

An Integrated Microsimulation and Applied General Equilibrium Approach to Modelling Fiscal Reform

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Abstract

In recent times there has been an increase in both the number and scope of empirical methods for providing economic assessments of tax and welfare reform. This paper develops a framework for analysing fiscal reforms that overcomes some of the significant conceptual and methodological deficiencies of existing approaches. The IMAGE (Integrated Microsimulation and Applied General Equilibrium) model developed for the UK is documented, and employed to analyse the important issue of corporate tax reform.

The IMAGE model is the first to integrate the detailed demand-based approach typical of microsimulation models with the market analysis of applied general equilibrium models. In this respect, the model can simulate the impact of a given tax reform on the personal distribution of income, the functional distribution of income, economic efficiency and government revenue. In addition, the model incorporates imperfect competition in production. These features of the model are central to the main application in the paper, namely the examination of the incidence of corporate taxation. For example, the incorporation of micro-unit household data enables the effects of corporation tax reform on the household distribution of income to be examined in detail, which has not been possible with existing empirical tax models.

Model simulation results are presented for a general reduction in corporation tax rates, financed by a reduction in public sector transfers. The model indicates a simulated efficiency gain from the reform, but entails substantial redistribution towards wealthier households and a significant increase in inequality. With respect to the functional distribution of income, the reform redistributes income from labour to owners of capital. The results are placed in the context of existing studies of the incidence of corporate taxation, and demonstrate how the methodological extensions implemented in the empirical model have a significant impact on corporate tax incidence. The paper goes further by applying recently developed techniques to compute measures of statistical reliability for simulation results, an area that has received insufficient attention in the empirical tax modelling literature.

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Key words: Microsimulation, Applied general equilibrium, Corporate tax incidence

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1. Introduction

In recent times there has been an increase in both the number and scope of empirical methods for providing economic assessments of tax and welfare reform. However, there are significant limitations associated with existing approaches. For example, many microsimulation tax models do not explicitly model the behavioural responses of household's or individual's to changes in the tax and social security system. If these effects are significant in any given case, then simulation results obtained under the assumption of no behavioural responses will be biased. Some microsimulation models have incorporated limited behavioural responses, primarily in the area of labour supply, but have not explicitly modelled behavioural change in other areas, such as demand for commodities. In addition, such models generally abstract from the production side of the economy, and are thus not capable of analysing the effects on income distribution of policies such as corporation tax reform. Other modelling approaches are also deficient in a number of respects. For example, applied general equilibrium (AGE) models have developed as a separate strand in the analysis of tax reforms, but existing AGE models also have a number of limitations. The most striking deficiency of existing AGE models is the inadequate treatment of the household side of the economy. The use of a small number of hypothetical household types or aggregate household groups (sometimes a single representative consumer) precludes any detailed distributional analysis, and in this respect, the distributional results obtained from a model could be seriously misleading. Restrictive consumer preference specifications are routinely imposed in AGE models, and this is another potential flaw in the demand specification.

This paper develops a framework for analysing fiscal reforms that overcomes some of the significant conceptual and methodological deficiencies of existing approaches. The IMAGE (Integrated Microsimulation and Applied General Equilibrium) model developed for the UK is documented, and employed to analyse the important issue of corporate tax reform.

The IMAGE model is the first to integrate the detailed demand-based approach typical of microsimulation models with the market analysis of applied general equilibrium models. More specifically, the model is a static applied general equilibrium model that incorporates a micro-unit household data set. In this respect,

the model can simulate the impact of a given tax reform on the personal distribution of income, the functional distribution of income, economic efficiency and government revenue. Household preferences are represented by more flexible functional forms than have been employed in previous AGE models, and allow income effects to be modelled in the demand specification. In addition, the model incorporates imperfect competition in production. These features of the model are central to the main application in the paper, namely the examination of the incidence of corporate taxation. For example, the incorporation of micro-unit household data enables the effects of corporation tax reform on the household distribution of income to be examined in detail, which has not been possible with existing empirical tax models.

The primary data sources employed in the model are the UK Family Expenditure Survey and the UK Input-Output Balances, and the model incorporates all major direct and indirect taxes in the UK. Section 2 outlines the theoretical structure underlying the IMAGE model, and Section 3 provides an overview of data sources and issues in the empirical implementation of the model. In Section 4 the model's capabilities are demonstrated by simulating the impact of a general reduction in corporation tax rates, financed by reductions in public sector transfers, on the distribution of income, economic efficiency and government revenue. The structure of the model enables empirical analysis of both the functional and personal distribution of income. A further feature of the present study, discussed in Section 5, is the employment of gaussian quadrature techniques to derive confidence intervals for simulation results, thus providing a measure of the statistical reliability of simulation results. The final section presents the conclusions of the analysis.

2. Theoretical Structure of the IMAGE Model

The IMAGE model is based on the real, static Walrasian general equilibrium framework. The two regions distinguished in the model are the United Kingdom (UK) and the rest of the world (RoW).

2.1 Production Sector

In terms of UK production, the model distinguishes 28 profit maximising industries, and the industry classifications employed in the model are listed in Table 1.

Table 1: Model Industry Classification

No.	Description	Industry abbrev.	Industry Type ^a
1	Agriculture, forestry and fishing	AGFOFI	PC
2	Mining and Extraction	MINEXT	PC
3	Food and soft drinks	FOODSD	IC
4	Alcoholic drinks	ALCOHL	IC
5	Tobacco products	TOBACO	IC
6	Textiles	TEXTIL	IC
7	Clothing, footwear and leather	CLOTFL	IC
8	Timber and furniture	TIMFUR	IC
9	Paper, printing and publishing	PAPRPU	IC
10	Coke, refined petroleum and nuclear fuel	CORPNF	PC
11	Chemicals, rubber and plastic	CHRUPL	IC
12	Glass, ceramics and building products	GLCEBP	IC
13	Metals	METALS	IC
14	Machinery	MACHIN	IC
15	Electrical and electronic engineering	ELCENG	IC
16	Motor vehicles	MOTVEH	IC
17	Other transport equipment	OTRANE	IC
18	Other manufacturing	OMANUF	IC
19	Electricity, gas and water supply	ELGAWS	PC
20	Construction	CONSTR	PC
21	Distribution, hotels and restaurants	DISTHR	PC
22	Transport service	TRANSV	PC
23	Communication	COMMUN	PC
24	Finance and insurance	FININS	PC
25	Real estate	REALES	PC
26	Business and legal services	BUSSER	PC
27	Social services	SOCSER	PC
28	Other services	OTHSER	PC

Notes: (a) PC and IC refer to perfect competition and imperfect competition respectively

The 4 primary industries and 9 service industries in the model classification are characterised by perfect competition and constant returns to scale, with production technologies represented by nested CES production functions. The remaining 15 manufacturing industries are characterised by imperfect competition and increasing returns to scale, and Chamberlinian monopolistic competition is assumed in each industry. The specification of perfectly competitive non-manufacturing industries and imperfectly competitive manufacturing industries is consistent with existing AGE models that incorporate imperfect competition (e.g. Harris, 1984; Harris and Cox, 1984; Willenbockel, 1994)¹. Production technologies in manufacturing industries are

¹ At this point, it should be acknowledged there is potential ambiguity in this classification. For example, it might be reasonable to suggest that industry 19 (ELGAWS) is not characterised by perfect

represented by nested generalised CES production functions with fixed primary factor requirements.

The production technologies of firms in all industries are represented by a two-stage nested production function. The top level of the nesting structure represents the firm's variable input requirement decision, and depicts the cost-minimising choice of labour, capital, and N composite intermediate inputs. Level two of the nested production function involves the allocation of expenditure on each composite intermediate input between a domestic composite intermediate and the corresponding foreign intermediate. Based on the work of Armington (1969), this approach assumes that commodities of different regional origin are imperfect substitutes in demand. The number of firms in each UK manufacturing industry is fixed, allowing pure profits to persist. Production in all UK industries requires the combination of two primary factors, UK labour and UK capital, and produced intermediate inputs from the UK and the RoW. Primary factors are internationally immobile. The supply of UK labour is variable, whilst the supply of UK capital is fixed. In addition, primary factors are intersectorally mobile, such that factor rewards are uniform across UK industries in the full-employment equilibrium. International trade enters the model via UK demand functions for imports and constant elasticity RoW demand functions for UK exports, and all final and intermediate commodities are tradable.

Formally, let \tilde{I}_1 and \tilde{I}_2 denote index sets over perfectly competitive and imperfectly competitive industries respectively, and let $\tilde{I} = \tilde{I}_1 \cup \tilde{I}_2$ denote an index set over all N industries. Also, let \tilde{K}_1 and \tilde{K}_2 denote an index set over domestic and foreign industries respectively, and let $\tilde{K} = \tilde{K}_1 \cup \tilde{K}_2$ denote an index set over all N industries. The production function for domestic industry $i \in \tilde{I}$ is defined as;

$$X_i = \gamma_i \left[\delta_{L_i} (L_i - L_{f,i})^{-\rho_i} + \delta_{K_i} (K_i - K_{f,i})^{-\rho_i} + \sum_{j \in \tilde{I}} \delta_{ji} x_{ji}^{-\rho_i} \right]^{-1/\rho_i}, \quad i \in \tilde{I} \quad (1)$$

with $\gamma_i > 0$, $\delta_{L_i} + \delta_{K_i} + \sum_{j \in \tilde{I}} \delta_{ji} = 1$, $-1 < \rho_i < \infty$, and

competition. However, data on 'minimum efficient scale', employed in the calibration of fixed factor requirements in imperfectly competitive industries, only exist for manufacturing industries, and could not be obtained for non-manufacturing industries.

$$x_{ji} = \left[\sum_{k \in \tilde{K}} \delta_{jik} x_{jik}^{-\kappa_j} \right]^{-1/\kappa_j}, \quad i, j \in \tilde{I} \quad (2)$$

with $\sum_{k \in \tilde{K}} \delta_{jik} = 1$, and $-1 < \kappa_j < \infty$,

where X_i is total output of industry i , L_i and K_i are total demand for labour and capital respectively by industry i , x_{jik} is the quantity of intermediate commodity j produced in region k demanded by industry i , x_{ji} is the quantity of the Armington composite intermediate commodity j demanded by industry i , $L_{f,i}$ and $K_{f,i}$ are the fixed labour and capital requirements respectively of industry i , and $L_{f,i} = K_{f,i} = 0 \forall i \in \tilde{I}_1$. In terms of the parameters of the top level of the production function (equation 1), γ_i is the efficiency parameter, δ_{Li} , δ_{Ki} and δ_{ji} are the intensity parameters for labour, capital and composite intermediate j respectively in industry i , ρ_i is the substitution parameter, and the elasticity of substitution between labour, capital and composite intermediates is given by $\sigma_i = 1/(1 + \rho_i)$. In terms of the parameters of the Armington level of the production function (equation 2), δ_{jik} is the geographical intensity parameter for intermediate commodity j produced in region k employed in the production of commodity i , κ_j is the substitution parameter, and the Armington elasticity of substitution for intermediate commodity j is given by $\sigma_{Aj} = 1/(1 + \kappa_j)$. Note that the production technology specification is weakly separable, in that the marginal rate of substitution between any pair of inputs in a composite is independent of the quantities of inputs in all other composites within the same level.

The total cost function dual to the nested generalised CES production function for industry $i \in \tilde{I}$ is;

$$C_i = c_i(w, r, \mathbf{q}) X_i + w L_{f,i} + r K_{f,i}, \quad i \in \tilde{I} \quad (3)$$

where;

$$c_i(w, r, \mathbf{q}) = \gamma^{-1} \left[\delta_{Li}^{\sigma_i} w^{1-\sigma_i} + \delta_{Ki}^{\sigma_i} r^{1-\sigma_i} + \sum_{j \in \tilde{I}} \delta_{ji}^{\sigma_i} q_{ji}^{1-\sigma_i} \right]^{1/(1-\sigma_i)}, \quad i \in \tilde{I} \quad (4)$$

represents the marginal cost function, w and r denote the domestic wage rate and rental rate of capital respectively, \mathbf{q} is a $2N$ -vector comprising domestic and foreign intermediate input prices faced by domestic firms, and the price aggregator functions;

$$q_{ji}(\mathbf{q}) = \sum_{k \in \tilde{K}} \delta_{jik}^{\sigma_{Aj}} q_{jik}^{1-\sigma_{Aj}} \Big|^{1/(1-\sigma_{Aj})}, \quad i, j \in \tilde{I} \quad (5)$$

are the consistent price indices dual to the top-level composite intermediate commodities x_{ji} . Again, $L_{f,i} = K_{f,i} = 0 \forall i \in \tilde{I}_1$.

Application of Shepard's lemma yields the optimal primary factor demands and intermediate input demands for industry $i \in \tilde{I}$;

$$L_i = L_{f,i} + \frac{X_i}{\gamma_i} \delta_{Li} + \delta_{Ki} \left(\frac{\delta_{Li} r}{\delta_{Ki} w} \right)^{1-\sigma_i} + \sum_{s \in \tilde{I}} \delta_{si} \left(\frac{\delta_{Li} q_{si}}{\delta_{si} w} \right)^{1-\sigma_i} \frac{\sigma_i}{(1-\sigma_i)} \quad (6)$$

$$K_i = K_{f,i} + \frac{X_i}{\gamma_i} \delta_{Li} \left(\frac{\delta_{Ki} w}{\delta_{Li} r} \right)^{1-\sigma_i} + \delta_{Ki} + \sum_{s \in \tilde{I}} \delta_{si} \left(\frac{\delta_{Ki} q_{si}}{\delta_{si} r} \right)^{1-\sigma_i} \frac{\sigma_i}{(1-\sigma_i)} \quad (7)$$

$$x_{ji} = \frac{X_i}{\gamma_i} \delta_{Li} \left(\frac{\delta_{ji} w}{\delta_{Li} q_{ji}} \right)^{1-\sigma_i} + \delta_{Ki} \left(\frac{\delta_{ji} r}{\delta_{Ki} q_{ji}} \right)^{1-\sigma_i} + \sum_{s \in \tilde{I}} \delta_{si} \left(\frac{\delta_{ji} q_{si}}{\delta_{si} q_{ji}} \right)^{1-\sigma_i} \frac{\sigma_i}{(1-\sigma_i)}, \quad j \in \tilde{I} \quad (8)$$

where $L_{f,i} = K_{f,i} = 0 \forall i \in \tilde{I}_1$, and;

$$x_{jik} = x_{ji} \sum_{l \in \tilde{K}} \delta_{jil} \left(\frac{\delta_{jik} q_{jil}}{\delta_{jil} q_{jik}} \right)^{1-\sigma_{Aj}} \frac{\sigma_{Aj}}{(1-\sigma_{Aj})}, \quad j \in \tilde{I}, k \in \tilde{K} \quad (9)$$

2.2 Household Sector

The 6,415 UK households in the model choose combinations of labour supply and consumption levels of final goods in order to maximise nested LES/CES utility functions. The generalised CES function, or LES/CES function, introduces subsistence consumption quantities into the CES function, and is more general than either the simple LES or CES specifications. More specifically, the associated demand system is not necessarily linear in prices, and does not impose unitary income

elasticities. Consequently, income effects are captured in the model. The budget of a UK household comprises profits from imperfectly competitive UK industries that are entirely distributed to UK shareholders, income from renting factor services to UK industries, and transfer payments received from the UK government. Total pure profits are redistributed to households in proportion to their share of total capital supply.

Formally, let \tilde{M}_1 and \tilde{M}_2 denote index sets over final consumer commodities produced by perfectly competitive industries and imperfectly competitive industries respectively, and let $\tilde{M} = \tilde{M}_1 \cup \tilde{M}_2$. Also, let \tilde{H} denote an index set over all households. The top level of the nesting structure of household demand involves the allocation of household full income between the aggregate consumption commodity X_h and leisure ℓ_h , and thus determines household labour supply L_h . The second level involves the allocation of aggregate consumption expenditure between the M Armington composite final commodities X_{mh} , and the third level involves the allocation of expenditure on each Armington composite final commodity between final commodities of different regional origin X_{mhk} . The bottom level involves the allocation of expenditure on each domestic final commodity between different varieties of that commodity produced in imperfectly competitive industries ($m \in \tilde{M}_2$). It is assumed that each household consumes equal quantities of each variety.

The generalised CES (or LES/CES) utility function of UK household $h \in \tilde{H}$ corresponding to the top level of the household preference nesting structure is depicted by;

$$U_h = \left[\alpha_{xh}^{1/\mu_h} (X_h - X_{fh})^{(\mu_h-1)/\mu_h} + \alpha_{\ell h}^{1/\mu_h} \ell_h^{(\mu_h-1)/\mu_h} \right]^{\mu_h / (\mu_h-1)}, \quad h \in \tilde{H} \quad (10)$$

where U_h is the utility of household $h \in \tilde{H}$, X_h is demand for the aggregate consumption commodity, X_{fh} is the fixed aggregate consumption requirement for household $h \in \tilde{H}$ and ℓ_h is household leisure demand. In terms of the parameters of the top level of the utility function, α_{xh} and $\alpha_{\ell h}$ are the share parameters for aggregate consumption and leisure demand respectively for household $h \in \tilde{H}$ ($\alpha_{xh} + \alpha_{\ell h} = 1$),

and μ_h is the elasticity of substitution between aggregate consumption and leisure demand ($0 < \mu_h < \infty$).

The second level of the nested household utility specification employs an LES/CES function to model the allocation of aggregate household consumption X_h between composite final commodities, and is depicted by;

$$X_h = \sum_{m \in \tilde{M}} \alpha_{mh}^{1/\nu} (X_{mh} - X_{fmh})^{(\nu-1)/\nu} \Big|^{ \nu/(\nu-1) }, \quad h \in \tilde{H} \quad (11)$$

with $\sum_{m \in \tilde{M}} \alpha_{mh} = 1$ and $0 < \nu < \infty$,

where X_{mh} is the demand for composite final commodity $m \in \tilde{M}$ by household $h \in \tilde{H}$, and X_{fmh} is the fixed consumption requirement of composite final commodity $m \in \tilde{M}$ for household $h \in \tilde{H}$. In terms of the parameters of the second level of the utility function, α_{mh} is the share parameter for composite final commodity $m \in \tilde{M}$ in aggregate consumption of household $h \in \tilde{H}$, and ν is the elasticity of substitution in demand between final composite commodities.

The Armington level of the nested household utility specification employs a CES function to model the allocation of demand for each final composite commodity X_{mh} between goods of domestic and foreign origin, and is depicted by;

$$X_{mh} = \sum_{k \in \tilde{K}} \alpha_{mhk}^{1/\sigma_{Am}} X_{mhk}^{(\sigma_{Am}-1)/\sigma_{Am}} \Big|^{ \sigma_{Am}/(\sigma_{Am}-1) }, \quad m \in \tilde{M}, h \in \tilde{H} \quad (12)$$

with $\sum_{k \in \tilde{K}} \alpha_{mhk} = 1$ and $0 < \sigma_{Am} < \infty$,

where X_{mhk} is the quantity of final commodity m produced in region k demanded by household h . In terms of the parameters of the Armington level of the household demand specification, α_{mhk} is the geographical intensity parameter for final commodity m produced in region k demanded by household h , and σ_{Am} is the Armington elasticity of substitution for final commodity m . Note that the CES specification has been maintained for the Armington level of the nesting structure. This is plausible, as there are not likely to be strong income effects associated with the choice between domestic and foreign commodities.

Recall that for commodities produced in imperfectly competitive industries, households consume each variety of the commodity in equal proportions, and this is not depicted in the formal representation of the utility function above.

The consistent price index p_{mh} dual to the Armington composite final commodity X_{mh} for household $h \in \tilde{H}$ is defined by;

$$p_{mh} = \sum_{k \in \tilde{K}} \alpha_{mhk}^{\sigma_{Am}} p_{mk}^{1-\sigma_{Am}} \Big|^{1/_{(1-\sigma_{Am})}}, \quad m \in \tilde{M}, h \in \tilde{H} \quad (13)$$

where p_{mk} is the UK price of final commodity m produced in region k .

Similarly, the consistent price index p_h dual to the aggregate consumption commodity X_h for household $h \in \tilde{H}$ is defined by;

$$p_h = \sum_{m \in \tilde{M}} \alpha_{mh}^v p_{mh}^{1-v} \Big|^{1/_{(1-v)}}, \quad h \in \tilde{H} \quad (14)$$

Based on the household preference specification detailed above, the utility maximising set of labour supply and commodity demand functions for UK household $h \in \tilde{H}$ are;

$$X_h = X_{fh} + \frac{\alpha_{Xh}(Y_h^F - p_h X_{fh})}{p_h^{\mu_h} (\alpha_{Xh} p_h^{1-\mu_h} + \alpha_{\ell h} \hat{w}_h^{1-\mu_h})}, \quad h \in \tilde{H} \quad (15)$$

$$\ell_h = \frac{\alpha_{\ell h}(Y_h^F - X_{fh})}{\hat{w}_h^{\mu_h} (\alpha_{Xh} p_h^{1-\mu_h} + \alpha_{\ell h} \hat{w}_h^{1-\mu_h})}, \quad h \in \tilde{H} \quad (16)$$

$$L_h = L_h^E - \ell_h, \quad h \in \tilde{H} \quad (17)$$

with;

$$X_{mh} = X_{fmh} + \frac{\alpha_{mh} p_h X_h - \sum_{s \in \tilde{M}} p_{sh} X_{fsh}}{p_{mh}^v \sum_{s \in \tilde{M}} \alpha_{sh} p_{sh}^{1-v}}, \quad m \in \tilde{M}, h \in \tilde{H} \quad (18)$$

and;

$$X_{mhk} = \frac{\alpha_{mhk} p_{mh} X_{mh}}{p_{mhk}^{\sigma_{Am}} \sum_{l \in \tilde{K}} \alpha_{mhl} p_{mhl}^{1-\sigma_{Am}}}, \quad m \in \tilde{M}, h \in \tilde{H}, k \in \tilde{K} \quad (19)$$

where Y_h^F is full income of household $h \in \tilde{H}$, \hat{w}_h is the wage rate received by household h after all taxes (i.e. the price of leisure), L_h is household labour supply and L_h^E is the fixed labour endowment of household h . Equations (15)-(17) correspond to the top level of the household preference nesting structure, equations (18) correspond to the second level and equations (19) correspond to the Armington level.

2.3 The External Sector

The UK is assumed to face fixed RoW market prices for each intermediate and final commodity, and this approach is typical of single region AGE models. This does not imply that the UK faces an infinitely elastic import supply curve for each commodity, since imports to the UK are linked to the finitely elastic RoW demand functions by the external balance equilibrium condition.

With respect to UK exports, RoW demands are represented by constant elasticity demand functions for each intermediate and final UK commodity. Formally, RoW demand for exported UK final commodity $m \in \tilde{M}$ is defined by;

$$X_{mk}^* = \bar{X}_{mk}^* \frac{q_{mk}}{e} \Big|_{\eta_m^*}, \quad k \in \tilde{K}_1 \quad (20)$$

where X_{mk}^* is the RoW demand for UK final commodity m , \bar{X}_{mk}^* is the benchmark RoW demand for UK final commodity m , q_{mk} is the UK producer price of final commodity m , e is the nominal exchange rate variable, η_m^* is the export demand elasticity and $-\infty < \eta_m^* < 0$.

Similarly, RoW demand for exported UK intermediate commodity $i \in \tilde{I}$ is defined by;

$$x_{ik}^* = \bar{x}_{ik}^* \frac{q_{ik}}{e} \Big|_{\eta_i^*}, \quad k \in \tilde{K}_1 \quad (21)$$

where x_{ik}^* is the RoW demand for UK intermediate commodity i , \bar{x}_{ik}^* is the benchmark RoW demand for UK intermediate commodity i , q_{ik} is the UK producer

price of intermediate commodity i , e is the nominal exchange rate variable, η_i^* is the export demand elasticity and $-\infty < \eta_i^* < 0$.

The adopted external sector formulation is similar to that employed by Boadway and Treddenick (1978) and Willenbockel (1994). It is worth reiterating that under the almost small country assumption, the set of imported RoW commodities forms a Hicks-Leontief composite, where e is the variable price of this composite. Given that only relative prices matter in the Walrasian framework, one price can be determined exogenously. Consequently, e is made the numeraire price, and without loss of generality is set equal to unity in the empirical model. This is equivalent to setting all RoW import supply prices to unity.

2.4 Public Sector and Equilibrium Conditions

The role of the UK government is purely redistributive in the empirical model. Revenue is generated from a combination of factor, commodity, income and corporation taxes, and is then redistributed to UK households in the form of transfers.

Equilibrium in the empirical model requires that supply equals demand for each commodity and each factor, that the external balance is zero, and that the public sector budget deficit is zero. Under the assumptions of increasing returns to scale and a fixed number of firms in imperfectly competitive industries, aggregate profits will generally be positive in equilibrium.

3. Data, Parameters and Model Tax Rates

The construction of a benchmark equilibrium data set is described by Dervis et al. (1982) as “a nightmare with which every model builder is all too familiar”, and can be tedious and time-consuming. The process is described in Dervis et al. (1982), St-Hilaire and Whalley (1983), Piggott and Whalley (1985), Ballard et al. (1985), Shoven and Whalley (1992) and Willenbockel (1994). The complicated and involved process of constructing the benchmark data set for the IMAGE model is only sketched in this paper.

Constructing a benchmark equilibrium data set involves the assumption of an observable equilibrium. That is, a data set that is consistent with model definitions and that satisfies its general equilibrium conditions. Following Shoven and Whalley (1992; p103-106), model-conformable benchmark equilibrium data sets are usually constructed from national accounts and other government data sources. In published form these data do not usually satisfy general equilibrium conditions or accord with economic definitions typically employed in AGE models. For example, government budget and external sector balance conditions are not generally satisfied in published data sets. Also, household expenditure data is generally inconsistent with production data in terms of both classifications adopted and overall totals. A substantial number of adjustments to the data are required to ensure that equilibrium conditions are satisfied, and a significant degree of subjective judgement is required on behalf of the modeller.

The first step in the data construction process involves the use of input-output data to establish the structure of intermediate transactions and overall final demand, as well as the composition of gross value added by industry. This provides the basis for many of the variables defined in the model, including:

- industry intermediate purchases by commodity
- industry primary factor employment
- total household final demand by commodity
- government final demand by commodity
- investment demand by commodity
- export demand by commodity,

and some information on indirect taxes. The source of this information is the 1997 Input-Output Balances for the UK (Office of National Statistics, 1999). The breakdown of intermediate and final purchases into domestically produced and imported components is not provided in the Input-Output Balances, and is based on the 1990 Input-Output Tables for the UK (CSO, 1995).

Information on taxes in the model is derived from a variety of sources, including Inland Revenue Statistics, the Family Expenditure Survey, National Accounts data and the Input-Output Balances. The empirical model incorporates a combination of

taxes on labour, commodities, corporate income and household income, which all enter the model in ad valorem form. Taxes must be represented in model-consistent form, but a large degree of subjective judgement is involved in the implementation of any given tax (Shoven and Whalley, 1992; p5-6). It is not possible in this paper to detail the considerable procedures involved in deriving model-conformable tax rates. The tax rates employed in the model are presented in Appendices I and II.

Finally, model data on households is based on the 1996/97 Family Expenditure Survey, which contains detailed expenditure, income and demographic information for a sample of 6,415 UK households. Variables from this source are re-categorised according to model definitions, and income and expenditure totals are brought into line with national accounts totals via a re-weighting procedure (Gomulka, 1992).

Given that benchmark equilibrium data are generally produced in value terms, units must be chosen for goods and factors so that separate price and quantity observations are obtained. This practice is innocuous in the Walrasian framework, as only relative prices matter. A commonly adopted units convention, originally employed by Harberger (1962), is to choose units for both goods and factors so that they have a price of unity in the benchmark equilibrium. Given the existence of various taxes in the present model, units for goods and factors are chosen such that the prices received by producers for supplying commodities and by households for supplying factors are unity.

Having specified functional forms for the model equations and constructed the benchmark equilibrium data set, the parameters of the model can be calibrated. Calibration can be described as the requirement that the entire model specification be capable of generating the benchmark equilibrium data as a model solution. In effect, the model is “solved from equilibrium data for its parameter values” (Shoven and Whalley, 1992; p103). Given that calibration is based on data for one period, the benchmark equilibrium data do not usually identify a unique set of values for the parameters in the model². Consequently, various parameter values (e.g. elasticities) must be obtained from extraneous sources, and are usually specified on the basis of

² Only when very restrictive functional forms are used (e.g. Cobb-Douglas) will the benchmark equilibrium data uniquely identify all parameters of the model.

other research. Along with the benchmark equilibrium data, these extraneously specified parameters are used to uniquely identify the remaining parameters in the model. Due to the adoption of more flexible functional forms relative to existing AGE models, the calibration of parameters in the IMAGE model is more involved. The various parameter estimates from extraneous sources employed in the IMAGE model have been obtained from existing studies, and are presented in Appendix III.

4. Simulating a General Reduction in Corporation Tax Rates

4.1 Overview of the Simulation³

The fully specified IMAGE tax model for the UK can be employed to analyse a wide range of potential reforms. This section employs the model to analyse the incidence of a reduction in the UK corporation tax, financed by a reduction in public sector transfer payments to households. Analysing corporate tax reform within the context of the present study is appropriate for a number of reasons. For example, the public finance literature has paid significant attention to the analysis of the incidence of corporate taxation. Following the pioneering work of Harberger (1962), a significant number of studies have considered various extensions and modifications in order to assess the effective incidence of the corporation tax. It has been demonstrated within a theoretical context that relaxing various assumptions of the basic Harberger model can affect results regarding the incidence of corporate taxation (e.g. Atkinson and Stiglitz, 1980). Extensions include the specification of non-homothetic preferences and pre-existing distortions, heterogeneous consumers, intermediate production, imperfect competition and sectoral factor immobility. Empirical work by Shoven and Whalley (1972) made significant advances over the Harberger analysis by incorporating non-infinitesimal changes, heterogeneous consumers and intermediate production. The methodology and simulation results presented in this paper aim to make a significant contribution to the existing body of literature by simultaneously incorporating all the theoretical extensions mentioned above (excluding sectoral factor immobility). That is, the incidence of corporate taxation is examined within a fully integrated applied general equilibrium model that incorporates non-homothetic preferences and pre-existing distortions, heterogeneous consumers, intermediate

³ The simulations described in the paper were carried out using the GEMPACK software. Full details of the software and hardware requirements can be obtained from the GEMPACK documentation (Codsì and Pearson, 1988).

production, imperfect competition and non-infinitesimal changes. Also, analysing corporate tax reform serves to highlight the model's capabilities, particularly in relation to existing methodologies for analysing fiscal reform. To illustrate, results for a simulated reduction in corporation tax rates are presented below, including a comprehensive and detailed analysis of the effects on the household distribution of income. That is, the IMAGE model can simulate the detailed impact of taxation reform in the production sector on a representative sample of households. The empirical model discussed in this paper is the first empirical tax model to provide detailed distributional analyses within a fully integrated general equilibrium framework. The analysis presented below simulates the links between reform of taxation of firms and the distribution of household income, and therefore demonstrates a significant contribution of the empirical model in terms of existing models.

The simulated reform involves reducing the corporate tax rate in each industry by twenty percent of its current value, which translates to a reduction of between 4.5 and 5.9 percentage points in the tax rate for each industry. For example, the pre-simulation model corporation tax rate in industry 24 (FININS) is 23.5%. A twenty percent reduction in this rate gives the reform corporate tax rate of 18.8%, representing a reduction of 4.7 percentage points. The benchmark and reform values of the corporate tax rate for each industry are presented in Table 2. The simulation is therefore based on a general decrease in the level of corporate taxation, rather than a change in the structure of corporate taxation.

Table 2: Model Corporation Tax Rates by Industry – Benchmark and Reform (%)

<i>No</i>	<i>Industry</i>	<i>B'mark</i>	<i>Reform</i>
1	AGFOFI	26.7	21.4
2	MINEXT	25.9	20.7
3	FOODSD	26.2	20.9
4	ALCOHL	26.2	20.9
5	TOBACO	26.2	20.9
6	TEXTIL	26.2	20.9
7	CLOTFL	26.2	20.9
8	TIMFUR	26.2	20.9
9	PAPRPU	26.2	20.9
10	CORPNF	26.6	21.2
11	CHEMIC	22.5	18.0
12	GLCEBP	26.2	20.9
13	METALS	27.2	21.8
14	MACHIN	27.2	21.8
15	ELCENG	27.2	21.8
16	MOTVEH	27.2	21.8
17	OTRANE	27.2	21.8
18	OMANUF	26.2	20.9
19	ELGAWS	26.6	21.2
20	CONSTR	27.3	21.9
21	DISTHR	29.5	23.6
22	TRANSV	29.6	23.7
23	COMMUN	29.6	23.7
24	FININS	23.5	18.8
25	REALES	23.5	18.8
26	BUSSER	23.5	18.8
27	SOCSER	0.0	0.0
28	OTHSER	28.6	22.9

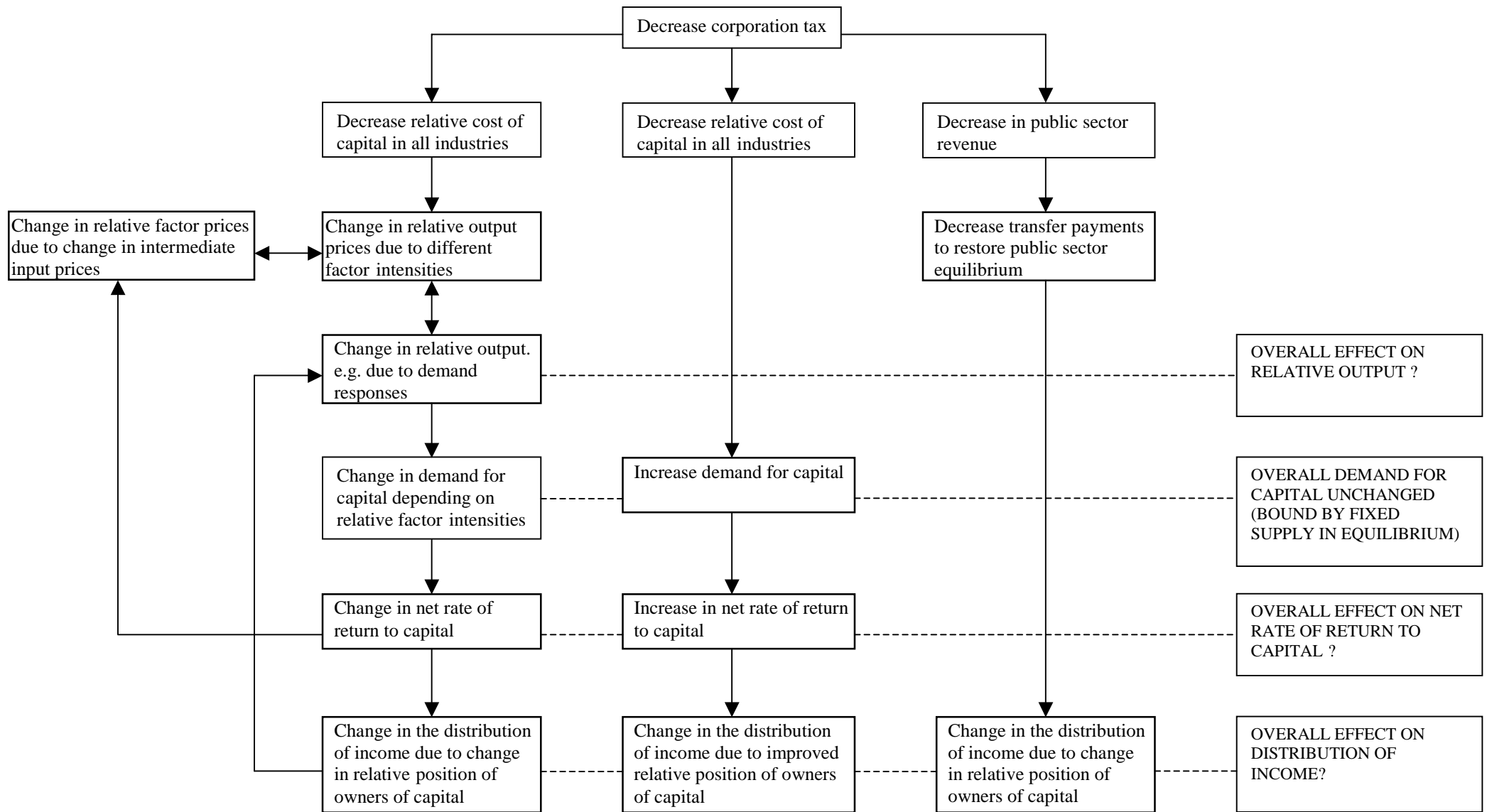
The theoretical structure underlying the IMAGE model requires that the government budget is balanced, and this budget-neutral approach is the appropriate framework for analysing fiscal reforms. That is, to determine the allocative and distributional effects of a particular reform, it is necessary to consider how the reform is funded in the case of tax cuts, or where the additional revenue is directed in the case of tax increases. To illustrate, consider the simulation outlined above, in which the reductions in corporate tax rates lead to a significant decrease in government revenue. To fund the reduction in revenue and restore public sector equilibrium in the model it would be possible to increase revenue from other taxes (such as indirect or personal income taxes) by increasing tax rates, to decrease public sector transfers to households, or to model some combination of the two approaches. The empirical model therefore provides significant flexibility in terms of how the budget-neutral condition is imposed.

The mechanism that the model user ultimately specifies to restore public sector equilibrium will affect simulation results, as choosing between mechanisms amounts to choosing between alternative policy reforms. In terms of the simulation presented below, public sector equilibrium is restored by reducing transfer payments in such a way that each household maintains its benchmark share in overall transfer payments. This approach maintains the shape of the distribution of public sector transfer payments. Analysing the incidence of corporate taxation under varying assumptions regarding the restoration of public sector equilibrium is an interesting issue, and one to be considered in future research.

4.2 Model Mechanisms

The IMAGE model produces a large amount of output for any given simulation. For example, the model simulates for each household the change in income, labour supply, tax burden and demand for each commodity; for each industry the change in output, intermediate and primary factor demand, output prices and tax burden; for each factor the change in factor price; for the public sector the change in transfer payments and revenue from different forms of taxation; and a range of summary measures relating to changes in the distribution of income and economic efficiency. In order to comprehend the results of a simulation and understand their implications, it is essential to understand the mechanisms through which variables interact in the model. Figure 1 provides a schematic representation of the model mechanics in the context of a general reduction in the corporation tax.

Figure 1: Potential Effects of Reducing the Corporation Tax



The schematic depiction of the simulation demonstrates how a reduction in the corporation tax across all sectors could potentially affect key variables within the model. Although the mechanics are interrelated, the impact of a reduction in the corporation tax can be broadly seen as a combination of three effects:

- **Output effect:** the general reduction in corporation tax rates decreases the relative cost of capital in all industries, and initially might be expected to decrease the relative price of output in capital intensive industries. Indeed, if there were no intermediate production then this would be the case. To illustrate, consider two industries X and Y , where X employs only capital and Y employs only labour. A reduction in the corporation tax reduces the marginal cost in industry X , but has no effect on the marginal cost in industry Y , such that the relative output price of X decreases. However, this may not be the case when intermediate goods are employed, as changes in relative output prices will feed back into relative input prices. To illustrate, consider two industries A and B , where A employs only capital and B employs only output from industry A . A reduction in the corporation tax directly reduces the marginal cost in industry A , but also reduces the marginal cost in industry B via the reduction in the output price of A . Hence, the effect of a reduction in the corporation tax on relative output prices depends upon both the relative capital intensity across industries and the relative capital intensities of intermediate factors across industries. As demands shift in response to changes in relative output prices, the output responses will affect the demand for factors, and therefore the returns to factors, in a way that reflects relative factor intensities. The change in relative factor prices will then feed back into relative output prices. In addition, the presence of heterogeneous households with non-homothetic preferences implies that changes to factor returns will affect the distribution of income and the demand for commodities.
- **Factor Substitution effect:** the general reduction in corporation tax rates decreases the relative cost of capital in all industries, and will therefore tend to increase the relative demand for capital and capital intensive intermediates. The increase in the relative demand for capital is likely to increase the net rate of return to capital, such that the relative position of capital owners in the income distribution improves. This will affect the demand for commodities to the extent that the preferences of capital owners differ from other households and from each other.

- **Balanced Budget effect:** the general reduction in corporation tax rates decreases public sector revenue. The assumptions underlying the simulation imply that public sector equilibrium is restored by reducing transfer payments to households in a manner that leaves each household's share of total transfer payments constant. Again, the presence of heterogeneous households with non-homothetic preferences implies that the restoration of public sector equilibrium in this way will affect the distribution of income and the demand for commodities.

Relative to the basic Harberger framework, the relaxation of several major assumptions in the empirical model implies that the transmission mechanisms are significantly more complicated. The output and factor substitution effects are considerably more involved than those for the Harberger model, and a third effect enters the general equilibrium system due to the assumptions underlying the restoration of public sector equilibrium in the model. It becomes apparent that it is not possible to determine *a priori* the effects on many key variables of a general reduction in the corporation tax. More specifically, the simulation results depend upon the relative strength of the output, factor substitution and balanced budget effects, which in turn depend upon the underlying data and parameters employed in the IMAGE model. The schematic representation of the simulation and the accompanying discussion serve the dual purpose of highlighting the effects of relaxing several assumptions of the Harberger model and facilitating the interpretation of simulation results presented in this paper.

4.3 Simulation Results

Simulation results for a general reduction in the corporation tax are presented for scalar variables in Table 3 and for industry level variables in Table 5 below. Results for each variable are usually presented in terms of the percentage change from the benchmark equilibrium value.

Table 3: Impact of Simulation on Selected Scalar Variables

Variable	Percentage Change
Gini coefficient	0.8
Ratio of aggregate capital income to labour income	4.0
Net rate of return to capital	3.9
Net wage	0.0
Aggregate output	0.0
Aggregate net pure profit	5.7
Aggregate capital demand/supply	0.0*
Aggregate gross trading surplus	-0.4
Aggregate net trading surplus	2.6
Aggregate labour demand/supply	-0.0
Aggregate intermediate input demand	0.3
Public sector revenue	-3.6
Other Variables	
Marginal cost of funds:	1.2% of each additional pound in revenue
Capital share of corporate tax burden:	88.5% of corporate tax burden

* Under the assumptions of fixed domestic capital supply and international capital immobility, the percentage change in aggregate capital demand/supply is necessarily zero in equilibrium.

In terms of the distribution of household income, the gini-coefficient is calculated for the equivalised disposable income distribution in the benchmark and reform settings⁴. The gini-coefficient increases by 0.8% of its benchmark value following the general reduction in corporation tax, implying that inequality increases as a result of the reform. A comprehensive analysis of the effects of the simulation on the household distribution of income is provided below.

In relation to the functional distribution of income, the ratio of aggregate capital income to aggregate labour income is calculated as;

⁴ A household's equivalised income is obtained by adjusting the household's actual income for household size and composition. In the present study this is achieved by adopting an equivalence scale in which the first adult is assigned a weight of 1, all other adults are assigned a weight of 0.66, and children are assigned a weight of 0.33.

$$\frac{\text{capital income}}{\text{labour income}} = \frac{\sum_h (r^r K_h + \pi_h)}{\sum_h w^r L_h} \quad (22)$$

where K_h and L_h are the supply of capital and labour by household h respectively, and π_h is pure profits received by household h . r^r is the net rate of return to capital, defined as the return for supplying a unit of capital, net of corporation tax and before personal income tax. w^r is the net wage, defined as the return for supplying a unit of labour, net of labour taxes and before personal income taxes. Following the general reduction in the corporation tax, the ratio of aggregate capital income to aggregate labour income increases from 0.51 to 0.53, suggesting that the reform improves the position of owners of capital relative to labour.

Recall that pure profits in the IMAGE model are distributed to households in proportion to their share in ownership of total capital. That is, the theoretical structure outlined above makes the distinction between the return for supplying capital and pure profits. However, data is only available for the sum of these components, referred to as net trading surplus, and it is not conceptually possible to distinguish between the components from the data. Hence, in the simulation discussed below, it is assumed that 25% of net trading surplus in imperfectly competitive industries is comprised of pure profits. This is an ad hoc assumption. Importantly, some simulation results are sensitive to the value assigned to this parameter, although the general tenor of the results remains the same. To illustrate, consider the model specification in which all net trading surplus is attributed to return for supplying capital, which is equivalent to a free entry model where all pure profits are eroded. Simulation results for such a model (not presented here) suggest that the efficiency costs of the corporation tax are not as great when industries generate pure profits, and that capital bears a greater burden of the corporation tax. Also, a reduction in corporation tax rates leads to a marginally greater increase in inequality when pure profits exist. The reasons behind these differences are not addressed in the present study, but will be discussed in a forthcoming paper.

Within the context of balanced-budget simulations, in which the overall level of public sector payments change between the benchmark and reform equilibria, it has

been argued that the appropriate measure of efficiency gain is the marginal cost of funds (e.g. Mayshar, 1990; Creedy, 1999), defined as;

$$MCF = \frac{\sum_h EV_h}{dGTR} \quad (23)$$

where MCF is the marginal cost of funds, EV_h is the equivalent variation for household h , and $dGTR$ is the change in public sector revenue. Equivalent variation is the amount that the household would be prepared to pay in the reform equilibrium to avoid the price change, and is defined here in terms of full income (e.g. Creedy, 1999; pxxiv-xxx). Therefore a negative equivalent variation implies that the household would need to be paid to accept the benchmark prices in the reform equilibrium. Hence, a positive (negative) value for the marginal cost of funds implies that each additional pound spent by the public sector in the reform setting leads to an efficiency loss (gain). The simulation produces an estimate for the marginal cost of funds of 1.2%. This implies that for each additional £1 reduction in public sector revenue in the reform setting there is a 1.2 pence reduction in deadweight loss.

The reduction in corporation tax decreases the cost of capital to firms in all industries, and the increased demand for capital contributes to a 3.9% increase in the net rate of return to capital. To illustrate, the cost of one unit of capital to a firm (including corporation tax) is related to the return to the supplier of the same unit of capital (net of corporation tax, but before personal income tax) by the following relationship;

$$r^c = (1 + \tau_i^\pi) r^r \quad (24)$$

where r^c is the cost of capital to the firm, r^r is the net rate of return to the supplier of capital and τ_i^π is the rate of corporation tax faced by industry i . Consider the benchmark and reform values of these variables for industry 1 (AGFOFI) as presented in Table 4.

Table 4: The Cost of Capital and Return to Capital in Industry 1 (AGFOFI)

	r^c	τ_1^π	r^r
Benchmark	1.267	0.267	1.000
Reform	1.261	0.214	1.039

The reduction in τ_1^r simultaneously reduces the cost of capital to the firm, increases the net rate of return to owners of capital, and reduces public sector revenue from corporate taxation. This outcome is reflected in the 0.4% decrease in aggregate gross trading surplus, defined as the sum of pure profits, payments made by firms for capital and corporation tax obligations, and the 2.6% increase in aggregate net trading surplus, defined as the payments made by firms to owners of capital, including the distribution of profits. The effects of the reform on relative factor prices, output prices and output lead to small increases in the use of intermediate inputs (0.3%), and aggregate labour demand is essentially unchanged.

The reduction in corporation tax rates leads to an overall reduction in public sector revenue of 3.6%. This is primarily a result of the reduction in revenue from corporate taxation due to the decrease in rates, but is also affected by a decrease in indirect tax revenue due to shifting demand patterns, and an increase in revenue from personal income tax due to changes in the distribution of income.

In the spirit of previous studies of the incidence of corporate taxation (e.g. Harberger, 1962; Shoven and Whalley, 1972) the burden of the corporation tax borne by capital can be defined as;

$$\text{Capital share of burden} = \frac{[r_0^r - r_1^r]K_0}{\text{change in revenue}} \quad (25)$$

where subscripts 0 and 1 refer to the benchmark and reform equilibria respectively. This records the aggregate change in payments to capital as a proportion of the change in public sector revenue. By this measure, capital bears 83.7% of the burden of corporate taxation. In the context of the present study, it can be argued that a measure of capital's burden should also incorporate capital-related income, such as pure profits. That is, since pure profits are distributed in proportion to ownership of capital, then the aggregate burden of owners of capital should incorporate changes in the overall level of pure profits. Hence, an alternative measure of capital's share of the corporate tax burden is:

$$\text{Capital share of burden} = \frac{[r_0^r - r_1^r]K_0 + \Delta\pi}{\text{change in revenue}} \quad (26)$$

where $\Delta\pi$ is the change in aggregate pure profit resulting from the reform. By this second measure, owners of capital bear a greater burden of the corporation tax (88.5%). This outcome suggests that part of the burden of corporate taxation falls on pure profit.

Simulation results for industry level variables are presented in Table 5 below. As discussed in Section 4.2, the changes in relative output prices are brought about by the change in relative input prices, and reflect the relative factor intensities across industries.

Table 5: Simulation Results for Selected Industry Level Variables (% change)

No	Industry	Output Price	Final Demand	Industry Output	Labour Demand	Capital Demand	GTS	NTS	Profit
1	AGFOFI	-0.091	-12.8	-3.9	-3.8	-3.7	-4.7	-3.5	0.0
2	MINEXT	-0.207	-56.8	-2.9	-2.8	-2.8	-3.1	-1.9	0.0
3	FOODSD	-0.010	3.6	-0.2	-0.2	0.1	-0.3	4.2	35.9
4	ALCOHL	-0.031	-2.9	-1.8	-1.9	-1.6	-1.9	2.4	9.6
5	TOBACO	-0.015	-1.7	-2.0	-2.0	-1.8	-2.1	2.2	3.8
6	TEXTIL	0.040	14.5	4.1	4.2	4.4	4.0	8.9	10.0
7	CLOTFL	0.036	8.7	4.0	4.0	4.2	3.8	8.7	18.1
8	TIMFUR	0.028	7.7	3.8	3.9	4.1	3.7	8.6	18.9
9	PAPRPU	-0.008	-2.9	3.9	3.9	4.1	3.8	8.8	64.9
10	CORPNF	0.090	-8.5	-3.2	-3.2	-3.1	-3.5	-2.4	0.0
11	CHEMIC	0.069	8.0	1.1	1.1	1.1	1.2	3.0	43.6
12	GLCEBP	-0.023	-2.9	-0.2	-0.2	0.0	-0.3	4.2	10.4
13	METALS	0.006	6.0	0.3	0.3	0.6	0.1	4.4	27.7
14	MACHIN	0.008	3.9	-0.2	-0.2	0.1	-0.4	3.9	42.2
15	ELCENG	-0.005	3.8	0.5	0.5	0.8	0.3	4.6	47.8
16	MOTVEH	0.041	7.6	-0.5	-0.5	-0.2	-0.8	3.4	12.9
17	OTRANE	0.047	5.8	3.8	3.8	4.1	3.8	8.4	18.4
18	OMANUF	0.027	6.7	2.3	2.3	2.5	2.2	6.9	8.5
19	ELGAWS	-0.153	-11.2	-5.3	-5.4	-5.3	-5.9	-4.9	0.0
20	CONSTR	-0.023	-7.3	0.9	0.9	1.2	0.8	2.3	0.0
21	DISTRH	0.120	-10.6	-6.9	-7.1	-6.9	-7.8	-6.3	0.0
22	TRANSV	-0.067	-15.6	-6.5	-6.5	-6.1	-7.9	-5.2	0.0
23	COMMUN	-0.141	-32.5	-6.2	-6.1	-6.0	-7.2	-6.0	0.0
24	FININS	0.122	24.1	5.7	5.7	5.7	6.3	7.0	0.0
25	REALES	-0.003	13.2	9.3	8.7	8.7	9.6	11.8	0.0
26	BUSSER	0.122	33.1	1.7	1.8	1.8	1.9	2.8	0.0
27	SOCSER	0.270	45.5	4.6	4.7	3.9	5.4	5.4	0.0
28	OTHSER	-0.037	-14.2	-5.9	-5.9	-5.6	-7.2	-4.6	0.0

Notes: 1. Final demand, industry output, and labour, capital and intermediate demand refer to physical quantities in the model.
2. GTS and NTS refer to gross trading surplus and net trading surplus respectively.

The results for output are reflected in the aggregate changes in final, intermediate and export demand (latter two categories not reported). Note that the percentage change in aggregate final demand is large for some commodities, particularly commodities 2 (MINEXT), 23 (COMMUN), 24 (FININS), 26 (BUSSE) and 27 (SOCSE). In the case of commodity 2 (MINEXT), the benchmark value of total household final demand is small so the absolute value of the large *percentage* change is small. For the other four commodities, these results suggest that the relatively modest percentage changes in industry output are predominantly absorbed by changes in final household demand, rather than changes in intermediate or export demand. For example, consider commodity 26 (BUSSE). The 3.0% increase in domestic output for this commodity implies an increase of £4,819 million. Final demand for this commodity increases by 48.9%, implying an increase of £3,932 million. Hence, although the changes in household demand are large relative to the benchmark household demand for these four commodities, they are not large relative to the benchmark total demand. This suggests that household demands in the empirical model are sensitive to perturbations in equilibrium prices and outputs for the reform under consideration. There are three primary explanations for this outcome. Firstly, the mechanisms depicted in Figure 1 suggest that the impact of the reform on consumption and output will depend upon relative output prices and changes in the distribution of income. In the absence of income effects and cross-price effects, a reduction in the price of a commodity should lead to an increase in the demand for that commodity. However, if income and/or cross-price effects are significant then this outcome might not be realised. For example, if the reform redistributes income from poor to rich households, then demand for commodities consumed in proportionately higher quantities by rich households will tend to increase. If this effect was sufficiently pronounced, then the demand for a given commodity could increase even if its price had increased. The results presented in Table 5 support the existence of significant income effects, and evidence to support this proposition is provided below. As an illustration, consider the reported results for industry 16 (MOTVEH). The increase in output price might be expected to lead to a decrease in demand. However, the model simulates a 7.6% increase in aggregate final demand for commodity 16. Results presented below suggest that the reform redistributes income from the lower half of the income distribution to the top, and also that wealthier households spend a significantly higher

proportion of their income on motor vehicles than poorer households. Consequently, price effects are dominated by income effects, and the demand for motor vehicles increases. Secondly, the macro closure rules employed in the empirical model imply that the marginal propensity to consume out of disposable money income is 100% for all households. Consequently, changes in household income will have pronounced effects on final demand. Finally, the magnitude of the changes is generally driven by the underlying elasticity and other parameter values, and the sensitivity of model results to the extraneously specified values is examined in Section 5. Given the calibration procedures adopted and the extraneously specified parameters, an interesting issue involves the distribution of the remaining calibrated household parameters. A detailed examination of calibrated parameter values across households might reveal outliers that are influential in a given set of simulation results, and this is an area for future research.

The demand for primary and intermediate factors is largely driven by the output effect in each industry, with the percentage changes in inputs broadly consistent with the percentage change in output in each industry. However, there is some evidence of factor substitution effects. That is, industries 3 (FOODSD) and 14 (MACHIN) both record slight increases in the use of capital alongside slight decreases in intermediate and labour use and output. This would appear to be a result of the decrease in the relative cost of capital. In addition, the remaining industries in which output fell all record greater percentage reductions in labour and intermediate use than in capital use, suggesting that the factor substitution effect is present at least to some extent. Similarly, the industries in which output increased generally recorded greater percentage increases in capital use than in intermediate and labour use, again providing evidence for factor substitution effects. Hence, the decrease in the relative cost of capital leads to an increase in capital intensity in all industries subject to the corporation tax. The only industry in which the percentage increase in labour and intermediate use is greater than the percentage increase in capital is industry 27 (SOCSEK). This industry is not subject to corporation tax in the empirical model, such that the increase in the net rate of return on capital translates to an increase in the cost of capital (refer equation (24), where $\tau_i^\pi = 0$). Therefore the relative cost of

capital in industry 27 increases, and the factor substitution effect implies that production becomes less capital intensive as a result of the reform.

All imperfectly competitive industries record substantial percentage increases in pure profits as a result of the simulated reform. Given that the corporation tax is levied on gross trading surplus less deductions, imperfectly competitive industries with the highest levels of gross trading surplus record the greatest increases in net pure profits as a result of the reform. This is reflected in the outcomes for industries 3 (FOODSD), 9 (PAPRPU), 11 (CHEMIC), 14 (MACHIN) and 15 (ELCENG).

The increase in the gini-coefficient recorded for the simulation implies that inequality increases as a result of the reform. However, a more comprehensive and detailed analysis is required to assess the distribution of gains and losses across the income distribution. The remainder of this section provides such an analysis for the distribution of household full income. The results are expressed in terms of the average decile change in household annual full income, and are presented by household type. The presentation of results by household type serves to account for variations in household characteristics, and provides significant insight into the distributional effects of the simulated reform.

To facilitate the interpretation of distributional results, Table 6 presents average decile annual full income for all households taken together and for the different household types. Note that in this and subsequent tables associated with the distributional analysis, the decile-group results for each household type refer to the distribution of that household type only. For example, in Table 6 the average full income of the bottom 10% of the full income distribution for non-working singles is £2000 per annum. This information will prove useful in understanding how the simulated reform impacts upon households at different full income levels.

Table 6: Average Decile Full Income by Household Type (£000 per year)

Household Type	Decile									
	1	2	3	4	5	6	7	8	9	10
All households	3	5	8	12	18	25	32	41	53	88
One earner couple no children	6	9	13	19	25	31	39	46	58	108
One earner couple children	6	9	11	15	21	29	37	43	54	90
Two earner couple no children	8	12	18	26	33	41	50	61	74	109
Two earner couple children	8	12	17	24	31	39	46	55	67	104
No earner couple no children	4	5	7	10	15	21	27	33	42	62
No earner couple children	3	5	7	8	13	22	27	32	38	53
Working sole parent	4	6	8	15	23	30	35	43	53	79
Non-working sole parent	3	3	4	5	6	7	13	21	27	44
Working single	4	8	11	16	23	31	38	45	54	93
Non-working single	2	3	4	5	6	8	13	20	27	44

A number of patterns emerge from the information presented in Table 6:

- The average full income of two earner households across all deciles is higher than that for one earner households, which in turn is higher than that for no earner households. These differences are substantial. For example, the average full income for ‘non-working sole-parent’ households in the sixth decile is lower than that for ‘two earner couple’ households in the bottom decile.
- The presence of children in the household is associated with lower full income, *ceterus paribus*, except for non-working single households where there appears to be little difference.

Table 7 presents the reform-induced average decile change in household annual full income, and reveals that the gains arising from the reform are concentrated in the top half of the distribution. Taking all households together, the bottom five deciles all record decreases in full income as a result of the reform, with average annual losses of

over £210 for households in decile three. The gains increase towards the top end of the equivalised full income distribution, with significantly higher gains realised in the top decile.

Table 7: Average Decile Change in Household Annual Full Income (£ per year)

Household Type	Decile									
	1	2	3	4	5	6	7	8	9	10
All households	-55	-155	-216	-151	-14	16	38	85	74	228
One earner couple no children	-287	-217	-151	-231	13	28	149	110	41	273
One earner couple children	-217	-223	-118	-111	56	-6	55	-32	72	220
Two earner couple no children	-520	-197	51	136	126	134	160	154	180	343
Two earner couple children	-418	-319	7	212	45	55	133	126	155	288
No earner couple no children	-108	-137	-207	-21	4	46	15	-4	41	97
No earner couple children	-75	-160	-114	51	-301	69	29	9	-17	2
Working sole parent	-116	-216	-273	-47	110	-78	109	109	67	235
Non-working sole parent	-41	-24	-50	-222	-183	-103	9	42	-26	13
Working single	-99	-204	-255	-5	-28	-8	24	87	42	234
Non-working single	-64	-17	-116	-131	-190	-144	1	-20	9	9

In terms of different household types, two-earner households record significant losses in the bottom two deciles, but record substantial increases in average full income from the fourth decile upwards. Noting from Table 6 that households in decile four of the two-earner distribution have an average decile full income that places them in the sixth decile of the full income distribution over all households, the reform appears to benefit relatively wealthy households. One-earner households, whether single or couple, all record significant losses in the bottom four deciles, and sometimes in decile six. The losses are considerably higher in the bottom four deciles for one-earner couples and in the bottom three deciles for singles who are working. Again, this

suggests that the simulated reform redistributes income towards relatively wealthy households. This outcome is supported by the results for no-earner couples, with losses recorded in the bottom four or five deciles, and modest gains or small losses recorded in the top deciles. Non-working single households with and without children each record decreases in average full income in seven deciles, and where increases are recorded, they tend to be relatively modest. Noting from Table 6 that these households have the lowest average full incomes of all household types, it is apparent that the simulated reform redistributes income towards wealthier households.

Hence, a general reduction in the corporation tax financed by reductions in transfer payments clearly benefits wealthy households. This outcome is not surprising, given that transfer payments are directed towards less wealthy households and that income from capital generally constitutes a higher proportion of total income for wealthier households. The preceding analysis elucidates the nature of gains and losses throughout the income distribution and across households of different composition.

An issue of significant interest in the present study is whether the changes in income distribution detailed above have any impact on demand, output, factor demand and factor returns. The mechanisms depicted in Figure 1 indicate that this is possible, and the industry level results presented in Table 5 suggest that this might be the case. That is, several commodities record an increase in price and an increase in final consumption. Given that redistribution towards wealthy households has been demonstrated, if it can be shown that wealthy households consume a commodity in relatively higher proportions than poor households, then this would explain why demand for that commodity has increased even when its price has increased. Similarly, several commodities record a decrease in price and a decrease in final consumption. If it can be shown that poor households consume a commodity in relatively higher proportions than wealthy households, then this would explain why demand for that commodity has decreased even when its price has decreased. Stated alternatively, income effects might dominate price effects.

Following the preceding discussion, in order to determine the impact of the distributional changes induced by the simulated reform on final consumption, Table 8 presents the average budget share of expenditure on each commodity by full income

decile in the benchmark equilibrium. For example, the first entry indicates that on average, households in the bottom 10% of the full income distribution spend 2.8% of their disposable money income on commodity 1 (AGFOFI). This serves to demonstrate which commodities are consumed in higher proportions by wealthy households.

Table 8: Average Household Budget Share of Expenditure in Benchmark by Full Income Decile (%)

No	Commodity	Decile									
		1	2	3	4	5	6	7	8	9	10
1	AGFOFI	2.8	2.5	2.3	2.1	2.0	1.9	1.8	1.8	1.7	1.6
2	MINEXT	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
3	FOODSD	13.7	12.0	10.9	10.1	9.3	8.9	8.5	8.3	7.7	7.3
4	ALCOHL	3.5	3.6	3.7	3.9	4.0	4.3	3.8	3.9	4.2	3.9
5	TOBACO	5.6	5.1	4.8	3.3	3.2	2.9	2.7	2.3	1.9	2.0
6	TEXTIL	1.0	0.9	0.9	1.1	0.9	1.0	0.9	0.9	1.0	0.9
7	CLOTFL	3.4	3.7	3.5	3.7	4.0	4.2	4.5	4.3	4.4	4.6
8	TIMFUR	0.7	1.0	0.8	1.0	1.0	1.2	1.0	1.2	1.1	1.3
9	PAPRPU	4.6	4.0	3.8	3.5	3.1	3.0	3.1	3.0	2.7	2.9
10	CORPNF	1.5	1.8	2.0	2.4	2.8	3.0	3.1	3.2	3.3	3.5
11	CHEMIC	4.6	4.3	4.4	4.1	3.7	3.7	3.6	3.5	3.4	3.3
12	GLCEBP	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
13	METALS	0.3	0.4	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5
14	MACHIN	1.4	1.6	1.8	1.5	1.6	1.7	1.9	1.6	1.9	1.9
15	ELCENG	0.9	1.1	1.4	1.3	1.4	1.6	1.7	1.5	1.8	1.9
16	MOTVEH	0.7	1.6	2.4	3.0	3.7	4.0	4.2	4.4	4.5	4.8
17	OTRANE	0.1	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.8
18	OMANUF	1.1	1.4	1.6	1.7	1.7	1.7	1.9	1.9	1.5	1.6
19	ELGAWS	10.4	7.5	6.1	4.9	4.2	3.7	3.4	3.2	2.8	2.6
20	CONSTR	0.6	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
21	DISTR	9.4	13.8	16.0	18.9	20.9	20.9	22.2	23.4	23.4	23.5
22	TRANSV	3.1	3.0	2.3	3.1	2.4	3.3	2.8	3.1	2.8	3.6
23	COMMUN	5.5	4.5	3.8	3.2	2.7	2.5	2.3	2.3	2.1	2.0
24	FININS	3.0	3.5	3.6	4.0	3.8	4.0	3.9	3.8	3.8	3.7
25	REALES	12.9	12.2	12.6	12.0	11.9	11.0	10.6	10.6	9.9	8.2
26	BUSSER	0.5	0.7	0.9	1.1	1.1	1.1	1.2	1.2	1.3	1.3
27	SOCSER	2.0	2.0	2.0	2.0	2.2	2.2	2.5	2.5	4.0	4.4
28	OTHSER	6.4	6.3	6.1	5.9	6.0	6.1	6.1	6.0	6.7	7.3
	Total	100	100	100	100	100	100	100	100	100	100

In order to process this information, Table 9 shows whether a commodity is consumed in relatively higher proportions by wealthy households (*W*), in relatively higher proportions by poorer households (*P*), or if no clear differential is discernible (-). Also reported in the table are the percentage change in output price and final consumption.

The final column depicts the results for each commodity in terms of the relationship between price and income effects. For example, consider commodity 7 (CLOTFL). The price of commodity 7 increases, and the commodity is consumed in higher proportions by wealthy households (see Table 8). This suggests that the price effect on consumption is negative and that the income effect is positive. Final demand for commodity 7 increases as a result of the reform, implying that the income effect outweighs the price effect.

Table 9: Income Effects, Price Effects and Final Consumption – Actual Outcomes

No	Commodity	Output Price	Consumed by wealthy/poor	Final Demand	Price v Income Effects
1	AGFOFI	-0.091	<i>P</i>	-12.8	Income effect dominates
2	MINEXT	-0.207	<i>P</i>	-56.8	Income effect dominates
3	FOODSD	-0.010	<i>P</i>	3.6	Price effect dominates
4	ALCOHL	-0.031	-	-2.9	Income effect dominates*
5	TOBACO	-0.015	<i>P</i>	-1.7	Income effect dominates
6	TEXTIL	0.040	-	14.5	Income effect dominates*
7	CLOTFL	0.036	<i>W</i>	8.7	Income effect dominates
8	TIMFUR	0.028	<i>W</i>	7.7	Income effect dominates
9	PAPRPU	-0.008	<i>P</i>	-2.9	Income effect dominates
10	CORPNF	0.090	<i>W</i>	-8.5	Price effect dominates
11	CHEMIC	0.069	<i>W</i>	8.0	Income effect dominates
12	GLCEBP	-0.023	-	-2.9	Income effect dominates*
13	METALS	0.006	<i>W</i>	6.0	Income effect dominates
14	MACHIN	0.008	<i>W</i>	3.9	Income effect dominates
15	ELCENG	-0.005	<i>W</i>	3.8	Work in same direction
16	MOTVEH	0.041	<i>W</i>	7.6	Income effect dominates
17	OTRANE	0.047	<i>W</i>	5.8	Income effect dominates
18	OMANUF	0.027	<i>W</i>	6.7	Income effect dominates
19	ELGAWS	-0.153	<i>P</i>	-11.2	Income effect dominates
20	CONSTR	-0.023	<i>P</i>	-7.3	Income effect dominates
21	DISTR	0.120	<i>W</i>	-10.6	Price effect dominates
22	TRANSV	-0.067	-	-15.6	Income effect dominates*
23	COMMUN	-0.141	<i>P</i>	-32.5	Income effect dominates
24	FININS	0.122	<i>W</i>	24.1	Income effect dominates
25	REALES	-0.003	<i>P</i>	13.2	Price effect dominates
26	BUSSER	0.122	<i>W</i>	33.1	Income effect dominates
27	SOCSER	0.270	<i>W</i>	45.5	Income effect dominates
28	OTHSER	-0.037	-	-14.2	Income effect dominates*

Income effects clearly dominate price effects for 18 of the 28 commodities as a result of the reform-induced price and income changes. Price effects dominate for 4 commodities, and the effects reinforce each other for one commodity. For the

remaining 5 commodities (marked with an * in Table 9), the results for final demand suggest that income effects dominate. However, it is difficult to discern any clear differential in consumption patterns throughout the income distribution for these commodities (refer Table 8). Such patterns might emerge if the information in Table 8 was analysed by household type. Hence, the incorporation of heterogeneous households with different preferences and endowments and non-homothetic demands has a significant impact on simulation results.

5. Statistical Reliability of Results

It is routine practice in studies employing empirical tax models to report simulation results as point estimates, providing no indication of the statistical reliability of results. However, a simulated result from an empirical tax model should be regarded as a statistical estimate of a population characteristic of interest. Consequently, like any other statistical estimate, it should be accompanied by some measure of statistical reliability, such as a standard error or confidence interval.

Comprehensive methods have been developed for determining the robustness of AGE simulation results. These methods can generally be referred to as systematic sensitivity analysis (SSA), and can be employed to estimate the standard error of variables of interest when the source of uncertainty is the extraneous specification of parameter values. Hence, SSA is a method for determining the statistical reliability of simulation results.

Following a number of recent developments⁵, SSA methods have been developed that drastically reduce the number of simulations required to obtain estimates of the standard deviation of endogenous variables in the model. Based on programming or optimisation procedures, this method poses the question: given the distribution of m exogenous parameters, what is the best possible choice of perturbations to parameters in N simulations if we want to estimate means and standard deviations for all endogenous variables? A procedure for choosing the N simulations in this way is based on Gaussian quadratures.

⁵ See Arndt (1996), DeVuyst and Preckel (1997), Liu (1997), and Arndt and Pearson (1998).

A Gaussian quadrature is a discrete approximation to the actual continuous distribution specified for a given exogenous parameter, where the first few moments of the discrete distribution are identical to those of the continuous distribution. If the first d moments agree, then the quadrature is said to be of order d . From the discrete distribution, points are chosen for each exogenous parameter, and the model is solved at these points to obtain the SSA results.

In general, the answer to the question posed above regarding the best choice of perturbations to parameters in N simulations will be complex and difficult to obtain. However, under various assumptions, sets of optimal perturbations to exogenous parameters can be obtained relatively quickly, and the resulting estimates of means and variances for the endogenous variables are accurate. More specifically, assume that⁶:

- the simulation results are well approximated by a third-order polynomial in the varying extraneously specified parameters.
- the extraneously specified parameters to be perturbed all have a symmetric distribution.
- the perturbed parameters either vary independently (zero correlation), or within specified groups of parameters variations are perfectly correlated.

Under these assumptions, Stroud's (1957) quadrature can be employed to estimate the mean and variance of the endogenous variables. Stroud's quadrature is a particular Gaussian quadrature of order 3. Consequently, the first 3 moments of the Stroud discrete distribution will be the same as those for the continuous distribution assumed for each extraneously specified parameter. If there are m parameters varying independently in the SSA, then Stroud's quadrature has $2m$ points. Consequently, the model need only be solved $2m$ times to achieve estimates of the means and standard deviations of the endogenous variables.

The SSA procedure for the simulation was carried out using the GEMPACK software (Codsì and Pearson, 1988). The procedure employs Stroud's quadrature based on perturbations to all extraneously specified parameters, with each parameter assumed to follow a triangular distribution. The software requires the maximum percentage

variation from the benchmark value of each parameter to be specified. In the results presented below, each extraneously specified parameter is permitted to take on any value within 50% of its benchmark value. For example, if the elasticity of substitution in a given industry is assigned a value of 0.9, then the value of this parameter can vary between 0.45 and 1.35 in the SSA. The extraneously specified parameters to be varied in the SSA are listed in Table 10.

The total number of parameters to vary is 141. As noted above, Stroud's quadrature therefore involves solving the model 282 times in order to achieve accurate estimates of the means and standard deviations of endogenous variables.

Table 10: Extraneously Specified Parameters Varied in SSA

Parameter	Description	Dimension
σ_i	Elasticity of substitution in production for industry i	28
σ_{A_j}	Armington elasticity of substitution	28
φ	Uncompensated labour supply elasticity	1
ε_m	Uncompensated price elasticity of demand for final composite commodity m	28
η_m	Income elasticity of demand for final composite commodity m	28
η_i^*	Export demand elasticity	28
Total number of parameters to vary		141

SSA based on Stroud's quadrature only provides estimates of the mean and variance for each endogenous variable. Noting that the mean and variance are generally not sufficient statistics for describing a distribution, the computation of confidence intervals from SSA results based on Stroud's quadrature must therefore either:

- employ distribution-free statistical rules, such as Chebyshev's inequality.
- make ad hoc assumptions about the distribution of the endogenous variables (e.g. normality).

There is no theoretical reason why any of the endogenous variables should be distributed normally, uniformly or in some other convenient manner over the

⁶ Methods exist for dealing with non-symmetric distributions and cases where parameter perturbations

extraneously specified parameters. Consequently, this approach is deemed inappropriate. Hence, the present study employs Chebyshev's inequality to compute confidence intervals for endogenous variables, such that the confidence intervals presented below are conservative.

SSA results for scalar variables are presented in Table 11. Note that all variables are expressed as percentage changes, with the exception of the last, which is expressed as a percentage.

Table 11: SSA Results for Selected Scalar Variables

Variable	Simulation Result	SSA Mean	SSA Std. Deviation	90% Conf. Interval
Gini coefficient	0.79	0.80	0.14	± 0.41
Ratio of agg. capital income to labour income	3.99	3.76	0.85	± 2.69
Rate of return to capital	3.92	3.92	0.00	± 0.01
Net wage	0.00	0.01	0.00	± 0.01
Aggregate output	0.01	0.02	0.24	± 0.77
Aggregate capital demand/supply	0.00*	0.00*	0.00*	$\pm 0.00^*$
Aggregate gross trading surplus	-0.42	-0.40	0.08	± 0.24
Aggregate net trading surplus	2.60	2.62	0.02	± 0.05
Aggregate labour demand/supply	-0.01	-0.11	0.27	± 0.84
Aggregate intermediate input demand	0.33	0.48	0.39	± 1.22
Public sector revenue	-3.62	-3.52	0.56	± 1.78
Marginal cost of funds	1.22	1.02	0.13	± 0.41

* Under the assumptions of fixed domestic capital supply and international capital immobility, the percentage change in aggregate capital demand/supply is necessarily zero in equilibrium.

With respect to the interpretation of SSA results, consider the outcome for the Gini coefficient reported in Table 11. Based on the 282 solutions computed as part of the SSA, the average increase in the Gini-coefficient was 0.80%, with a standard deviation of 0.14. The 90% confidence interval, based on Chebyshev's inequality, is therefore $0.80\% \pm 0.41$. That is, in repeated simulations and irrespective of the underlying distribution of the Gini-coefficient, there is at least a 90% chance that the

are not independent. However, such procedures are more difficult to implement.

simulated change in the Gini-coefficient will lie between 0.39% and 1.21%. Although this represents a significant degree of variation for a measure such as the Gini-coefficient, the results almost certainly imply that inequality increases as a result of the simulated reduction in corporation tax rates.

The percentage changes in the net rate of return to capital, the net wage and aggregate net trading surplus are very precisely simulated. The percentage change results for the ratio of aggregate capital income to labour income, aggregate gross trading surplus and public sector revenue are less robust, but the direction of the change in each case is clear. The marginal cost of funds is unambiguously positive, suggesting an efficiency loss due to the imposition of the corporation tax, with a 90% confidence interval ranging from 0.6 to 1.4 pence in each additional pound of revenue raised. Although the percentage changes are small, the results for aggregate output, aggregate labour demand and aggregate intermediate demand are ambiguous with respect to the direction of change in these variables.

With respect to industry level variables, SSA results for output price, output and final demand are presented in Tables 12-14 below. Results obtained for other industry level variables, such as labour demand, capital demand, intermediate use, net trading surplus and gross trading surplus, are comparable to those obtained for industry output, and therefore are not presented.

The results for industry output prices in Table 12 suggest that these variables are very accurately simulated, although it should be noted that very small percentage changes in output prices could have significant repercussions throughout the model.

Table 12: SSA Results for Industry Output Price

No	Industry	Simulation Result	SSA Mean	SSA Std. Deviation	90% Conf. Interval
1	AGFOFI	-0.091	-0.081	0.00	± 0.01
2	MINEXT	-0.207	-0.197	0.00	± 0.01
3	FOODSD	-0.010	-0.010	0.00	± 0.01
4	ALCOHL	-0.031	-0.031	0.01	± 0.02
5	TOBACO	-0.015	-0.015	0.01	± 0.02
6	TEXTIL	0.040	0.050	0.00	± 0.01
7	CLOTFL	0.036	0.046	0.00	± 0.01
8	TIMFUR	0.028	0.038	0.00	± 0.01
9	PAPRPU	-0.008	0.002	0.00	± 0.01
10	CORPNF	0.090	0.100	0.00	± 0.01
11	CHEMIC	0.069	0.069	0.00	± 0.01
12	GLCEBP	-0.023	-0.023	0.00	± 0.01
13	METALS	0.006	0.006	0.00	± 0.01
14	MACHIN	0.008	0.008	0.00	± 0.01
15	ELCENG	-0.005	-0.005	0.00	± 0.01
16	MOTVEH	0.041	0.041	0.00	± 0.01
17	OTRANE	0.047	0.057	0.00	± 0.02
18	OMANUF	0.027	0.027	0.00	± 0.01
19	ELGAWS	-0.153	-0.153	0.00	± 0.01
20	CONSTR	-0.023	-0.023	0.00	± 0.02
21	DISTHR	0.120	0.130	0.00	± 0.01
22	TRANSV	-0.067	-0.067	0.00	± 0.01
23	COMMUN	-0.141	-0.131	0.00	± 0.01
24	FININS	0.122	0.112	0.01	± 0.03
25	REALES	-0.003	-0.013	0.00	± 0.01
26	BUSSER	0.122	0.112	0.01	± 0.04
27	SOCSER	0.270	0.260	0.01	± 0.02
28	OTHSER	-0.037	-0.037	0.01	± 0.02

In terms of the SSA results for industry output (Table 13 below), simulation results are subject to a significant degree of variation. For example, the average of the percentage change in output for industry 1 (AGFOFI) across the 282 SSA solutions is -12.1%. However, the computed confidence interval is ± 10.3, or ± 85% of the mean estimate, suggesting that the percentage change in output for industry 1 could feasibly lie between 1.8% and 22.4%. Variation of this magnitude is common throughout the results for other industries. Although the magnitude of the variations in industry output results is significant, the direction of the change in output can be simulated with confidence in at least 23 of the 28 industries.

Table 13: SSA Results for Industry Output

No	Industry	Simulation Result	SSA Mean	SSA Std. Deviation	90% Conf. Interval
1	AGFOFI	-3.91	-12.1	3.27	± 10.33
2	MINEXT	-2.94	-8.45	2.28	± 7.20
3	FOODSD	-0.21	0.02	0.22	± 0.71
4	ALCOHL	-1.81	-1.71	0.43	± 1.36
5	TOBACO	-2.02	-1.87	0.46	± 1.47
6	TEXTIL	4.13	4.06	0.77	± 2.43
7	CLOTFL	4.02	3.72	0.74	± 2.34
8	TIMFUR	3.89	3.85	0.74	± 2.33
9	PAPRPU	3.99	4.06	0.57	± 1.79
10	CORPNF	-3.25	-9.04	2.37	± 7.51
11	CHEMIC	1.16	3.24	0.83	± 2.61
12	GLCEBP	-0.27	-0.14	0.35	± 1.09
13	METALS	0.31	0.31	0.03	± 0.08
14	MACHIN	-0.20	-0.21	0.09	± 0.30
15	ELCENG	0.54	0.53	0.14	± 0.44
16	MOTVEH	-0.51	-0.50	0.11	± 0.36
17	OTRANE	3.82	3.77	0.98	± 3.10
18	OMANUF	2.33	2.13	0.39	± 1.22
19	ELGAWS	-5.39	-15.57	4.12	± 13.03
20	CONSTR	0.94	0.89	0.22	± 0.69
21	DISTHR	-6.99	-21.03	5.65	± 17.88
22	TRANSV	-6.55	-6.19	1.68	± 5.30
23	COMMUN	-6.27	-16.86	4.26	± 13.48
24	FININS	5.79	21.24	6.57	± 20.78
25	REALES	9.31	8.24	1.71	± 5.41
26	BUSSER	1.78	7.35	2.37	± 7.51
27	SOCSER	4.66	12.56	3.25	± 10.28
28	OTHSER	-5.90	-5.24	1.08	± 3.40

Finally, the results for final demand by commodity are presented in Table 14 below. Once again, results at the industry level exhibit a large degree of variation. This suggests that not a lot of confidence can be placed on the simulated results for final demand at the industry level. For example, the average of the percentage change in output for industry 19 (ELGAWS) across the 282 SSA solutions is -32.9%. However, the computed confidence interval is ± 27.5, or ± 83% of the mean estimate, suggesting that the percentage change in output for industry 1 could feasibly lie between -60.4% and -5.4%. Again, variation of this magnitude is common throughout the results for other industries. Although the magnitude of the variations in industry output results is significant, the direction of the change in output can be simulated with confidence in at least 26 of the 28 industries.

Table 14: SSA Results for Final Demand by Commodity

No	Industry	Simulation Result	SSA Mean	SSA Std. Deviation	90% Conf. Interval
1	AGFOFI	-12.89	-38.99	10.52	± 33.26
2	MINEXT	-56.88	-166.71	43.85	± 138.66
3	FOODSD	3.66	3.77	1.04	± 3.29
4	ALCOHL	-2.91	-2.77	0.70	± 2.21
5	TOBACO	-1.70	-1.52	0.42	± 1.33
6	TEXTIL	14.52	14.23	2.99	± 9.46
7	CLOTFL	8.71	8.04	1.60	± 5.06
8	TIMFUR	7.79	7.76	1.32	± 4.19
9	PAPRPU	-2.97	-2.67	1.08	± 3.40
10	CORPNF	-8.59	-24.45	6.49	± 20.53
11	CHEMIC	8.01	23.99	5.99	± 18.93
12	GLCEBP	-2.91	-2.76	3.49	± 11.02
13	METALS	6.07	5.61	0.38	± 1.19
14	MACHIN	3.94	3.27	0.69	± 2.18
15	ELCENG	3.81	2.94	0.77	± 2.44
16	MOTVEH	7.62	7.07	2.35	± 7.43
17	OTRANE	5.85	5.07	1.80	± 5.70
18	OMANUF	6.70	6.15	1.14	± 3.61
19	ELGAWS	-11.29	-32.91	8.69	± 27.47
20	CONSTR	-7.31	-6.17	2.37	± 7.49
21	DISTHR	-10.68	-32.53	8.77	± 27.72
22	TRANSV	-15.60	-15.22	4.11	± 13.01
23	COMMUN	-32.59	-95.61	25.44	± 80.44
24	FININS	24.19	89.12	27.30	± 86.33
25	REALES	13.24	11.72	2.46	± 7.79
26	BUSSER	33.18	123.2	38.77	± 122.59
27	SOC SER	45.59	123.49	31.34	± 99.10
28	OTHSER	-14.20	-12.73	2.61	± 8.25

Hence, the empirical model is capable of providing reliable simulation results for the percentage change in a number of key scalar or macro variables, including the net rate of return to capital, the net wage and aggregate net trading surplus. Other key scalar variables, such as the Gini coefficient, the marginal cost of funds and public sector revenue exhibit greater variation in response to perturbations in the underlying parameters. However, the direction of the percentage change in each of these variables can be simulated with a high degree of confidence.

Results at the industry level can be simulated with less certainty, and exhibit considerable variation in the SSA. However, it is possible to simulate the direction of

the percentage change in industry level variables with a high degree of confidence in most cases.

6. Conclusion

The IMAGE model developed in the present study is the first empirical tax model to provide detailed distributional analyses within a fully integrated general equilibrium framework. The analysis presented in this study simulates the links between reform of taxation of firms and the distribution of household income, and therefore demonstrates a significant contribution of the empirical model in terms of existing models. In addition, the model depicts the empirical relationship between the functional distribution and household distribution of income.

A general reduction in corporation tax rates of around 5 percentage points in each industry, financed by reductions in transfer payments, produced a simulated efficiency gain of 1.2 pence in every pound of revenue foregone by the public sector. However, the reform entails substantial redistribution towards wealthier households, resulting in a significant increase in inequality. With respect to the functional distribution of income, the reform appears to redistribute income from labour to owners of capital.

Using comparable measures to those employed by Harberger (1962) and Shoven and Whalley (1972), the results for the simulation suggest that capital bears 88.5% of the burden of the corporation tax in the UK. This result is contingent upon the mechanism by which public sector equilibrium is restored in the simulation, whereby reductions in the corporation tax are financed by decreases in transfer payments. Within the IMAGE model it is possible to explore the sensitivity of simulation results to variations in the mechanism for restoring public sector equilibrium, and this is an issue to be examined in future research.

The analysis of simulation results at the industry level indicate that income effects, generated by the relative increase in the net rate of return to capital and the substantial redistribution towards wealthier households, proved to be highly significant. If income effects are a significant feature of actual household behaviour, then models that preclude income effects by assumption could potentially give misleading results. The incorporation of heterogeneous households, with different preferences and

endowments, and non-homothetic demands is therefore an extremely important issue, and one that must receive considerable attention in the development of empirical models for tax policy analysis.

Hence, this study develops an integrated microsimulation and AGE methodology for analysing taxation reform. Economic assessments of actual fiscal reforms are primarily concerned with the impact on income distribution and/or resource allocation, including government revenue effects. The empirical model developed in the present study represents a fully integrated, theoretically consistent economic framework in which all of these effects can be analysed. The approach is particularly suited to reforms in which general equilibrium feedback effects are likely to be strong. That is, in situations where policy repercussions are likely to flow between and within the household, production and government sectors, an AGE model is an appropriate tool of analysis. This is likely to be the case for many fiscal reforms, and is illustrated in the study by model simulation results for a general reduction in corporation tax rates. The incorporation of micro-unit household data ensures that general equilibrium effects at the household level, including distributional effects, are incorporated in simulation results. In addition, the explicit microeconomic foundations of the AGE approach provide it with an internal consistency and theoretical transparency that facilitate the interpretation of simulation results.

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Appendix I: Model Labour Tax Rates and Corporation Tax Rates by Industry (%)

<i>No</i>	<i>Industry</i>	<i>Labour Tax Rate</i>	<i>Corp. Tax Rate</i>
1	AGFOFI	13.12	26.73
2	MINEXT	13.12	25.91
3	FOODSD	13.12	26.17
4	ALCOHL	13.12	26.17
5	TOBACO	13.12	26.17
6	TEXTIL	13.12	26.17
7	CLOTFL	13.12	26.17
8	TIMFUR	13.12	26.17
9	PAPRPU	13.12	26.17
10	CORPNF	13.12	26.55
11	CHEMIC	13.12	22.46
12	GLCEBP	13.12	26.17
13	METALS	13.12	27.20
14	MACHIN	13.12	27.20
15	ELCENG	13.12	27.20
16	MOTVEH	13.12	27.20
17	OTRANE	13.12	27.20
18	OMANUF	13.12	26.17
19	ELGAWS	13.12	26.55
20	CONSTR	13.12	27.33
21	DISTHR	13.12	29.53
22	TRANSV	13.12	29.58
23	COMMUN	13.12	29.58
24	FININS	19.60	23.55
25	REALES	13.12	23.55
26	BUSSER	13.12	23.55
27	SOCSER	19.95	0.00
28	OTHSER	13.12	28.57

Appendix II: Model Expenditure Tax Rates by Commodity

(expressed as 1 + *ad valorem* tax rate)

No	Commodity	Final Domestic Tax Rate	Final Import Tax Rate	Intermed Domestic Tax Rate	Intermed Import Tax Rate
1	AGFOFI	1.00	1.01	0.82	1.02
2	MINEXT	1.00	1.01	1.00	1.01
3	FOODSD	1.08	1.12	0.93	1.02
4	ALCOHL	2.19	2.24	2.35	1.69
5	TOBACO	7.76	7.96	2.19	2.04
6	TEXTIL	1.19	1.20	1.01	1.01
7	CLOTFL	1.24	1.26	0.88	1.01
8	TIMFUR	1.35	1.38	0.82	1.01
9	PAPRPU	1.30	1.32	0.95	1.01
10	CORPNF	3.13	3.26	2.39	2.45
11	CHEMIC	1.31	1.34	0.95	1.01
12	GLCEBP	1.19	1.20	1.01	1.01
13	METALS	1.19	1.20	1.01	1.01
14	MACHIN	1.43	1.44	0.99	1.01
15	ELCENG	1.29	1.31	1.01	1.01
16	MOTVEH	1.19	1.20	0.94	1.01
17	OTRANE	1.34	1.35	1.00	1.01
18	OMANUF	1.36	1.38	0.47	1.01
19	ELGAWS	1.00	1.00	1.06	1.03
20	CONSTR	1.12	1.00	1.11	1.09
21	DISTHR	1.09	1.11	0.90	1.01
22	TRANSV	0.99	1.03	0.97	1.02
23	COMMUN	1.23	1.24	1.01	1.01
24	FININS	1.02	1.03	1.01	1.02
25	REALES	0.97	1.00	1.06	1.01
26	BUSSER	1.00	1.01	1.05	1.01
27	SOCSER	1.04	1.08	1.00	1.01
28	OTHSER	1.22	1.27	1.02	1.03

Appendix III: Parameters from Extraneous Sources

<i>No</i>	<i>Commodity/ Industry</i>	<i>Price Elasticity</i>	<i>Income Elasticity</i>	<i>Armington Elasticity</i>	<i>Elasticity of Substitution in Production</i>
		<i>(a)</i>	<i>(b)</i>	<i>(c)</i>	<i>(a)</i>
1	AGFOFI	0.47	1.00	1.5	0.61
2	MINEXT	0.95	1.00	1.5	0.83
3	FOODSD	0.49	0.44	2.5	0.79
4	ALCOHL	0.61	0.85	2.5	0.66
5	TOBACO	0.51	0.30	2.5	0.85
6	TEXTIL	0.46	1.03	2.5	0.91
7	CLOTFL	0.46	1.03	2.5	1.02
8	TIMFUR	0.97	1.00	2.5	0.84
9	PAPRPU	0.36	1.00	2.5	0.91
10	CORPNF	1.59	1.44	1.5	0.83
11	CHEMIC	0.72	1.00	2.5	0.83
12	GLCEBP	0.59	1.00	2.5	0.94
13	METALS	1.08	1.00	2.5	0.81
14	MACHIN	1.01	1.00	2.5	0.59
15	ELCENG	1.06	1.00	2.5	0.75
16	MOTVEH	0.99	1.75	2.5	0.81
17	OTRANE	0.99	1.75	2.5	0.81
18	OMANUF	0.59	1.00	2.5	0.94
19	ELGAWS	0.66	0.25	0.5	1.00
20	CONSTR	1.00	1.52	0.5	1.00
21	DISTHR	1.00	1.52	1.5	1.00
22	TRANSV	0.98	1.00	2.0	1.00
23	COMMUN	1.00	1.00	1.5	1.00
24	FININS	0.64	1.52	1.5	1.00
25	REALES	0.51	1.52	1.5	1.00
26	BUSSER	0.96	1.52	1.5	1.00
27	SOCSER	1.00	1.52	0.5	1.00
28	OTHSER	0.96	1.52	0.5	1.00

Notes: (a) Based on Piggott and Whalley (1985).

(b) Based on Baker et al. (1990).

(c) Based on Willenbockel (1994).