CHAPTER 4: STUDY APPROACH

4.1 Introduction

In this chapter, the model for estimating interfuel substitution and energy aggregation is specified. This is followed by specification of the CGE model used to assess the implications of shifting the energy mix of the Malawi economy from biomass and fossil fuels to hydroelectricity. In an economy like Malawi where carbon-intensive fuels make up 39 percent of energy used by production activities and fuelwood accounts for over 20 percent of energy use in some sectors (NSO, 2001), taxes on carbon emission and on fuelwood use are expected to raise energy prices causing a fall in demand for energy by production activities. Hence, the CGE model is specified to assess the distributional effects of an environmental policy regime that taxes fuelwood and high carbon fuels and subsidizes alternative low carbon substitutes.

The rest of the chapter is organized as follows. Section 4.2 presents the model for estimating substitution elasticities among fuels in the energy aggregate and between energy and non-energy aggregate inputs. Section 4.3 presents the empirical framework for analysing energy-economy interactions. Section 4.4 summaries the chapter.

4.2 Modelling interfuel substitution and aggregate energy and non-energy input substitution

Following the work of Fuss (1977) this study adopts the assumption of homothetic weak separability between energy and other inputs (labour and capital) in production, which allows writing of the firms' technology constraint as:

$$Y = f\left(K, L, E(E_i)\right) \qquad (4.1)$$

Where Y is output, K and L refer to capital and labour, respectively and E is the aggregator function of the energy sub-model. Duality theory implies that the corresponding cost function (C) under cost minimization will also be weakly separable:

$$C = G\left(P_E\left(P_{E_i}\right), P_K, P_L, Y\right) \tag{4.2}$$

P_E is the energy price aggregator index and P_{E_i}, P_K and P_L refer to prices of individual energy components, capital and labour inputs, respectively. Under the assumption of homothetic separability one can apply the two-stage aggregation model which assumes that firms first decide their optimal fuel-mix before considering quantities of non-energy inputs. Once the energy aggregate is composed, firms then vary their optimal energy aggregate in response to changes in demand for non-energy factor inputs (Mountain and Hsiao, 1989; Kemfert and Welsch, 2000; Klepper and Peterson, 2006). Applying Shephard's lemma (Diewert, 1971) we derive from equation 4.2 the system of cost-minimizing input demands $Z_i = \left[\partial C / \partial P_i\right]$.

This study uses the unrestricted quadratic quasi Cobb-Douglas system of equations based on relative fuel demands in the energy aggregate. This is a parsimonious system that extends the multi-input log-ratio formulations of the translog and linear logit models and is consistent with Pindyck's (1979) two-stage aggregation model. Others have used Pindyck's assumption to minimize the number of estimated parameters (Mountain and Hsiao, 1989). Once the energy aggregate is composed, firms then vary their optimal energy aggregate in response to changes in demand for other factor inputs. Thus, the energy demand system is estimated on the assumption of homotheticity and separability of energy from other inputs (Mountain and Hsiao, 1989; Kemfert and Welsch, 2000; Klepper and Peterson, 2006).

The main energy sources used by firms in Malawi are hydroelectricity, oil, fuelwood and coal. Ignoring sector specific identifiers and time subscripts, the unrestricted quadratic log-ratio demand system for four fuels is specified as:

$$\ln\left(\frac{X_i}{X_1}\right) = \ln\left[\frac{\left(\partial C / \partial p_i\right)}{\left(\partial C / \partial p_1\right)}\right] =$$

$$\alpha_i + \sum_{j=2}^{4} \alpha_{ij} \ln\left(\frac{p_i}{p_1}\right) + \frac{1}{2} \sum_{j=2}^{4} \sum_{m=2}^{4} \alpha_{ijm} \ln\left(\frac{p_j}{p_1}\right) \ln\left(\frac{p_m}{p_1}\right) + \beta_i^X d_i^X + \iota(t) + \varepsilon_i \tag{4.3}$$

Where $X_i, i = 2,3,4,$ is fuel $i's$ demand in real quantities, p_i is the corresponding unit price, α, β and ι are unknown parameters, t is time trend variable and ε_i is a white-noise error term. To account for differences in energy mix technologies in estimating equation (4.3), a set of dummy variables are defined in order to incorporate all observations for which the variables $\ln\left(\frac{X_i}{X_1}\right)$ and $\ln\left(\frac{p_j}{p_1}\right)$ are undefined or zero. This method was suggested by Battese (1997) and has been applied in energy studies (Brannlund and Lundgren, 2004). In particular, let:

$$d_i^X = \begin{cases} 1 \quad if \quad \ln\left(\frac{X_i}{X_1}\right) \text{is undefined} \Rightarrow \text{set} \ln\left(\frac{X_i}{X_1}\right) = 0 \\ 0 \,\text{otherwise} \end{cases} \tag{4.4}$$

According to Considine and Mount (1984), most producers would base their input demands on expected prices of inputs. Accordingly, the aggregate input demand function would be more realistic by incorporating price expectations that proxy adjustment costs over time. Also, since there are asymmetric responses among firms to energy price changes, an econometric specification that includes a lagged dependent variable approximates firm specific adjustment cost to input price changes. The dynamic adjustment term that must be added to equation 4.3 is defined as:

$$\lambda_i \ln\left(\frac{X_i}{X_1}\right)_{t-1} \tag{4.5}$$

Where λ_i is a coefficient for the lagged value of the dependent variable.

The hypothesis that the rate of dynamic adjustment influences energy use intensities and vice-versa could not provide meaningful policy insights if tested on a relative demand system of fuel inputs only (Jones, 1996; Brannlund and Lundgren, 2004). Instead, a relative demand system that includes the energy aggregate, labour and capital is preferred with the view to accounting for cross-elasticities of substitution between energy and labour and between energy and capital, in addition to accounting for dynamic adjustments. Since technological change could also be influenced by the rate of dynamic adjustment, an interactive term for share neutral technological change is included in the specification of factor demands. Accordingly, the relative factor demand system under the assumption of non-neutral technical progress with dynamic costs is specified as:

$$\ln\left(\frac{Z_i}{Z_n}\right) = \beta_i + \sum_j \beta_j \ln\left(\frac{w_i}{w_n}\right) + \frac{1}{2}\sum_j \sum_m \beta_{ijm} \ln\left(\frac{w_j}{w_n}\right) \ln\left(\frac{w_m}{w_n}\right) + \beta_t t + \beta_y \ln Y + \lambda \ln\left(\frac{Z_i}{Z_n}\right)_{t-1} + \mu_t \tag{4.6}$$

For i, j, m referring to (K, L, E) and $\beta_{ijm} = \beta_{imj}$ while Z_n is quantity of a quasi-fixed input chosen from among capital (*K*), labour (*L*) and energy aggregate (*E*) and $w's$ are input prices.

In most time series studies, price elasticities vary according to sector suggesting that sectoral size or energy intensity differences may have a role in determining elasticities. Price and production elasticities may also vary between sectors due to differences in production technology across sectors (Mountain and Hsiao, 1989). For these reasons, it seems natural that the appropriate approach to estimating energy demand elasticities is micropanel econometric techniques. Micropanel models allow for heterogeneity between sectors unlike aggregate macro data or micro cross-section data models (Bjørner et al., 2001).

The assumption made about the error term of equations 4.3 and 4.6 would in most cases determine the estimation method. Generalized least squares (GLS) and seemingly unrelated regression (SUR) methods provide consistent and efficient estimates when equations are contemporaneously correlated through the error terms. While GLS parameter estimates depend on the choice of base variable or the equation dropped to achieve a non-singular equation system, maximum likelihood (ML) estimates are invariant to arbitrarily choice of base variable (Frondel, 2004; Urga and Walters, 2003). Also, since the iterative Zellner estimator for SUR is equivalent to ML and is invariant to the choice of transformation used to define the base (Considine and Mount, 1984), ML is the preferred method for estimating both the interfuel demand system and system of aggregate energy and non-energy inputs. ML is also appropriate if the covariance matrix and parameters are changed after every iteration regardless of whether errors are independently and identically distributed.

In this study, only capital is considered quasi-fixed over the relevant time frame in estimating equation 4.6. This allows the estimation of the dynamic adjustment rate, λ as labour and energy inputs vary. Also, the equation system 4.6 is estimated using GLS assuming uncorrelated but autoregressive structure of the residuals within panels. Econometrically, price response dynamics may be interpreted as an approximation for first differences which is a method for eliminating activity or firm specific effects. Mountain and Hsiao (1989) interpreted this specification as an error-correction mechanism denoting the target equilibrium factor demand ratio that is derived from Shepherd's lemma.

The unrestricted quadratic log-ratio specification has other appealing properties. First, the system does not suffer from the same econometric problems that plague the linear logit model. Second, the resultant demand system can be derived from some underlying cost function satisfying regularity conditions (Mountain, 1989; Mountain and Hsiao, 1989; Considine, 1990). Third, for energy and natural resource inputs that are usually a small proportion of total production cost, realistic elasticities of substitution can be estimated without compromising structure and parsimony of the estimated system.

The specification of factor demands in equations 4.3 and 4.6 has conceptual similarities to the cost shares model used by Jones (1996), and Brannlund and Lundgren (2004). First, both systems are theoretically consistent as they are derived from Shephard's lemma. Second, both systems can be used to estimate elasticities of substitution that are based on viable cost functions, in the sense that the underlying functions satisfy homogeneity, monotonicity, symmetry, and concavity conditions (Mountain and Hsiao, 1989). Whereas the cost shares system from linear logit model is closer to translog specification, the relative factor demand system in log form is closer to CES formulations and to generalized Leontief forms when relative factors are in levels (Mountain and Hsiao, 1989). Since the unrestricted quasi Cobb-Douglas demand system in equation 4.1 satisfies homogeneity assumption (Mountain and Hsiao, 1989), the system can be rewritten as:

$$\ln\left(\frac{X_i}{X_1}\right) = \left\{\frac{\left[\partial C/\partial p_i\right]}{\left[\partial C/\partial p_1\right]}\right\} \qquad (4.7)$$

Where C is a homothetic cost function from which equation 4.3 is derived (Mountain, 1989).

Also since the unrestricted quasi Cobb-Douglas function is a finite order function of the logarithms of factor input prices (Hsiao and Mountain, 1989), the Morishima substitution elasticity exists and is defined as:

$$MES_{ij} = -\frac{\partial \ln\left(X_i / X_j\right)}{\partial \ln\left(p_i / p_j\right)} = -\partial \ln\left\{\frac{\left[\partial C / \partial p_i\right]}{\left[\partial C / \partial p_1\right]}\right\} \Big/ \partial \ln\left(p_i / p_j\right) \tag{4.8}$$

The subsidy and tax policy would, through own-price and cross-price elasticities, have impacts on energy and non-energy input demands that could alter output and welfare outcomes in the economy. Thus, equations 4.3 to 4.6 can only give answers concerning substitutability among fuels and between energy and non-energy aggregates such as labour, and capital, in addition to offering insights on dynamic elements giving rise to structural changes in aggregate input demands over time. Also, the linearly homogenous forms makes these functions suitable for analysing factor price responses from the corresponding dual production function (Färe and Mitchel, 1989). However, considering that policy induced changes in energy supply may have profound effects throughout the economy, a general equilibrium framework is the appropriate method for analysing the impact of policy restriction on demand for biomass fuel and on carbon emission from fossil fuels.

4.3 The general equilibrium framework for analysing impacts of energy policies

To analyse the interdependence between the economy and the environment, there is need for explicit functional specifications of the links between the economy, measured in monetary terms, and the physical levels of environmental flows (Leontief, 1970; Mestelman, 1986). Materials extracted from the environment must ultimately either be embodied in durable assets or returned to the environment as wastes or pollutants (Ayres, 2001). In this study, the economy's interaction with the environment consists of a set of energy, material resources and pollutants per monetary unit of final output of commodities produced (Kratena, 2004; Ferng, 2002).

Letting D be a $1 \times N$ vector of sectoral environmental input use i.e., biomass and fossil fuels, A be a direct requirement matrix and I be an identity matrix, the factor multipliers representing an embodiment of energy, material resources and pollutants per monetary unit of final output are given as:

$$M^{*E} = D(I - A)^{-1} \tag{4.9}$$

Taking final demand, Q^D as the amount of industry output consumed by final consumers and AQ as the total output consumed by domestic production processes, the following equilibrium condition must hold:

$$Q^D = Q - AQ \tag{4.10}$$

If Q^D is exogenous, and the input structure does not change when industry changes scale, the model can be solved for final output Q:

$$Q = (I - A)^{-1} Q^D \tag{4.11}$$

Similarly, any given level of final output and vector of environmental inputs, Z^E (biomass and fossil fuel in this case), there is a corresponding level of carbon emissions:

$$D_C^E = Z^E (I - A)^{-1} Q \tag{4.12}$$

Equations 4.9 to 4.12 are adequate for input-output analysis of the environmental problem at hand. However, modelling the integrated aspects of environment and economy linkages requires functional specification of the behaviour of main drivers of change. Since production activities are the main energy users, a tax on emissions simultaneously implemented with targeted tax and subsidy policies on some fuels will alter not only profit conditions of concerned firms but also the distribution of gains and losses in the economy.

The objective function for a sector that faces environmental taxes is expressed as one of maximizing profit subject to technology and environmental constraints:

$$\pi(p,q) = p \times f\left(z, z_{ij}^{E}\right) - g\left(w, p^{E}\tau', q\right) \tag{4.13}$$

Where $f\left(z, z_{ij}^{E}\right) = q$ is a production function with regular first and second partial derivatives, $z = (K, L, S, IND)$ is a vector of inputs namely capital (K), labour (L), land (S), and non-energy intermediate inputs (IND), z_{ij}^{E} are energy intermediate inputs and $g\left(w, p^{E}, q\right)$ is a cost function with dual analogy to the production function, and $w = \left(p_{K,} p_{L}, p_{S}, p_{ji}\right)$ is a vector of prices corresponding to the inputs in vector z. Similarly p^{E} is a vector of prices corresponding to energy intermediate inputs in the vector $z_{ij}^{E} = (Fuelwood, Coal, Oil, Hydroelectricity)$ and τ' is a column vector of taxes or subsidies levied on biomass fuel and carbon emissions embodied in the energy inputs, respectively.

A profit maximizing sector would demand energy and non-energy inputs depending on the level of output, price of final output, unit cost of inputs as well as taxes imposed on carbon emissions and biomass fuel use. Thus production sectors choose inputs according to the following set of first order conditions:

$$\frac{\partial \pi(\cdot)}{\partial z} = p \cdot f'\left(z, z_{ij}^{E}\right) - g'\left(w, p^{E}\tau', q\right) = 0 \tag{4.14}$$

Re-arranging equation 4.14 provides an implicit rule for selecting inputs in the presence of environmental constraints. In particular, environmental taxes reduce the net value of output by the corresponding unit environmental taxes on output. Hence, the rule states that at optimum, a sector would be maximizing profit if it equates the net value of marginal product of an input to its marginal cost:

$$p \cdot f'\left(z, z_{ij}^{E}\right) = g'\left(w, p^{E}\tau', q\right) \tag{4.15}$$

The implication of equation 4.15 is that sectors that use highly taxed energy sources are expected to have large reductions in output, and if such sectors contribute a large share to total output of the economy, economic welfare may also decline substantially. However, when fossil fuels and fuelwood are substitutes for hydroelectricity, some of the output and welfare losses may be offset by subsidizing hydroelectricity.

Given the energy profile of the Malawi economy, hydropower use per unit of output is a key determinant of the rate at which firms adjust demand for other fuels in the presence of environmental policy constraints. Specifically, firms have the choice of using hydroelectricity as an alternative source of energy that does not put pressure on forests or increase the economy's greenhouse inventory. With appropriate targets for increasing hydropower demand to offset reductions in fossil and biomass fuels, a subsidy on hydroelectricity would enter equations 4.13- 4.15 as a negative tax when intermediate demand for hydroelectricity is positive to account for the mitigating effect of increasing hydropower on net output loss.

Environmental tax and subsidy combinations are required since the market economy cannot on its own decide the optimal values for biomass and carbon emissions. The problem for the planner is therefore to define socially acceptable levels of biomass extraction and carbon emissions. Accordingly, the vector of taxes in equation 4.15 is associated with constraints imposed on the relevant environmental externality. With duality, the optimal tax and subsidy combination can be established by varying the environmental constraints. The tax and subsidy and the associated environmental constraints trace out marginal cost curves for reducing an environmental externality. The general equilibrium impacts of environmental tax and subsidy policy combination depend to a large extent on the initial fuel shares in the energy input (Klepper and Peterson, 2006).

Sectors that are carbon intensive or biomass fuel intensive face high costs of adjustment to environmental taxes on carbon and biomass. The adjustment costs, often measured in terms of reduction in output, may escalate if there are limited substitution possibilities among energy inputs, and between energy and non-energy inputs. As demand shifts from high to low cost energy inputs, producers may increase or decrease demand for other factor inputs depending on complementarity or substitution possibilities between energy and non-energy inputs. These changes could raise or reduce prices of not only factors of production but also of goods and services, thereby affecting household consumption, government expenditure, savings, investment and economic growth.

In developing countries however, the combined problem of biomass loss in forests and increasing emissions due to energy use pose policy dilemmas. On one hand, emissions per unit of output from developing countries are generally increasing and are proportional to not only fossil fuel use but also deforestation rates in some countries. Thus, reducing emissions now may translate to substantial environmental gains since for every ton of carbon abated from fuelwood combustion at least two tons of fuelwood biomass could be conserved in standing forests (Girard, 2005). In addition, some carbon-intensive fuels like coal and oil can be replaced with capital intensive but energy saving technologies. In addition, environmental taxes aimed at curtailing emissions may stifle development either by reducing output directly as producer prices fall or indirectly through income and consumption effects on households. According to Jorgenson et al. (1992) the analysis of taxes to reduce emissions must consider not only efficiency losses but also effects on equity in the distribution of welfare among households since a tax affects relative prices faced by consumers.

The distributional impacts of biomass and carbon taxes on the economy would also depend on government's option of spending the additional tax revenues. Most studies conclude that the aggregate environmental compliance costs may reduce economic growth because of the existence of other distortionary taxes (Goulder, 1995a; Boyd et al., 1995). Hence, an increase in the price of energy resulting from the imposition of a carbon tax, would disproportionately affect households with large share of energy in total expenditure. For production activities, the impact of a tax on energy inputs would depend not only on the initial input shares but also the substitution possibilities between energy and non-energy factors of production. To reduce negative impacts of additional tax revenue on the economy, most studies propose revenue-neutral environmental taxes, i.e., taxes whose revenue are used to reduce other distortionary taxes so that the overall tax revenue remain constant (Goulder, 1995a; Bovenberg and Goulder, 1996; Goulder et al., 1997; Goulder et al., 1999; Bye, 2000).

In most cases, reducing or eliminating pre-existing inefficiencies may be the only necessary condition for environmental taxes to successfully correct an externality without affecting economic growth and household welfare (Kumbaroglu, 2003; Bovenberg and Goulder, 1997; Böhringer, 1997). When the additional revenue is added to the pool of government revenue, it may be saved or used for current government consumption. The environmental taxes are therefore not revenue-neutral and could potentially aggravate pre-existing tax distortions by raising the cost of pollution abatement (Bovenberg and Goulder, 1996; Kim, 2002). If the government uses the revenue to reduce household direct tax obligations proportional to the initial share of direct tax payments while keeping net government revenues from environmental taxes zero, the system is said to be revenue-neutral.

Equations 4.9 to 4.15 extend the standard CGE model for Malawi developed by Lofgren (2001). Lofgren (2001) explored the effects of external shocks and domestic policy changes aimed at poverty alleviation using a static CGE model calibrated against a disaggregated 1998 social accounting matrix (SAM) for Malawi. However, unlike Lofgen (2001), production in sector i is assumed to be constant returns to scale Cobb-Douglas technology that transforms intermediate inputs including fuels and value added aggregates.

$$Q_i = A_i K_i^{\alpha_{Ki}} L_i^{\alpha_{Li}} S_i^{\alpha_{Si}} E_{im}^{\alpha_{Emi}} ID_{ij}^{\alpha_{ij}}; \qquad \sum_{(K,L,S,E,ID)} \alpha = 1 \tag{4.16}$$

Where K, L, S and ID_{ij} are capital, labour, land, and non-energy intermediate inputs, respectively, while E_{im} is energy intermediate of type $m = (\text{coal, fuelwood, oil, hydropower})$. The parameters A_i and $\alpha(*)$ are total factor productivity and Cobb-Douglas elasticities, respectively.

Meeting energy demand by production activities involves distribution of carbon-intensive fuels such as oil and coal and biomass extracted from forests for fuelwood. For accounting purposes, energy producing sectors' transactions with other economic activities are expressed in British thermal units (Btu) to provide a link between partial equilibrium estimates of interfuel substitution at industrial level with the inter-industry transaction represented by the general equilibrium model (Hoffman and Jorgenson, 1977).

In estimating externalities associated with energy inputs, we assume that environmental issues are at the lowest level a function of energy inputs which in turn are determined by the output level. This is consistent with Jorgenson et al. (1992) who assumed that carbon emissions are proportional to energy inputs (fuels). However, we go further and assume that since emissions are generated in production processes, environmental issues have a small positive elasticity of substitution with output. This formulation is consistent with Mizobuchi and Kakamu (2007) who based their functional form on the hypothesis of existence of an environmental Kuznets curve. Environmental issues therefore take the form:

$$E_j^{V^E} = \lambda_j^{V^E} f\left(z, z_{ji}^E\right)^{\sigma_j^{V^E}} \tag{4.17}$$

Where $E_j^{V^E}$ is for production sector j a specific environmental issue, V^E including carbon emissions, biomass extraction and hydro-energy consumption in physical units, $\lambda_j^{V^E}$ is a scale coefficient for environmental issue, $f\left(z, z_{ji}^E\right)$ is production function and $\sigma^{V_j^E}$ is elasticity of environmental issue with respect to output of the sector.

A complete specification of the general equilibrium model would include equilibrium conditions for factor markets, as well as market clearing conditions for energy and carbon emissions. Thus, assumptions must be made about behaviour of households (owners of factors of production) and government (environmental regulator). In particular, saving and investment behaviour must be specified for domestic institutions including regular income generation and expenditure outlays. In addition, the general equilibrium model would not be complete without assumptions about the economy's interaction with the rest of world. A summary of assumptions made about the different actors and markets are given below while the algebraic specification of the general equilibrium model is included in the appendix.

In general, it is assumed that all actors in the economy maximize their respective objective functions. Households are assumed to solve a standard household utility maximization problem involving choosing a consumption bundle that yields the highest possible utility to the household subject to its budget constraint. Household expenditure on consumption is bounded by income that in turn depends on the household's limited endowment of primary factors (labour, capital and land), and exogenous income. In Lofgren (2001), factor incomes generated in the production process are paid in fixed shares to enterprises (owners of capital and land) and to households (owners of labour). In this study, households own all factors of production and that factor incomes are paid directly to households. The allocation of enterprise income to taxes, savings and the rest of the world are likewise interpreted as outlays made by the households themselves. Households also allocate their income to savings, direct taxes and transfers to the rest of the world.

Government receives income from indirect and direct taxes, import taxes and direct transfers from abroad. It is also assumed that government consumes final products in fixed proportions, and that government saves and distributes income to households as direct transfers. The distribution formula applied by this study is regressive in the sense that households with high tax obligations get lower relief than their counterparts. Households receiving a tax relief may save or consume the windfall income in the current period. Unlike Lofgren (2001), government savings are not treated as the residual of the difference between government current revenue and expenditures. Instead, it is assumed that government has an exogenous marginal propensity to save out of its current revenue. It is further assumed that government overall budget deficit is offset by foreign direct transfers to government.

The rest of the world contributes to national savings and because of the small open economy character, it is assumed that Malawi faces exogenously determined international trade volumes and prices. Unlike Lofgren (2001), all domestic demands for imported goods and services by households, government, and for investment and intermediate use are indistinguishable from domestic supply of the same commodity since imports and domestic goods are considered perfect substitutes. However, the quantity of imports and domestic output that makes up composite supply of a commodity is determined by the relative prices of imports and domestic output. Similarly, it is assumed that there is perfect transformability between domestic output that is exported and sold domestically, and export-domestic sales ratios are influenced by relative prices.

The general equilibrium model requires that all markets be in equilibrium. Factors markets are in equilibrium when the total quantity demanded and the total quantity supplied for each factor are equal. Similarly, commodity markets are in equilibrium when the sum of intermediate use, household consumption, government consumption, fixed investment, stock change and trade import use are equal to the aggregate supply of commodities in the economy (Lofgren et al., 2000). In addition, each institution equates its income to expenditures while balance of payments equilibrium is achieved when the sum of import spending and transfers to the rest of the world equal the sum of exports revenue, institutional transfers from the rest of the world and foreign savings. Finally, investment demand equals the supply of loanable funds (savings) in the economy.

4.4 Summary of empirical approach

The chapter has specified in detail the empirical models employed in the next two chapters. The interfuel substitution and aggregate input demand systems are sector specific microeconometric models specifically intended to estimate short-run and long-run elasticities and dynamic adjustment costs for the energy sector. Policy simulations conducted using the microeconometric analysis will reinforce or refute the prospect that energy sector changes could have wider economic implications whose overall cost or benefit can be assessed using an economywide model.

One of the hypotheses to be tested by the microeconomic analysis is that capital, labour and energy input aggregates are substitutes for each other. Hence, the microeconometric model would reveal the direction of change in demand for aggregate inputs as a result of relative prices change. However, partial equilibrium models cannot inform policy when there are multiple objectives such as searching for an optimal environmental tax that internalises an externality without compromising economic growth and household welfare. Also, given that multiple prices may be changing simultaneously, the partial equilibrium analysis may underestimate or overestimate costs and benefits of environmental policy since the microeconometric simulations are conducted on the assumption that some prices are held constant over the simulation period. Since prices are endogenous in general equilibrium analysis, the CGE approach is appropriate for assessing the economic impact of a fiscal policy regime that taxes high carbon fuels and subsidizes alternative low carbon substitutes.

CHAPTER 5: INTERFUEL SUBSTITUTION AND DYNAMIC ADJUSTMENT IN INPUT DEMAND

5.1 Introduction

This chapter estimates the elasticity of substitution between energy and non-energy factors of production in Malawi using a micropanel model of 59 sectors of the Malawi economy between 1998 and 2004. The chapter also estimates the rate of dynamic adjustment in energy consumption by industrial energy users in response to price changes. The estimated interfuel substitution elasticities and energy and non-energy input substitution elasticities are then used to conduct an environmental policy simulation aimed at reducing energy-related carbon emissions through interfuel substitution. Specifically, the chapter simulates the impact of a subsidy on cleaner fuel sources on carbon efficiency and on biomass conservation in forests.

The rest of the chapter is organized as follows. Sections 2 describes the data and main variables used in the estimation. Sections 3 and 4 discuss the econometric estimates of interfuel demand and aggregate inputs. Estimates of carbon emissions from fuel use and results of policy simulations are presented in section 5. The chapter concludes with some policy suggestions.

5.2 Data and variable definitions

Equations 4.3 and 4.6 were estimated using data from the AES. AES data are collected annually by the Malawi National Statistical Office (NSO). However, reports are only compiled every four years and are summarised at the 3-digit ISIC level. The AES itself is by design a panel of companies selected to reflect the current economic situation in the industrial sector. The variables in AES include sale of goods, stocks, purchases of intermediate materials and supplies used in production, employment, capital investment in fixed assets and profit. Other variables obtained from the AES are production, employment of labour, capital investment and profitability of enterprises. The main variables used in the analysis are summarised in Table 10.

Table 10: Definitions of variables

Variable	Description	Mean	Sd
X_1	Quantity of hydroelectricity purchased in Megawatts	15,568.03	38,345.32
X_2	Quantity of oil purchased in Megawatts	7,222.40	10,944.96
X_3	Quantity of fuelwood purchased in Megawatts	12.31	39.13
X_4	Quantity of coal purchased in Megawatts	114.86	101.50
p_1	Price of 3,413,000 Btu of electricity = price of 1000 Kilowatts of energy	993.23	405.91
p_2	Price of 3,413,000 Btu of oil = price of 1000 Kilowatts of energy	4,738.83	2,736.75
p_3	Price of 3,413,000 Btu of fuelwood = price of 1000 Kilowatts of energy	693.68	218.32
p_4	Price of 3,413,000 Btu of coal = price of 1000 Kilowatts of energy	346.30	203.41
L	Number of workers employed	17,865.45	102,127.40
K	Gross Investment minus depreciation plus changes in stocks in million Malawi Kwacha	30,300.00	180,000.00
E	Energy aggregate in Megawatts	185,467,330.79	295,927,336.65
w_L	Remuneration per worker in Kwacha	538.99	1,189.65
w_K	User cost of capital (Kwacha)	14.33	8.32
w_E	The weighted average price of 1000 kilowatts of energy	511.89	223.55
Y	Output value measured by net sales in million Malawi Kwacha	207.48	842.34

The estimation covers two survey periods from 1998 to 2005. Since the NSO only reports aggregate use and supply figures, micro level energy demand data were obtained by the author from archives of AES questionnaire responses. The data were then aggregated according to activity classifications used by the NSO. Energy data were classified by fuel type, i.e., hydroelectricity, coal, fuelwood, and oil (ethanol, diesel, petrol). All fuels were measured in both physical quantities and monetary values. For uniformity, all energy inputs were converted into British thermal units (Btu) using standard conversion factors from IEA (2003) expressed at Lower Heating Value (LHV)[6]. For lack of unit price data for the fuels, the study uses average prices obtained by dividing total energy expenditures per fuel by corresponding Btu quantities. Bjorner et al. (2001) argue that this is acceptable if the average

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[6] Comparable conversion factors can be obtained from the U.S. National Institute of Standards and Technology website.

price is not a function of sales and thus reflects marginal price. In the case of Malawi, virtually all firms are net buyers of fuels and are thus price takers in the energy market.

5.3 Estimates of relative fuel demands and interfuel elasticities

Regression results of the relative fuel demand functions are reported in Table 11. Since equation 4.3 is an unrestricted model of fuel demand, a set of linear restrictions are tested to verify the underlying structure of energy aggregation. Except for coal, demand functions for oil and fuelwood (models 1 and 2) are flexible as they satisfy the following set of restrictions:

a) Test if $\beta_j^X = 0$. Failing to reject the hypothesis that Battese (1997) dummies are equal to zero implies that production technologies at firm level are so different that it is not possible for some firms to use all fuels. Thus, equation 4.3 would be a misspecification since it is not feasible to substitute any of the fuels that a firm currently uses for another that the firm does not use.

b) Test if $\alpha_{ij} = \alpha_{ijm} = 0, \forall i, j, m$. If this condition holds, it means that the energy aggregate used by a firm is composed of fixed proportions of oil, fuelwood, coal and hydroelectricity. Thus, the ratio of quantities of any pair of fuels is constant (Leontief function case) (Mountain and Hsiao, 1989; Mountain, 1989).

c) Unit elasticity of substitution (Mountain and Hsiao, 1989; Mountain, 1989): $\alpha_{ii} = \alpha_{jj} = -1, \forall i, j; \alpha_{ij} = 0, i \neq j; \alpha_{ijm} = 0, \forall i, j, m$. These conditions mean that elasticities of the fuels are restricted to unity and cross-price terms are zero. When these restrictions hold, the unrestricted function reduces to a regular Cobb-Douglas function.

Reading diagonally for the first three variables in Table 11, all demand equations have the expected signs for own-price elasticities. For both oil and fuelwood, demand would increase if the price of any other fuel rises. For coal, demand rises with increases in relative price of fuelwood implying that coal and fuelwood are substitutes but the negative sign on the price of oil suggests a complementary relationship between coal and oil. However, the linear restriction tests show that coal has a slightly different structure as it follows a Cobb-Douglas specification that fails neutral technological change assumption.

Table 11: Fuel-mix regression results

	Model 1: Oil	*Model 2: Fuelwood*	*Model 3: Coal*
Variable	$\ln\left(X_2/X_1\right)$	$\ln\left(X_3/X_1\right)$	$\ln\left(X_4/X_1\right)$
$\ln(p_2/p_1)$	-1.96 (0.19)*	0.03 (0.12)	-0.07 (0.09)
$\ln(p_3/p_1)$	2.83 (0.85)*	-2.49 (0.50)*	0.25 (0.36)
$\ln(p_4/p_1)$	0.03 (0.48)	3.88 (0.45)*	-0.85 (0.29)*
$[\ln(p_2/p_1)]^2$	0.62 (0.07)*	0.00 (0.06)	0.02 (0.04)
$[\ln(p_3/p_1)]^2$	-0.22 (1.24)	-2.61 (0.77)*	0.34 (0.55)
$[\ln(p_4/p_1)]^2$	-0.24 (0.29)	2.50 (0.34)*	0.61 (0.23)*
$\ln(p_2/p_1)\times\ln(p_3/p_1)$	-1.14 (0.33)*	0.55 (0.23)**	-0.11 (0.17)
$\ln(p_2/p_1)\times\ln(p_4/p_1)$	-0.22 (0.18)	-1.30 (0.17)*	0.27 (0.11)*
$\ln(p_3/p_1)\times\ln(p_4/p_1)$	0.53 (0.50)	-2.14 (0.43)*	-0.97 (0.26)*
t	0.10 (0.03)*	-0.03 (0.02)***	0.02 (0.02)
β_j^X	-0.93 (0.31)*	1.58 (0.23)*	1.06 (0.20)*
Constant	0.62 (0.17)*	-1.63 (0.27)*	-1.04 (0.22)*
Linear Constraints (Chi-squared tests)			
Test for $\beta_j^X = 0$	8.92*	38.61*	19.56*
Test for Leontief restrictions	204.14*	153.27*	52.99*
Unit elasticity (Cobb-Douglas case)	26.57*	7.23*	1.60
Cobb-Douglas linear restrictions	12.28*	19.98*	0.72
Test for $t = 0$	9.03*	6.84*	1.22

* Significant at 1% level ** Significant at 5% level *** Significant at 10% level

The relative demand for coal also failed to satisfy the assumption of neutral technical change. However, coal demand is still influenced by prices of other fuels through interactive price terms. This implies that cross-price effects strongly determine demand for coal and that some fuel prices may fall over time as firms switch to coal. Thus, the time trend in the demand function for coal may be reflecting only expansion in coal production and use due to cheaper prices and not necessarily technological change. Hence firms that use coal are less likely to change their fuel mix because of technological constraints but would shift demand from coal to another fuel only because of price effects.

Allen cross-price elasticities between hydroelectricity and other fuels were estimated and reported in Table 12. Oil and coal are Allen-Uzawa complements to hydroelectricity while fuelwood is a substitute. However, the Allen partial elasticity of substitution is inappropriate in energy studies since it lacks economic meaning. In addition, the estimated demand functions were not symmetric in sign and size of coefficients, hence rendering pairs of cross-price elasticities inconsistent. With three or more inputs, the percentage change in the relative input of factor *i* due to a change in the relative price of factor *j* is a meaningless statistic that holds all other inputs constant, when in fact all inputs adjust to any change in factor prices (Thompson, 2006).

Morishima substitution elasticities were instead estimated for all fuels and reported in Table 12. The MES measures the percent change in the input quantity ratio $\left(X_j / X_1\right)$ with respect to a percent change in the corresponding price ratio $\left(p_j / p_1\right)$. Oil, fuelwood and coal are all Morishima substitutes to hydroelectricity. This implies that it would be possible to switch energy demand from carbon-intensive fuels such as coal and oil to cleaner fuels. It also means that it would be possible to substitute some biomass energy demand for other fuels and hence avert deforestation. The MES between oil and hydroelectricity is comparable to that between fuelwood and hydroelectricity although the MES between fuelwood and hydroelectricity is larger. The MES between fuelwood and hydroelectricity however is almost three times the MES between coal and hydroelectricity. This implies that in all cases relatively more electricity would be used when the other fuel becomes expensive with the greatest response when the price of fuelwood is raised.

Table 12: Allen-Uzawa cross-price and Morishima substitution elasticities

Allen-Uzawa cross-price elasticities			
	Oil	***Fuelwood***	***Coal***
Hydro	-0.65	0.91	-0.39
Oil		0.29	-0.05
Fuelwood	3.79		1.25
Coal	-0.85	3.51	
Morishima Elasticities of substitution			
	Oil	***Fuelwood***	***Coal***
Hydro	1.11	1.42	0.52
Oil		0.49	0.32
Fuelwood	2.67		1.41
Coal	0.36	2.54	

Although oil and coal are Allen-Uzawa complements for hydroelectricity, the Morishima substitution elasticity unequivocally classifies all fuels as substitutes. This is consistent with the observation in several studies including Stiroh (1999), Frondel (2004), and Shankar et al. (2003) that Allen-Uzawa complements might be Morishima substitutes. This is because the Allen-Uzawa elasticity considers the percentage change in an input as a result of a change in any one price whereas the Morishima elasticity measures a change in input ratio resulting from the change in the price of interest. Since the price change affects both inputs in the ratio, it is conceivable that the Morishima elasticity may be positive when the Allen-Uzawa elasticity is negative.

There are sectoral differences in the size of Morishima substitution elasticities for oil, fuelwood and coal paired with hydroelectricity, respectively (Table 13). Activities such as manufacturing of fertiliser and plastics, pharmaceuticals, mining of hard coal and quarrying and bakeries and confectionaries have the greatest potential for switching from oil to hydroelectricity. Thus, these sectors are expected to substantially curb emissions from oil combustion as the price of hydroelectricity falls relative to the price of oil. Manufacturing of sugar and of "soaps, detergents and toiletries" have the lowest MES between hydroelectricity and oil, implying that these sectors would not substantially reduce their carbon emissions from oil combustion even if a revenue-neutral environmental tax was levied on oil offset by subsidies on hydroelectricity. Only the activity of manufacturing fabricated metal and metal stamping use oil as a complement to hydroelectricity, implying that a revenue-neutral environmental tax on oil would almost certainly not change the sector's demand for oil.

Similarly, there would be substantial environmental gains from raising the price of fuelwood relative to the price of hydroelectricity from activities of mining of hard coal and quarrying, bakeries and confectionaries, and fertiliser and plastic products (Table 13). However, tobacco and sugar growing, and manufacturing of sugar, have the lowest potential for substituting fuelwood for hydroelectricity, although between them they use 87 percent of all fuelwood demanded by production activities (NSO, 2001). Thus, these sectors would bear the highest burden of a tax levied on fuelwood proportional to weight of fuelwood used or alternatively, according to equivalent forest area that must be cleared to obtain that amount of fuelwood. The activity of manufacturing fabricated metal and stamping of metal would reduce demand for hydroelectricity by more than 3 percent if the price of fuelwood was raised by 1 percent since hydroelectricity and fuelwood are complements in the activity's production. There is also strong complementarity between fuelwood and hydroelectricity in the manufacturing of soaps, detergents and toiletries whereas for distilling spirits and manufacturing of malt liquor and soft drinks, the complementarity is weak.

For coal, only the activity of distilling spirits and manufacturing malt liquor and soft drinks has elastic Morishima substitution for hydroelectricity. This is important for environmental policy because the sector's demand for coal accounts for 34 percent of all coal use by production activities (NSO, 2001). Thus, a fuel switch from coal to hydroelectricity is possible for at most 34 percent of the coal in the sector. However, the demand for coal by manufacturing of soaps, detergents and toilets is inelastic to change in price of hydroelectricity although the activity uses 63 percent of the coal used by all production activities (NSO, 2001). This means that a carbon tax on coal offset by subsidies on hydroelectricity would disproportionately affect the cost of producing soaps, detergents and toiletries compared to the emissions that may be reduced.

Table 13: Sectoral Morishima elasticity of substitution for hydroelectricity calculated for 1% increase in price of oil, fuelwood or coal.

Sector Name	*Oil*	*Fuelwood*	*Coal*
Tobacco & sugar growing	0.82	0.91	0.18
Tea, coffee & macadamia growing	0.95	1.25	0.31
Mining of hard coal and quarrying	1.51	2.09	0.65
Grain milling	1.17	1.79	0.51
Bakeries and confectionaries	1.43	2.03	0.62
Sugar	0.20	0.58	-0.02
Manufacturing of tea and other food products	0.95	1.25	0.31
Printing (books, music)	1.44	2.03	0.63
Pharmaceuticals	1.58	2.15	0.69
Soaps, detergents and toiletries	0.05	-1.52	0.68
Cement, lime & plaster	1.22	1.84	0.53
Construction	1.23	1.85	0.53
Sale of motor vehicles	1.36	1.96	0.59
Retail of auto fuel	0.89	1.55	0.38
Hardware, paints, and vanish	1.31	1.92	0.57
Other retail sale in specialised stores	1.23	1.85	0.53
Hotels	1.34	1.94	0.58
Restaurants, bars	1.23	1.85	0.53
Horticulture, fishing & forestry	1.19	1.81	0.51
Cattle, dairy & poultry	0.98	1.17	0.29
Meat and dairy products	1.20	1.82	0.52
Textiles and wearing apparel	1.19	1.81	0.52
Publishing	1.22	1.27	0.36
Fertiliser & plastics	1.61	2.18	0.70
Rubber tyres & plastic products	1.15	1.78	0.50
Ceramics and structural metals	1.33	1.94	0.58
Fabricated metal and stamping of metal	-0.25	-3.07	0.62
Batteries & motor vehicle trailers	0.96	1.61	0.41
Maintenance of motor vehicles and sale of spare parts	1.44	2.03	0.63
W/sale on fee and agric raw mate	1.27	1.88	0.55
Retail in non-specialised Stores, Pharmacies and textiles	1.38	1.98	0.60
Distilling spirits/Malt liquor/Soft drinks	0.95	-0.45	1.16

The discussion above suggests that both carbon emissions and forest resource depletion due to industrial fuelwood use could be significantly reduced by changing the relative price of fossil and biomass fuels. This could be achieved for instance by imposing a tax on oil, coal and fuelwood while subsidizing hydroelectricity. In particular, since coal and oil are carbon-intensive but have strong substitution possibilities with hydroelectricity in some sectors, raising the price of these fuels relative to hydroelectricity would significantly reduce carbon emissions. However, some key sectors of the economy such as manufacturing of sugar and of soaps, detergents and toiletries have inelastic demand for hydroelectricity relative to oil, implying that a fossil fuel tax could significantly raise costs for these activities.

Similarly, fuelwood demand responds strongly to relative price changes of hydroelectricity in almost all sectors except for main users of fuelwood namely tobacco and sugar growing, and manufacturing of sugar. Thus, if price effects alone are not enough to reduce fuelwood use by production activities, it would be prudent to focus on sectors that have inelastic demand to find alternative policies that could ensure sustainable use of fuelwood for industrial use. Coal has a large substantial substitution potential for fuelwood. However, it would be inappropriate to support a switch from fuelwood to coal without corresponding carbon tradeoffs.

5.4 Estimates of aggregate energy and labour demand functions

Following the theoretical framework outlined in chapter 4, firms are assumed to combine their least cost fuel mix (the energy aggregate) with other least cost factor inputs. At this input aggregation stage, firms are assumed to combine energy, labour and capital using the same technology with which energy input is aggregated. This assumption is consistent with the assertion that energy mix varies with technology. In this regard, the hypothesis that the rate of dynamic fuel cost adjustment varies across industry is tested. This indirectly tests the proposition by Brannlund and Lundgren (2004) that the rate of dynamic adjustment varies with individual fuel mix.

Estimates of the unrestricted quasi Cobb-Douglas demand functions for labour and energy are reported in Table 14. Both equations were estimated assuming panel specific first order autocorrelation in the residuals. The results show that both relative demand for labour and for energy satisfy regularity conditions and are consistent with theoretical expectations. An increase in the price of energy may lead to a fall in labour demand as indicated by the large negative coefficient for the price of energy. However, there could be some rather weak substitutability between labour and energy in some sectors indicated by small but positive coefficients for the squared price of energy and energy-labour cross-price terms in the labour demand function. Also, an increase in a sector's output will lead to more employment of labour while the positive sign on the Hicks-neutral technical term may be interpreted as indicating expansion of industrial employment of labour over time and that technical progress has favoured labour.

Table 14: Aggregate Energy and Labour demand regressions

Relative demand for labour					**Relative demand for energy**				
Variables	Coef.	Std. Err.	Z	P>|Z|	Variables	Coef.	Std. Err.	Z	P>|Z|
$\ln(w_L/w_K)$	-0.19	0.05	-3.45	0.00	$\ln(w_L/w_K)$	0.12	0.04	3.17	0.00
$\ln(w_E/w_K)$	-0.74	0.13	-5.52	0.00	$\ln(w_E/w_K)$	-0.93	0.08	-12.20	0.00
$[\ln(w_L/w_K)]^2$	-0.04	0.02	-2.79	0.01	$[\ln(w_L/w_K)]^2$	0.02	0.01	2.53	0.01
$[\ln(w_L/w_K)]\times[\ln(w_E/w_K)]$	0.07	0.03	2.63	0.01	$[\ln(w_L/w_K)]\times[\ln(w_E/w_K)]$	-0.04	0.02	-2.38	0.02
$[\ln(w_E/w_K)]^2$	0.06	0.10	0.61	0.54	$[\ln(w_E/w_K)]^2$	0.34	0.07	4.97	0.00
$\ln Y$	0.08	0.05	1.70	0.09	$\ln Y$	-0.88	0.05	-16.88	0.00
t	0.26	0.09	2.74	0.01	t	0.07	0.07	1.08	0.28
$\ln(L/K)_{t-1}$	0.12	0.04	2.82	0.01	$\ln(E/K)_{t-1}$	0.02	0.01	2.30	0.02
β_2	-2.88	0.42	-6.85	0.00	β_3	18.11	0.36	50.26	0.00

For aggregate energy demand however, an increase in the price of labour could lead to an increase in demand for energy which might be offset if the energy-capital price ratio in the cross-price term is large. Also, as in the case of labour, the positive sign on the Hicks-neutral technical term indicate that energy use by industrial sectors is expanding over time and that energy demand and capital adjust in the same direction. However, the negative sign on output implies that output growth does not necessarily lead to an increase in energy demand but rather that firms may be using energy inefficiently at low levels of output. Thus, growth in demand for a firm's output may lead to considerably energy savings over time.

In both demand equations for labour and energy, the dynamic adjustment parameter (λ) is positive and significant which is consistent with the Le Chatelier principle that short-run elasticities can never be greater than long-run elasticities in absolute value (Urga and Walters, 2003). The rate of adjustment for labour-capital ratio to its desired level is 88 percent $(1-\lambda)$

annually whereas energy-capital ratio adjusts by 98percent[7]. The high adjustment speed has important implications for the effectiveness of policies aimed at curtailing energy use in the economy. In particular, energy conservation policies may be costly if the introduction of energy-efficient capital is pursued while capital and energy are net complements in production or when the rate of dynamic adjustment is slow. Since we found substitution among fuels within the energy aggregate, energy conservation can be pursued with little or no labour effects in the short-run. However, the results show that firms adjust energy demands much faster than labour, implying that production sectors almost always match actual energy-capital ratios at their desired levels but afford mistakes with labour projections. The cumulative impact of projection errors on labour employment could be significant in the long run if energy policies are unpredictable.

To test the hypothesis that adjustment speed varies across industries, the rate of dynamic adjustment (λ) was multiplied by the observed lagged values for labour-capital and energy-capital ratios in log form, respectively (Table 15). The resulting values were compared across industries using one-way analysis of variance. For labour, the test statistic $(F(5,216)=2.23)$ is barely significant at 5 percent level while for energy, the test statistic $(F(5,216)=3.09)$ is significant at 1 percent level. In both cases however, the null hypothesis of equal variances cannot be rejected by the Bartlett's test. Further exploration of the adjustment structure revealed that for labour demand, services, mining and manufacturing have the highest long-run adjustment speeds with respect to labour-capital changes while agriculture and services have the highest long-run adjustment speeds with respect to energy-capital changes.

Table 15: Relative input adjustment speeds across industry

	Labour-capital adjustment speed			Energy-capital adjustment speed			Labour-energy adjustment speed*		
Industry.	Mean.	Sd.	Freq.	Mean.	Sd.	Freq.	Mean.	Sd.	Freq.
Agriculture	-0.21	0.22	28	0.15	0.12	28	-2.36	1.95	28
Manufacturing	-0.15	0.26	117	0.07	0.12	117	-1.89	2.10	117
Services	-0.1	0.18	14	0.14	0.17	14	-2.12	2.21	14
Mining	-0.14	0.25	7	0.06	0.12	7	-2.06	1.95	7
Distribution	-0.26	0.32	49	0.09	0.12	49	-2.24	2.18	49
All Industries	-0.18	0.27	215	0.09	0.13	215	-2.13	2.10	215

* Labour-energy adjustment is presented here for comparison only since it was calculated from regression of Labour normalised by energy aggregate.

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[7] For comparison, a labour-energy regression was estimated on the assumption that energy is quasi-fixed while capital is variable. Firms adjust their labour at the rate of 87% annually to the desired labour-energy ratio. This is comparable with the rate at which firms adjust labour to the desired labour-capital ratio.

Capital and energy have theoretically consistent Allen own-price elasticities (Table 16). Labour however has inconsistent own-price elasticity which can be explained by the large share of labour in production costs for most industries. In fact, the average share of labour in total cost over the entire estimation sample is 76percent. Capital and energy are moderately responsive to own-price changes but energy is more than twice as responsive as capital. The Allen-Uzawa cross-price elasticities show that capital and labour are complements, although the elasticity is quite low. However, energy and capital are Allen-Uzawa substitutes and that a change in the price of capital could trigger a large response in demand for energy.

The substitution possibility between energy and capital is verified by the MES. However, the extent of substitution possibility is significantly lower than suggested by the Allen-Uzawa substitution elasticity. Whereas labour and capital are Allen-Uzawa complements, the Morishima substitution elasticity suggests otherwise with a significantly large substitution possibility (Table 16). The elasticity of substitution between capital and labour and between capital and energy are fairly symmetric, suggesting that the underlying cost function is close to the constant elasticity of substitution formulation.

Table 16: Allen-Uzawa and Morishima elasticities

Allen-Uzawa own and cross–price elasticity of	Capital	Labour	Energy
Capital	-0.32	-0.03	21.61
Labour		0.01	-0.03
Energy			-0.65
Morishima substitution elasticity of	Capital	Labour	Energy
Capital		0.90	1.57
Labour	0.85		-0.62
Energy	1.58	-0.20	

Labour and energy are Morishima complements but energy-labour ratio is very responsive to adjustments to the relative price of labour. This result could similarly be explained by the relatively high share of labour in total production cost compared to the share of energy. Thus, a large compensating change in the energy-labour ratio is required for a given change in the price of labour. Thus, labour intensive activities are in general energy-using production technologies.

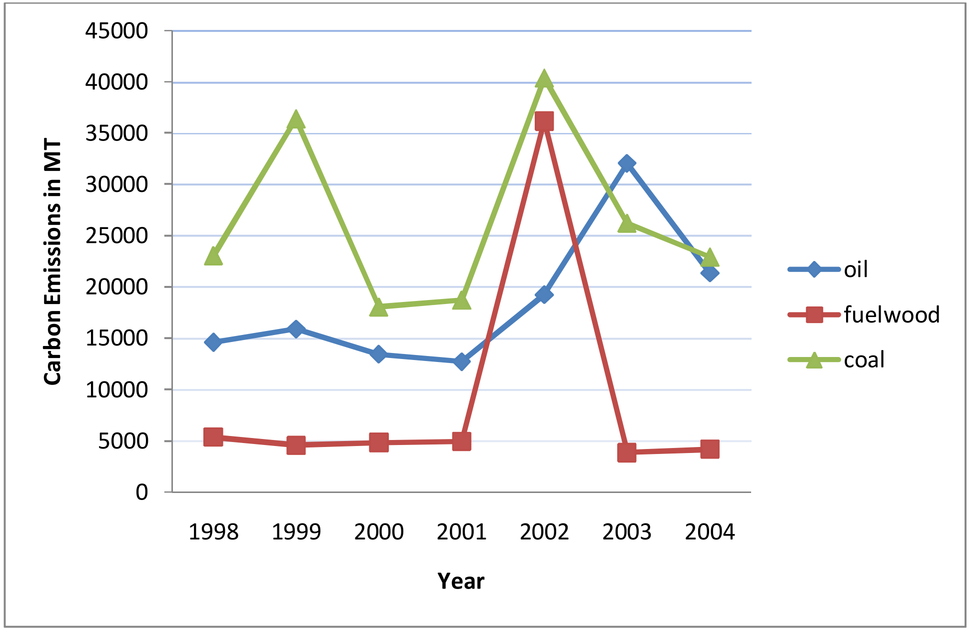
Long-run own- and cross-price elasticities provide better parameters on which to base projections for future labour and energy scenarios. This is calculated by dividing the short-run elasticity with the corresponding dynamic adjustment coefficient. In this regard, the adjustment parameter in the labour demand equation suggests that the long-run Allen own elasticity of capital is $-2.67 = \left(\frac{-0.32}{0.12}\right)$, and that of energy is -5.17. In addition, the long-run (Allen-Uzawa) cross-price elasticity of capital to labour is -0.25 and that of energy and labour, based on the more realistic Morishima, is -5.17. From the results above, policies that reduce labour intensity and increase capital intensity will contribute to lower energy use in the Malawi economy. As energy-efficient capital replaces existing physical capital, lower energy intensities would be realized per unit of output produced. However, such a policy is likely to impact negatively on labour employment since energy and labour are Morishima complements whereas capital and labour are Morishima substitutes.

Although labour effects can be inferred from estimates of substitution elasticities, the results from the aggregate regressions above only partially explain the link between interfuel substitution and the final composition of the energy aggregate. In section 5.3 we showed that there were differences in sectoral reaction to changes in relative prices of fuels. The implication of that result and the discussion above is that both economic and environmental outcomes can be influenced by manipulating the composition of the energy aggregate through prices. In the next section, we explore the possibility of reducing energy-related emissions and deforestation with energy taxes and subsidies and estimate, with several caveats, the resulting changes in emissions and fuelwood extraction.

5.5 Estimates of carbon emissions and policy simulations

Actual demand data for fuels and emission coefficients from IEA (2003) were used to calculate carbon emissions by sector and by fuel over time. Industrial use of coal is the largest source of carbon emission despite the fact that it was used by only three sectors. This result reflects the intensity of use of coal in the three sectors compared to the use of other fuels by all other sectors. The only time carbon emissions from fuelwood combustion were above oil related emissions was between 2001 and 2002 (figure 1) when Malawi had frequent power outages due to technical problems caused by floods and siltation at ESCOM main power generating station on Shire River.

Figure 2: Annual carbon emissions from industrial use of oil, coal and fuelwood



The activity of manufacturing of soaps, detergents and toiletries is a key sector as it accounts for 66.8 percent of carbon emissions from coal. The sector that distils spirits, and manufactures malt liquor and soft drinks is also an important activity as it accounts for 33.2 percent of the carbon from coal and 30 percent of oil related carbon emissions. The growing of tea and manufacturing of "tea and other products" are key sectors for deforestation as they account for 67.6 percent of fuelwood demand by production activities and about 8 percent of oil related carbon emissions. Tobacco and sugar growing, and the manufacturing of sugar are equally important for deforestation as together account for 27.4 percent of fuelwood demand by production activities.

Using these statistics and the Morishima elasticities estimated at the energy aggregation stage, two environmental policy implications can be drawn. First, since hydroelectricity and fuelwood are substitutes, deforestation associated with industrial fuelwood use could be reduced if the price of fuelwood is raised relative to the price of hydroelectricity or investing in more hydropower. Second, a large proportion of energy-related greenhouse gas emission reductions could be achieved by raising the prices of coal and of oil relative to the price of hydroelectricity, respectively. Since the Morishima elasticity is higher for oil than for coal, one could expect more greenhouse gas emission reductions to be achieved by slightly raising the price of oil to promote substitution towards hydroelectricity. This however will lead to larger increases in fuelwood use and hence more deforestation. On the other hand, to reduce fuelwood use and deforestation the highest potential substitution is in coal. However, more coal implies more emissions since coal has higher carbon content than any other fossil fuel.

In order to clarify the suggestions above, two environmental simulations were conducted in MS Excel Solver using the regression results and actual elasticity estimates. The first simulation was aimed at minimizing emissions from fuelwood, hence indirectly minimizing the contribution of industries to deforestation. The reasoning is that for every ton of carbon abated from fuelwood combustion, at least two tons of fuelwood biomass could be conserved (Girard, 2005). The policy scenario is one where a subsidy on hydroelectricity is envisaged within a range of 0 to12.5 percent, while ad valorem tax on fuelwood is expected to range from zero to 35percent. The subsidy of 12.5 percent on hydroelectricity is half the maximum subsidy envisaged under the rural electrification project while the maximum tax rate is set at 35 percent to coincide with the maximum income tax rate in Malawi[8].

The starting values for MS Excel Solver were 5 percent subsidy on hydroelectricity, 2 percent tax on oil, 5 percent tax on fuelwood and 3 percent tax on coal. At these fiscal values, a total of 1.67 megatons of carbon from fuelwood combustion would have been averted over the projection period (1998 to 2004). This translates to 3.34 megatons of biomass that could have been maintained as standing forest stock. The solver solution is a total abatement of 16.25 megatons of carbon or equivalently 32.5 megatons of biomass maintained as standing forest stock. This however is achieved only after implementing a 12.5 percent subsidy on hydroelectricity, a 35 percent tax on coal but zero tax rating on oil and fuelwood.

The second simulation was aimed at reducing total energy-related carbon emissions. The same starting values as above were used in MS Excel Solver. At these fiscal values, an additional 0.2 megatons of carbon would have been emitted from coal while 0.68 megatons would have been abated from oil, representing a total emission reduction of 22.55 megatons of carbon after factoring in abatement from fuelwood. The solver solution is a total abatement of 19.35 megatons of carbon consisting of 61.6 percent from fuelwood, 36.4 percent from oil and 2 percent from coal. These reductions in emissions are achieved only after implementing

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[8] This was reduced from 35% to 30% during the 2006/2007 Financial Year (GoM, 2006).

a 12.5 percent subsidy on hydroelectricity and levies of 35 percent tax on fuelwood and coal, respectively. The price of oil is however left at benchmark value.

These simulation results have several implications for environmental policy. First, if the focus of environmental or energy policy is conservation of biomass in forests, the highest rate of conservation could be achieved by levying a tax on coal while subsidizing hydroelectricity. However, no tax on fuelwood is required to achieve a maximum reduction in fuelwood use in industry. This result is consistent with Morishima elasticities estimated above since a subsidy on hydroelectricity and zero tax on fuelwood make hydroelectricity relatively cheaper than fuelwood. Second, if environmental or energy policy is aimed at reducing total carbon emissions, the greatest gain would come from reducing fuelwood use albeit at a maximum tax rate of 35 percent for fuelwood and coal, respectively, and a maximum subsidy of 12.5 percent for hydroelectricity.

5.6 Summary and conclusions

The chapter estimated interfuel substitution elasticities in the energy aggregate and also capital, labour and energy substitution elasticities for Malawian production sectors. The rates of dynamic adjustment in demand for labour and energy were presented in addition to potential environmental gains from abatement of energy-related carbon emissions in industry.

Several insights were drawn from the main findings of the chapter. One of the results was that the structure of relative demand for oil and fuelwood were relatively flexible implying that oil and fuelwood users have high potential for substituting other fuels under energy policy constraints. Coal users on the other hand have limited substitution alternatives although fuelwood emerged as a key substitute. Thus, coal users are unlikely to change their energy mix over time but would respond to relative fuel price changes. This implies that the potential for reducing emissions from coal is limited first by technology and second, by the environmental tradeoffs of increasing fuelwood use and the resulting deforestation. Hence, coal users would have the highest tax incidence when the thrust of environmental policy is to maintain biomass in standing forests. Coal and fuelwood users would also face the highest tax rates when environmental policy focuses on abating total energy-related carbon emissions.

Another finding was that Morishima interfuel elasticities and dynamic demand adjustment rates vary considerably across sectors. This has important implications for policy efficacy in that the sectors with high dynamic adjustment rates face lower transition costs (high benefits) as environmental taxes (subsidies) are imposed on various fuels. In addition, labour and energy employment impacts of environmental taxation would be lower for sectors with high adjustment rates. Therefore, to minimize the distributional impacts of energy taxes, the best option would be to reduce fuelwood use in industry by levying taxes on coal while subsidizing hydroelectricity. From fuel demand data, the tax burden would be heavily borne by the producers of soaps, detergents and toiletries and distilled spirits, malt liquor and soft drinks. On the other hand, when carbon taxes are implemented with the view to reducing total emissions, the growing of sugar, tea and tobacco and the manufacturing of tea and other products would bear the greatest burden. Since tobacco, tea and sugar are main export commodities accounting for over 80 percent of export earnings (FAO, 2003) the economic cost of carbon abatement may outweigh the environmental benefits.

Given the tradeoffs between increasing emissions and worsening deforestation, there is need to quantify the total economic costs of policies that aim at shifting energy mix from carbon-intensive fuels and biomass sources to hydroelectricity. The environmental costs of deforestation may be higher than the cost of additional carbon emissions. According to GoM (1994), the social cost of deforestation was US$55 million (2.7 percent of GDP) estimated by the replacement values of wood harvested above the sustainable yield and by reduced crop yield as a result of increased incidence of soil erosion. This estimate is rather conservative as other costs such as sedimentation of main rivers and their impacts are not included.

The results also suggest that policies that reduce labour intensity and increase capital intensity will lower energy use. However, since labour and energy are Morishima complements while capital and labour are substitutes, investing in energy saving capital equipment may increase unemployment over time. The dynamic adjustment parameters also showed that energy-capital ratios are adjusted at a faster rate than labour-capital ratios, implying therefore that unemployment costs may take hold within a short period. As a consequence, the long-run environmental gains from energy saving investments in capital could be lower than economic welfare losses resulting from unemployment.

Thus, to evaluate the net effect of shifting demand from fuelwood and fossil fuels (oil and coal) to hydroelectricity, there may be need to evaluate multiple objectives using either multi-criteria programming or CGE modelling to evaluate policies that give double or triple dividends in terms of smaller reductions in economic growth, lower emission and less deforestation. One objective could be investing in energy-efficient capital as a strategy for improving both energy efficiency and environmental quality in Malawian industrial sector. Although the econometric results suggest negative impacts on employment from capital-labour and energy-labour substitutions, it is conceivable that labour employment impacts may be dampened by growth elsewhere in the economy, especially in agriculture and mining. This proposition could be validated using a CGE model.