Deterministic MARKAL Elastic Demand

MARKAL (acronym for MARKet ALlocation) is a model generator that allows model developers to generate region-specific energy system models to analyse the tensions trade-offs between the energy-economic-environment and technology nexus. MARKAL is a widely-applied bottom-up, dynamic, linear programming (LP) optimisation model. UK MARKAL portrays the entire UK energy system, and in its elastic demand formulation maximises welfare (via the sum of producer and consumer surplus).

MARKAL portrays the entire energy system from imports and domestic production of fuel resources, through fuel processing and supply, explicit representation of infrastructures, conversion of fuels to secondary energy carriers (including electricity, heat and hydrogen (H₂)), end-use technologies and energy service demands of the entire economy. As a perfect foresight partial equilibrium optimization model, MARKAL minimizes discounted total system cost by considering the investment and operation levels of all the interconnected system elements. The inclusion of a range of policies and physical constraints, the implementation of all taxes and subsidies, and calibration of the model to base-year (2000) capital stocks and flows of energy, enables the evolution of the energy system under different scenarios to be plausibly represented. The UK MARKAL model hence provides a systematic exploration of least-cost configurations to meet demands for energy services. These are derived from standard UK forecasts on a subsectoral level (Anandarajah et al., 2009). Generally these sources entail a projection of low energy growth, with saturation effects in key sectors. Other key input parameters are detailed in section 3 and include resource supply curves and dynamically evolving technology costs.

MARKAL optimises (minimises) the total energy system cost by choosing the investment and operation levels of all the interconnected system elements. The participants of this system are assumed to have perfect inter-temporal knowledge of future policy and economic developments. Hence, under a range of input assumptions, which are key to the model outputs, MARKAL delivers an economy-wide solution of cost-optimal energy market development. Substantial efforts have been made in respect of the transparency and completeness of the model structure and assumptions, including through a range of stakeholder events (for example Strachan et al., 2007b), expert peer review, and publication of the model documentation (Kannan et al., 2007).

A major development of the UK MARKAL model for the UKERC Energy 2050 project (Anandarajah et al., 2009) was the implementation of an elastic demand version (MED) to account for the response of energy service demands to prices. In MED, exogenously defined energy service demands are replaced with demand curves (actually implemented in a series of small steps). Following calibration to a reference case that exactly matches the standard MARKAL reference case, MED now has the option of increasing or decreasing demands as final energy costs fall and rise respectively. Thus demand responses combine with supply responses in an alternate scenario (e.g. one with a CO₂ constraint). In MED, demand functions are defined which determine how each energy service demand varies as a function of the market price of that energy service. Hence, each demand has constant own-price elasticity (E) in a given period. The demand function is assumed to have the following functional form:

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Q = Q_0 \times (1 + E \times (P - P_0))
\]

Where:

\(Q\) is a demand for some energy service;

\(Q_0\) is the demand in the reference case;
is the marginal price of each energy service demand;

is the marginal price of each energy service demand in the reference case;

is the (negative) own-price elasticity of the demand.

A combination of the proportional change in prices and the elasticity parameter determines when the energy service demand changes by the step amount. Note that changes in energy service demand also depend on the availability and costs of technological conservation, efficiency and fuel switching options. The price elasticities used in this analysis (ranging from 0.25 to 0.61) are long-run elasticities (due to the MED model’s 5 year time periods and perfect foresight assumptions), and are derived from the literature of long-term energy modelling (see Anandarajah et al, 2009).

Now the MED objective function maximises both producer surplus (PS) and consumer surplus (CS). This is affected by annualized investment costs; resource import, export and domestic production costs; taxes, subsidies, emissions costs; and fuel and infrastructure costs as before in the standard model. However in addition the MED model accounts for welfare losses from reduced demands - i.e. if consumers give up some energy services that they would otherwise have used if prices were lower, there is a loss in utility to them which needs to be accounted for. Note that the MED model actually calculates the change in area under the shifted demand curve. The sum of consumer and producer surplus (economic surplus) is considered a valid metric of social welfare in microeconomic literature, giving a strong theoretical basis to the equilibrium computed by MARKAL.

Scenarios run using MARKAL Elastic Demand are deterministic. That is, only one result is obtained for any one set of inputs parameters.