source: General equilibrium model of the UK economy, Hull Economics Research Paper 278, 2000.

Table A2
A 16 Sector Industry by Industry Input-Output Table of the United Kingdom 1995

I x I Domestic Use Matrix	Agricult ure	Extracti on	Other Mining	Chemic als	Metals	Enginee ring	Food, drink	Other Manuf.	Utilities	Constru ction	Distribu tion	Transpo rt	Financi al	Public Admin	Educ. Health,	Housing	Total intermedia te	Consum ers' expendi ture	GGFC	GDFCF	Stocks	Exports	Total final demand	Total
Agriculture	2,096	0	14	27	7	5	12,132	435	0	4	564	48	15	0	148	0	15,495	6,730	42	0	0	1,942	8,713	24,208
Extraction	0	2,439	0	4,697	3	0	0	0	3,622	0	0	0	0	0	0	0	10,762	0	0	0	0	6,942	6,942	17,704
Other Mining	20	0	353	218	846	26	45	130	1,897	401	105	17	8	0	57	0	4,124	339	47	0	0	983	1,369	5,493
Chemicals	1,433	10	37	3,899	433	546	571	1,484	466	737	1,299	1,254	913	0	3,204	19	16,304	3,764	3,116	0	261	28,663	35,804	52,108
Metals	110	162	192	1,225	7,249	6,320	1,831	5,197	50	7,074	503	389	5	0	84	0	30,392	346	588	7,158	779	10,230	19,101	49,493
Engineering	0	576	317	682	1,254	5,705	528	2,432	634	788	848	1,808	1,018	0	1,567	36	18,192	0	1,589	2,613	332	50,923	55,457	73,649
Food, drink	2,797	52	25	356	82	120	6,382	350	64	51	6,589	650	1,058	0	1,796	4	20,377	25,904	411	0	153	10,270	36,737	57,114
Other Manuf.	583	80	134	1,781	1,839	3,005	2,816	16,404	474	4,242	6,702	4,139	8,242	0	3,340	283	54,064	18,082	3,872	8,933	1,185	39,858	71,928	125,992
Utilities	279	0	160	1,330	1,596	1,189	931	1,980	12,273	272	1,201	857	1,184	0	705	23	23,981	16,353	1,323	0	0	62	17,738	41,719
Construction	172	0	122	109	32	56	0	31	0	21,085	603	151	1,985	0	146	3,929	28,420	3,521	4,414	47,764	285	0	55,983	84,404
Distribution	1,005	200	206	1,479	2,489	4,115	1,647	3,724	355	1,371	4,164	2,470	2,276	0	790	0	26,289	111,181	1,229	2,586	0	13,701	128,698	154,987
Transport	245	704	335	1,232	2,047	1,415	1,583	3,614	183	887	14,871	15,642	17,082	0	3,175	198	63,216	19,715	2,637	779	0	12,194	35,324	98,540
Financial	1,949	671	471	4,070	2,781	6,194	4,205	9,177	1,884	10,483	22,425	12,387	50,836	0	13,435	15,221	156,189	25,373	8,458	8,483	0	12,545	54,859	211,047
Public Admin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63,843	0	0	0	63,843	63,843
Educ. Health,	378	1	41	520	253	581	496	2,618	179	242	1,001	1,369	4,031	0	7,756	67	19,535	43,653	46,265	0	0	4,504	94,422	113,957
Housing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53,269	0	0	0	0	53,269	53,269
Total intermediate	11,067	4,895	2,410	21,626	20,912	29,276	33,168	47,576	22,081	47,638	60,876	41,182	88,652	0	36,201	19,781	487,339	328,229	137,832	78,316	2,995	192,816	740,188	1,227,527
Imports	1,630	989	425	10,639	7,613	15,965	8,827	30,336	3,612	5,151	3,532	4,895	3,949	0	2,960	19	100,541	52,021	9,995	28,174	1,563	2,494	94,248	194,789
Duty on imports	34	6	5	136	101	214	171	405	48	66	51	26	2	0	9	0	1,273	547	91	382	20	32	1,073	2,346
VAT	0	0	0	0	0	0	0	0	0	0	0	218	3,259	0	1,181	0	4,658	33,257	3,915	3,731	0	0	40,902	45,561
Duties and levies	211	2	103	1,175	344	176	460	331	1,378	130	1,275	2,026	896	0	344	36	8,887	22,713	434	0	0	0	23,147	32,034
Other taxes and subsidies	-265	-25	-10	-50	-53	-46	-1,454	-212	-10	-34	-443	-404	-409	0	-186	-6	-3,607	4,559	-577	-45	4	-556	3,384	-223
Value added – Labour	7,143	1,409	1,822	10,151	15,790	18,529	9,691	36,483	5,492	29,947	61,877	35,191	70,149	60,316	69,067	0	433,059	0	0	0	0	0	0	433,059
Value added – Gross profits etc	4,388	10,428	738	8,432	4,786	9,536	6,250	11,074	9,118	1,505	27,820	15,406	44,549	3,527	4,381	33,440	195,376	0	0	0	0	0	0	195,376
Total inputs	24,208	17,704	5,493	52,108	49,493	73,649	57,114	125,992	41,719	84,404	154,987	98,540	211,047	63,843	113,957	53,269	1,227,526	441,325	151,691	110,558	4,582	194,786	902,942	2,130,468

Source: ONS, Input-Output Tables of the United Kingdom, 1995; Siddorn (1999).

Table A3
Industry by Industry Import Use Matrix for the UK economy 1995

I x I Imports Use Matrix	Agriculture	Extraction	Other Mining	Chemicals	Metals	Engineering	Food, drink	Other Manuf.	Utili-Ties	Construction	Distribution	Transport	Financial	Public Admin	Educ. Health,	Housing	Total interme-diate	Consumers' expenditure	GGFC	GDFCF	Stocks	Exports	Total final demand	Total
Agriculture	462	0	0	2	0	0	2,342	394	0	0	546	9	0	0	0	0	**3,755**	1,471	0	0	0	46	1,517	**5,272**
Extraction	0	133	0	1,532	0	0	0	0	1,613	0	0	0	0	0	0	0	**3,278**	0	0	0	0	0	0	**3,278**
Other Mining	0	0	68	359	540	31	4	50	312	540	0	0	0	0	0	0	**1,905**	29	3	0	0	2,003	2,035	**3,941**
Chemicals	802	11	142	7,931	1,028	1,274	844	7,476	382	196	165	609	22	0	299	0	**21,182**	2,259	873	0	199	165	3,495	**24,677**
Metals	26	180	57	222	5,249	2,251	378	1,745	0	1,690	64	0	0	0	0	0	**11,863**	0	0	3	220	0	222	**12,085**
Engineering	45	161	61	13	286	11,980	22	2,177	855	770	46	791	78	0	119	0	**17,403**	6,220	3,123	22,859	148	164	32,513	**49,916**
Food, drink	291	0	0	275	0	0	4,641	36	0	0	936	53	0	0	0	0	**6,232**	8,812	348	0	18	19	9,198	**15,430**
Other Manuf.	0	0	79	300	478	369	565	18,399	12	1,900	1,206	641	60	0	357	0	**24,365**	24,075	2,893	5,312	979	98	33,357	**57,722**
Utilities	0	0	0	3	4	1	2	3	432	0	0	0	0	0	0	0	**446**	0	0	0	0	0	0	**446**
Construction	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	**44**	0	0	0	0	0	0	**44**
Distribution	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	3,518	0	0	0	0	3,518	**3,518**
Transport	0	504	11	0	5	0	4	0	0	2	530	2,720	375	0	60	0	**4,211**	4,036	342	0	0	0	4,378	**8,590**
Financial	4	1	8	0	20	50	22	0	4	10	35	33	3,369	0	886	19	**4,463**	0	1,328	0	0	0	1,328	**5,791**
Public Admin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	416	0	0	0	416	**416**
Educ. Health,	0	0	0	1	3	8	2	55	2	0	3	38	45	0	1,238	0	**1,395**	1,035	669	0	0	0	1,704	**3,099**
Housing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	566	0	0	0	0	566	**566**
Total Imports	**1,630**	**989**	**425**	**10,639**	**7,613**	**15,965**	**8,827**	**30,336**	**3,612**	**5,151**	**3,532**	**4,895**	**3,949**	**0**	**2,960**	**19**	**100,541**	**52,021**	**9,995**	**28,174**	**1,563**	**2,494**	**94,248**	**194,789**

Source: ONS, Input-Output Tables of the United Kingdom, 1995; Siddorn (1999).

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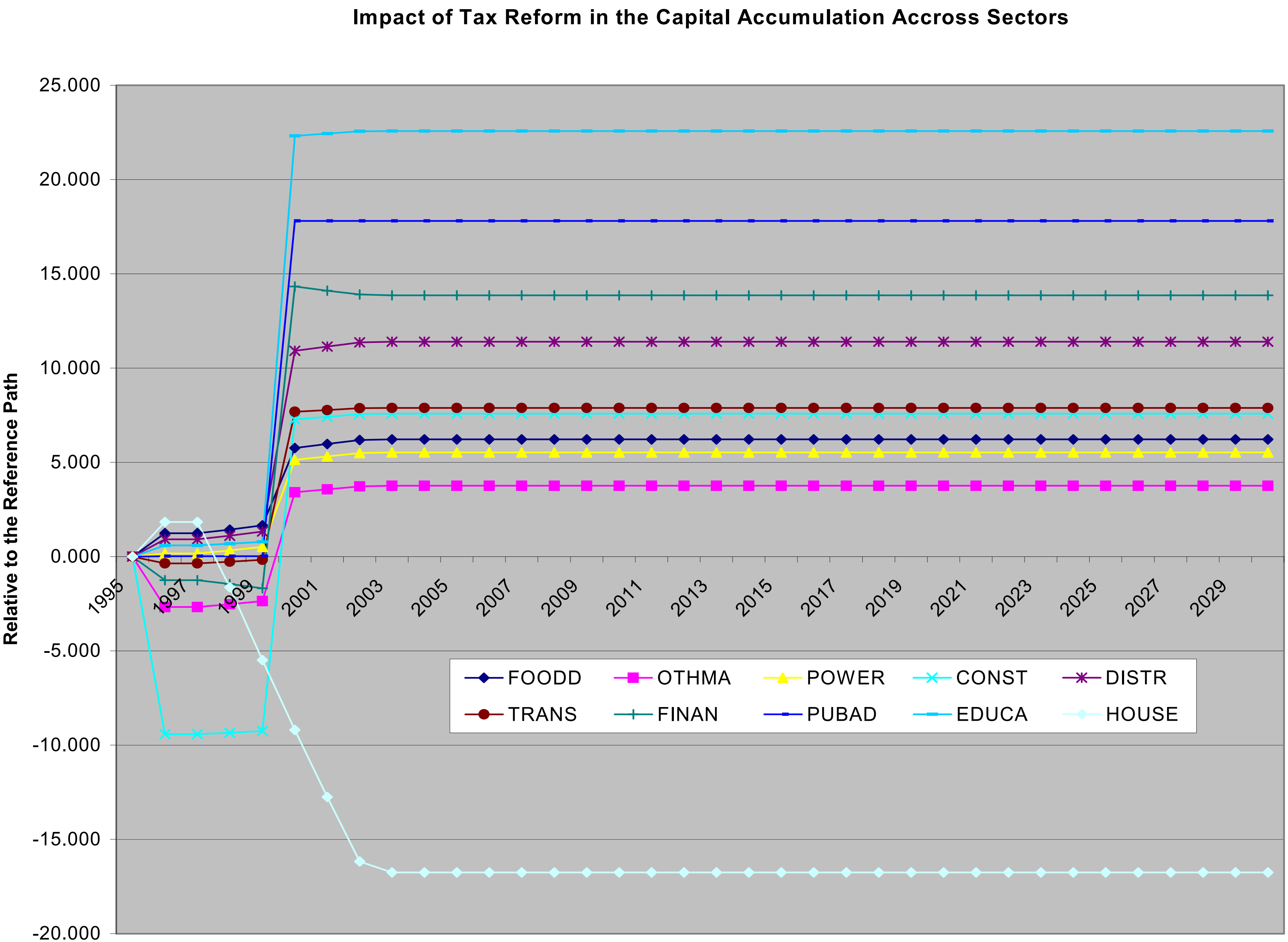
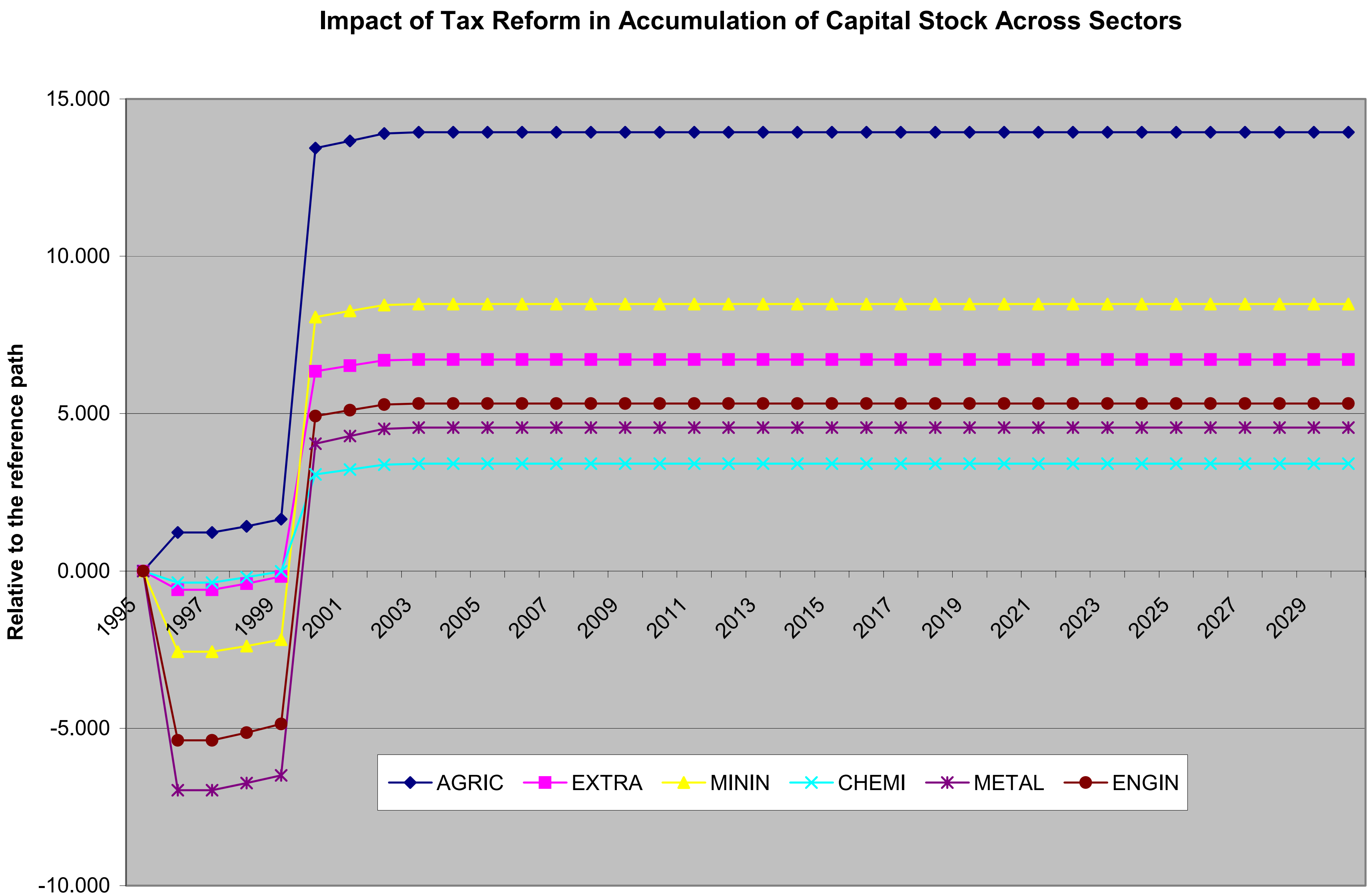


Impact of Tax Reform in the Capital Accumulation Accross Sectors
Relative to the Reference Path
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.000
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
FOODD
OTHMA
POWER
CONST
DISTR
TRANS
FINAN
PUBAD
EDUCA
HOUSE

Figure A1

Figure A2



Impact of Tax Reform in Accumulation of Capital Stock Across Sectors
Relative to the reference path
15.000
10.000
5.000
0.000
-5.000
-10.000
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
AGRIC
EXTRA
MININ
CHEMI
METAL
ENGIN