ENERGY MODELLING IN A GENERAL EQUILIBRIUM FRAMEWORK WITH ALTERNATIVE PRODUCTION SPECIFICATIONS

Mohammad Jaforullah
M.A. (Rajshahi), M.Ec. (New England)

A Dissertation
Submitted to the Faculty of Economics,
The University of Adelaide,
in Candidacy for the Degree of Doctor of Philosophy,
December 1988.

TABLE OF CONTENTS

Chapter

Appendix

LIST OF TABLES

TABLE

TABLE

TABLE

LIST OF FIGURES

FIGURE

ABSTRACT

This study investigates the suitability of the ORANI model for simulating the effect of the energy sector on the economy. Most recent large-scale energy models recognise the role of substitution between various fuels as well as between energy and other factors of production. But ORANI lacks such a feature. ORANI only allows substitution between labour and capital; it assumes fixed input-output relationships for intermediate inputs including fuels. To ascertain the importance of allowing interfuel as well as interfactor substitutions in production, three 9-sector general equilibrium models with alternative production specifications are constructed and applied to simulate the effects on the Australian economy of a 10 percent increase in the price of imported oil.

The first model, called CES-FC model, is similar to the ORANI model in specifying technologies for current production. In this model, substitution is allowed only between labour and capital but intermediate inputs including fuels are assumed to be used in fixed proportions to output. The second model, called CD model, employs Cobb-Douglas production specifications to describe the technologies of production. This model, in contrast to CES-FC, allows substitutions between energy and other factors as well as between intermediate inputs including fuels. The third model, called TL model, employs translog cost functions to describe the production technologies. This model, like CD, allows substitutions between energy and other factors as well as between intermediate inputs including fuels. But, unlike CD, where the elasticity of substitution between inputs is constant and unity, the elasticity of substitution varies across input pairs and an input can be either a substitute or complement for another.

Apart from these differences, the models are the same. Capital goods production, foreign trade, and preferences of the household and government sectors for goods and services are modelled in an identical way.

Simulating the effects of the afore-mentioned oil price shock on the endogenous variables suggests that these effects are sensitive to variations in production specifications. Although macroeconomic effects are found to be moderately sensitive to these variations, the sensitivity of sectoral effects is found to be substantial. It is therefore concluded that the ORANI model should be modified to allow interfactor as well as interfuel substitutions in production if it is to be useful in analysing the effects of developments in the energy sector on the economy.

RESEARCH DECLARATION

I solemnly declare that this thesis contains no material which has been accepted for the award of any other degree or diploma in any University and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except when due reference is made in the text of this thesis.

I further declare that I have no objection to the thesis being made available for photocopying and loan, if accepted for the award of the degree.

Signature of the Candidate

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Professor Peter B. Dixon, the Director of the Institute of Applied Economic and Social Research, of the University of Melbourne. Peter took over the supervision at a critical time when the research project was floundering. It is Peter's teaching, positive supervision and guidance, support and encouragement which helped me complete the research project in time. Peter had been very generous in giving of his valuable time throughout his supervision of the work. I am also greatly indebted to my other two supervisors, Dr. Brian L. Bentick and Dr. Trevor J. Mules of the University of Adelaide, who made constructive comments on the draft of the thesis and, in particular, corrected my English which is, obviously, less than perfect.

I would also like to thank Professor Alan Powell, the director of the IMPACT Project, for his valuable comments on a seminar paper (related to the present work) presented at the IMPACT Project Centre. I have also benefited from informal discussion with Professor Takayama over a conference paper presented out of this work at a Economics Postgraduate Research Conference at the University of Western Australia. So thanks to him too.

I would like to extend my thanks to two institutions, the University of Adelaide for providing me with necessary financial assistance for the study and the University of Rajshahi for granting me study leave.

GEMPACK software system for solving large economic models, developed at the IMPACT Project, has been used in solving the models of the present study. I would like to thank Mr. George Codsi for spending his time in explaining this software system to me. Thanks are also due to Mr. George Cookson and Ms. Melissa Gibbs for their help in writing computer programs required for processing data.

I would like to extend special thanks to Mr. and Mrs. Duluk for the help and friendly company which they have extended to me and my family during our stay in Adelaide.

Finally, very special thanks go to my wife Rosy for letting me devote maximum time to my study. She took full responsibility for raising our daughters Mithun and twins, Mousoom and Munmun. She also provided much needed boost and encouragement in my hours of depression. Without her hardship, sacrifice, forebearance and above all moral support it would be very difficult for me to finish my research project in time.

While I gratefully acknowledge the help and co-operation I received from various sources, I alone bear responsibilty for the remaining errors and shortcomings.

Chapter 1

INTRODUCTION

The important role played by energy in the economies of all nations was emphasised by the disruptions to world oil markets which led to large price increases in 1973–74 and 1979–80. Energy has come on the agenda in most countries mainly because of the change in the supply situation of crude oil and gas brought forth by the OPEC embargo and the ensuing price increases in 1973–74 and 1979–80. Although the timing and the course of action decided upon by the OPEC countries caused particular problems of adjustment for the industrialised countries, the underlying fact is that global supplies of crude oil and gas are limited. Hence increased worldwide petroleum production combined with falling real prices characteristic of the period since 1950 could no longer continue.

Uncertainty in world oil supply and fear of further oil price shock led the governments of the United States, Japan and most western European countries to take various measures to reduce their dependence on oil imports. They implemented, with varying degrees of urgency, policies designed to encourage indigenous production and reduce overall energy consumption. They also started to direct, at varying rates, resources to research on longer term energy problems.

The oil price shock of 1973–74 did not directly affect Australia. As Vincent *et al.* (1979, p.5) write,

> "Australian consumers of oil products were reasonably well insulated from the direct effects of this price hike because of our relatively large degree of self sufficiency in oil and the maintenance of fixed prices for domestic oil over this period."

At that time the country was more than 60 percent self-sufficient in oil and totally self-sufficient in black coal, lignite (brown coal), natural gas and renewables such as wood, hydro-power and bagasse. It was also exporting 28 megatonnes of black coal per year. 'The price of Australian crude oil had been fixed at $A2.06/bbl—just above import parity—in September 1970, and this remained unchanged for five years (at first to the benefit of producers, but after the world price rise to the benefit of consumers)' (Marks 1986, p.47). However, as a small trading economy Australia soon imported the direct effects of the oil price rise—inflation and the indirect one—rising unemployment resulting from world anti-inflation policies.

Although the 1973–74 oil price shock did not affect Australia directly, it did make the Government aware of the energy problems and the danger of depending on other countries for oil imports. To reduce dependence on foreign supply of oil and to encourage indigenous production the Commonwealth Government reviewed its energy policy, particularly its pricing policy of domestic crude oil. The price of domestic crude has been subject to Commonwealth Government control since production commenced in the mid-1960's. Up until September 1975, the pricing arrangements were such that the price of oil from a particular oil field was set equal to the world parity price existing at the time that field commenced production with appropriate allowances being made for quality differential. In some cases, this price also included an incentive loading. In September 1975, following the upheavals in the world oil market, a new pricing system was introduced. In this system, a distinction was made between oil from already discovered fields and oil from new discoveries. Oil from new discoveries was to be priced at import parity less an excise of $A2.00 per barrel. Oil from old discoveries was priced according to cost of production in each field rather than being set at import parity. Although a satisfactory return to various producers was ensured under this arrangement, the resulting prices were considerably below world price levels existing at that time.

In its report on crude oil pricing, the Industries Assistance Commission (1976) recommended that, for long-run efficient resource allocation, free market pricing was preferable to the existing system of price control on production from fields discovered before September 1975. Acting on this recommendation, the Government introduced a new pricing scheme in 1977 for oil discovered before September 1975. An annually increasing proportion of crude oil from each field discovered before 14^{th} September 1975 was priced at current import parity and the remainder sold at the fixed price for each field which prevailed on 16^{th} August 1977. From 10 percent in 1978 this proportion was to rise to 50 percent in 1981. A year later, in the August 1978 budget, the Government abandoned the stepwise approach and raised the price to refiners of all Australian crude to the import parity level.

The pricing of Australian crude oil at import parity levels had been fundamental to Australian energy policy until the Government deregulated the crude oil market in January, 1988. Import parity pricing was considered essential to encourage:

— conservation of liquid fuels;
— exploration and development;
— substitution by more plentiful gaseous and solid fuels; and
— the economic development of liquid fuel substitutes.

The oil price shock of 1973–74 has not only made governments and policy makers more concerned about energy problems but also made economists and researchers more interested in them. A great deal of economic research has been conducted since then leading to important advances in methodology and empirical findings. The majority of these studies have been conducted in a partial equilibrium framework. Some of these studies concentrate on specific types of energy with the goal of determining how supplies of these fuels might be augmented at minimal cost. Other studies focus on the demand for energy; a main concern here has been to assess the extent to which demand for energy can adjust to changes in energy prices. There are some studies which have been conducted in a general equilibrium framework. These studies address the broader questions of energy-economy interactions and the global impact of alternative energy policies.

Energy modelling has also been of considerable interest in Australia. The studies of Turnovsky, Folie and Ulph (1982), Donnelly (1982), Donnelly and Dragun (1984), Rushdi (1984) and Musgrove *et al.* (1983) reflect this interest. All of these studies, except those of Rushdi and Musgrove *et al.*, examine the demand for energy and interfuel substitution possibilities in different sectors of Australian economy. Rushdi studied the supply and demand of electricity in South Australia. The study of Musgrove *et al.* is wider in scope than others. Using a system analysis model called MARKAL they examined the evolution of the entire Australian energy system from 1975-2020. Their model has been specifically designed to examine interfuel substitution possibilities in satisfying given energy demands.

However, none of the models noted above has been constructed in a general equilibrium framework. In examining energy demand and possibilities of interfuel substitution, the demand models assume the prices of different types of energy and other independent variables to be exogenous to the model. But price is affected by demand and supply. Any exogenous shift in the demand or supply curve of a particular fuel will lead to a new price which will in turn affect the demand and supply curves of other fuels and of nonenergy products. This will generate feedback effects in the market for the fuel which underwent the initial demand or supply shift. Thus there will be further changes in its price and further repercussions in the rest of the economy and further feedbacks. The energy system model of Musgrove *et al.*, although it allows more variables to be determined endogenously, still falls short of being called a general equilibrium model. This is because it fails to allow the energy system and the rest of the economy to interact with each other. Any development in the energy sector such as the introduction of a new energy technology can affect the rest of the economy which, in turn, can affect the energy sector. But the MARKAL model does not consider such feedback effects in analysing the effects of energy policies.

However, a model designed to evaluate the effects of energy policies on the economy should incorporate all such interactions. As Borges and Goulder (1984, p.319) rightly remark,

> "The nature of energy problems strongly invites methodologies based on a general equilibrium approach. The interactions between supply and demand, both within the energy markets as well as between the energy sector and the economy as a whole, are far too important to be neglected."

Energy models based on a general equilibrium approach have many advantages over other models. These models, being highly disaggregated, can capture the simultaneous interactions among all product and factor markets. Therefore, these models are capable of evaluating the energy feedback—the effects of changing conditions in the energy sectors on other sectors and on labour and capital markets. In contrast, partial equilibrium models often use exogenous values for some macroeconomic variables such as the wage rate, the rental rate of capital services, etc. to derive key magnitudes for the energy sectors. Thus these models fail to capture the feedback effect of energy on these variables. Some studies indicate that the energy feedback is important enough to justify the careful modelling of interactions between the energy markets and the rest of the economy (Energy Modeling Forum 1977).

Highly disaggregated general equilibrium models can be very useful in exploring the effects of changing energy situations on economic growth. By incorporating interactions among all markets in an economy, they provide explicit connections between energy availability and commodity prices, between these prices and savings-investment decisions, and between these decisions and the growth of the economy.

Another important advantage of multisector general equilibrium models in energy modelling is that they reveal the compositional effects of changes in energy conditions or energy situations. Small aggregate effects often hide much more substantial consequences at the sectoral level. 'Rybczinski's (*sic*) theorem shows that on the supply side, the impact of a shock on one sector may even have a different sign from the impact on another sector' (Borges and Goulder 1984, p. 336). Highly aggregated models cannot bring out these compositional effects but the disaggregated general equilibrium models can.

Unfortunately, no general equilibrium model of energy has been constructed for Australia. However, there is a large-scale, general purpose, general equilibrium model of the Australian economy called ORANI (see Dixon *et al.* 1982) which has great potential for energy policy analysis. However, ORANI requires some modification before it can be applied to the effects of energy policies. In specifying the production technology of various sectors engaged in the production of consumption and capital goods, ORANI rules out interfuel substitution as well substitution among material inputs. This restrictive assumption means that sectoral input-output coefficients for intermediate inputs are constant. Thus in ORANI a strong linkage has been assumed between energy consumption and economic growth. In practice, such a tight linkage between energy consumption and economic growth may not be found. An increase in the price of a particular type of energy will imply changes in relative prices for factors/inputs of production and for consumer goods. The overall impact of higher energy prices will be mediated through the substitution, by many firms and households, of high-priced energy and energy intensive goods with cheaper energy sources and less energy intensive technologies and commodities.

Thus before applying the ORANI model to energy policy analyses it should be modified to allow interfuel substitution and substitution between material inputs as well as substitution between energy, labour, capital and aggregate materials. Otherwise, it will provide biased results. Consider, for example, the case where the government imposes a tax on the production of petroleum products. This tax will affect the relative prices of petroleum and other fuels as well as the prices of other non-fuel commodities. An increase in the price of petroleum products following the imposition of a tax will cause the demand for that fuel to decrease. The extent of this reduction in demand and hence the effect on tax revenues will depend, among other factors, upon the ability of producers and/or consumers to switch from one fuel to another, as well as from fuels to non-fuel commodities. This implies that a study of the implications of a change in the petroleum products taxation structure for government revenue using the ORANI model could be biased unless it is true that the sectoral input-output coefficients for intermediate inputs are fixed. However, from theoretical as well as empirical points of view such an assumption is hard to accept. Using time-series data, some recent studies, for example Turnovsky, Folie and Ulph (1982), Truong (1985), etc., found significant elasticities of substitution between different fuels as well as between energy, capital, labour and aggregate materials in Australian manufacturing industry.

Truong *et al.* (1985) demonstrated how interfuel and interfactor substitutions can be incorporated into the ORANI model through the 'technical change' coefficients of the model. A practical illustration of this procedure has been provided by Truong (1986) in respect of allowing interfuel substitution in ORANI. However, the approach suggested by Truong *et al.* (1985) for incorporating interfuel and interfactor substitutions into the ORANI model is one of many ways through which ORANI could be modified for energy policy applications. In the present study, a rather direct and straightforward approach is suggested for incorporating interfuel and interfactor substitutions into the ORANI model. This approach involves modification of the sectoral production functions incorporated in ORANI rather than the technical change coefficients.

Three different computable general equilibrium (CGE) models have been formulated based on three different types of production function employed to describe technologies of various sectors. In the first model, the production function is of the same type as is employed in the ORANI model. While substitution between primary factors—capital and labour—has been allowed in this version, substitutions among fuels, among material inputs and among energy, aggregate materials and aggregate primary factor are ruled out by assuming fixed sectoral input-output coefficients in respect of these inputs. It is further assumed that the elasticity of substitution between capital and labour is 0.5.

In the second model, both interfuel and interfactor substitutions are allowed. Thus in response to changes in the relative prices of inputs, the model allows substitution among various fuels, among various material inputs and among capital, labour, energy and aggregate materials. However, the elasticity of substitution has been restricted to unity by assuming Cobb-Douglas type of production functions. Moreover, complementarity between any two inputs has been ruled out.

In the third model, interfuel and interfactor substitutions are allowed, as in the second model. However, the production functions employed in this version are more flexible than in the second version. The elasticity of substitution is not restricted to any particular value. In fact, the elasticity of substitution can vary among input pairs. Moreover, any pair of inputs can be complementary to each other. Such flexibility in production has been modelled by using translog cost functions[1] to specify the production possibility set of the producers.

Apart from these differences among the three models regarding specification of technologies, the models are the same. They use the same types of function to describe sectoral technologies for capital formation, household and government preferences for goods and services, to represent foreigners' demand for exports and to model product differentiation between domestic and foreign commodities. Moreover, they include the same number and type of miscellaneous macroeconomic equations as well.

These three versions of the CGE model are formulated in order to examine the sensitivity of the results to variation of production structures. All three CGE models described above have been used to simulate a 10 percent increase in the world price of imported crude oil and to determine the impact of this price shock on aggregate employment and the balance of payments of Australia—two main areas of concern for the Government—as well as on sectoral outputs, employment and output prices. The differences between the models regarding projections of changes in these variables have been noted. An attempt has also been made to identify the factors which cause different models to make different projections for changes in variables of interest.

In brief, the objectives of the present study are:

(i) to suggest an approach for incorporating interfuel and interfactor substitution possibilities into the ORANI model;

[1]The translog cost function was introduced by Christensen, Jorgenson and Lau (1971).

(ii) to demonstrate how important it is to allow these substitution possibilities in CGE energy models; and

(iii) to explain why CGE models with different production structures will lead to different projections for changes in the endogenous variables.

Organisation of the Thesis

The thesis is organised into five chapters. In Chapter 2, some selected energy models are reviewed with particular attention given to the methodologies employed in these models. Merits and limitations of these models are also pointed out. Chapter 3 describes the theoretical structures of the energy models employed in the present study. At the end of this chapter, the methodologies of these models are compared with those discussed in Chapter 2. In Chapter 4, a description is provided of the data base which has been used to specify the models numerically. In Chapter 5, the models are used to simulate the effects of a 10 percent increase in the world price of imported crude oil on the Australian economy. The results obtained from the models are reported and explained in this chapter. In the last chapter, Chapter 6, some conclusions are drawn from the present study. Limitations of the models have been considered and directions for further research have been outlined.

Chapter 2

REVIEW OF SOME ENERGY MODELS

Since the early 1970's and particularly since the dramatic increase in the world price of oil in 1973, energy policy has received much greater attention in most countries than previously. Energy models have come to play an important role in the analysis of energy policy. Considerable intellectual efforts have been devoted to the development of energy models, some of which have been influential in energy policy making, during the years since the Arab oil embargo of 1973. The result has been literally hundreds of studies of energy prospects of different countries of the world. It is intended in this chapter to review a representative sample of the models that have been developed and applied to analysis of the energy prospects and to the development of forecasts for planning purposes. This review of energy models is not exhaustive[1], but rather is intended to illustrate the structure of recent and current efforts by energy model builders to provide constructive tools for energy forecasting, planning and policy analysis. The selection of models is somewhat arbitrary and does not imply any superior capabilities in comparison with other models of the same generic class that are not discussed. The selected energy models

[1]Other survey papers of energy models are Edelman (1977–78), Manne, Richels and Weyant (1979), Brock and Nesbitt (1977), Charles River Associates (1978), Hitch (1977), Hoffman and Wood (1976), Searl (1973), Ziemba and Schwartz (1980), Macrakis (1974), etc.

have been classified into five major groups according to the scope of analysis. These groups are: (1) energy demand or supply models; (2) energy industry or market models; (3) energy system models; (4) general equilibrium models for energy; and (5) integrated energy-economic models.

2.1 Energy Demand or Supply Models

The models in this category focus either on the demand for or supply of a particular type of energy. They are very limited in scope. The demand models have been used mainly to provide an analysis of the determinants of demand for a particular type of energy in a particular use and/or to forecast demand with given estimates of the variables that are exogenous to the model, including price and other variables measuring the market size for the energy inputs (e.g., population, GNP, income, etc.). Some energy demand models, however, have been used to serve somewhat broader objectives such as examination of substitution possibilities among various types of fuel as well as among energy, labour, capital and aggregate materials in production. The supply models have been used mainly to determine how supplies of specific fuels can be augmented at minimal cost.

The energy demand models used so far differ from one another with respect to the type and nature of the model employed, the type of the data used, the consumer group considered and the type of energy considered.[2] However, these models have one thing in common, that is, almost all of them have employed econometric techniques to analyse the demand for energy.

There have been several studies of demand for different types of energy in Australia. One of these studies is Donnelly (1982). The objective of the study was to examine the responsiveness of Australian consumers to changes in the

[2] For a survey of a cross-section of energy demand models see Taylor (1975, 1977). Nordhaus (1977) also contains a number of energy demand studies in detail.

price of petrol and personal income. A dynamic model was specified on the assumption that consumers lag in adjusting their actual levels of consumption to desired levels in response to changes in the price of petrol. The model was estimated by using quarterly data on Australian states for the period from the September quarter of 1958 through the June quarter of 1981. An iterative Zellner (1962) seemingly unrelated regression procedure was used to estimate the parameters of the model on the basis of the pooled time-series, cross-section data. The study suggested that per capita petrol demand was not income elastic as reported in other studies and supported the hypothesis that demand was price inelastic. Moreover, the study found that consumers in different states responded differently to price and income shocks implying that specification of a single national demand function for petrol might be misleading.

Turnovsky, Folie and Ulph (1982) focussed on the possibilities for substitution among energy, capital, labour and materials in Australian manufacturing industry. They examined substitution possibilities among various types of energy. A translog cost function was specified and estimated using time-series data for four inputs—capital, labour, energy and materials—and an energy submodel was estimated for solid fuels, oil, electricity and gas. The study covered the period 1946–1974. It was found that capital and energy were substitutes and labour and energy were complements. The factor price elasticities were found to be quite significant. The authors concluded that rising energy prices would induce significant shifts in both the mix of fuel inputs and the level of aggregate energy utilisation.

Another model was developed by Truong (1985) to investigate interfactor and interfuel substitution possibilities in New South Wales (NSW) manufacturing industry. The model used in this study is the Rotterdam specification of the differential approach to demand system analysis.[3] The study covered

[3]See Theil (1980), Clements and Johnson (1983), and Clements and Nguyen (1980) for details about the theoretical derivation of this type of model.

the period 1968–1980. In contrast to the study of Turnovsky, Folie and Ulph (1982), it was found that capital and energy were complements while energy and labour were substitutes in NSW manufacturing industry. Overall, the author found both energy and nonenergy inputs into the NSW manufacturing industry to be own- and cross-price responsive as well as production responsive.

Duncan and Binswanger (1976) investigated substitution possibilities between various types of energy in the disaggregated manufacturing industries of Australia. This is in contrast to the studies of Turnovsky, Folie and Ulph, and Truong who studied aggregate Australian manufacturing industry and aggregate NSW manufacturing industry respectively. Duncan and Binswanger disaggregated Australian manufacturing industry into 16 separate industries. The framework of the analysis is provided by a translog cost function. The study covered the time period 1948–1966. The authors found the demand for electricity inelastic in all industries whereas the demand elasticity for fuel oil was found to vary across industries. Moreover, it was found that fuel oil and coal might be substitutes while fuel oil and electricity might be complements in these industries.

2.2 Energy Industry or Market Models

Models for an energy industry or market encompass both the supply and demand for a specific or related set of energy products. Such models are very useful in providing a consistent framework for planning industrial expansion and studying the effects of regulatory policy on the industry. Much of the modelling work in this area involves the integration of process analysis and econometric techniques to exploit their strength in representing supply and demand relationships respectively.

One of the energy industry or market models is that of MacAvoy and Pindyck (1975). This is an econometric policy simulation model of the U.S.

natural gas industry. The model focuses on the supply of reserve additions and the demand for gas by pipeline companies for sale in wholesale markets. The supply of gas reserve additions in any period is the sum of new reserves discovered, and extensions and additions to reserves. New reserves discovered in a producing region are the product of wells drilled, the proportion of successful wells, and the average size of find. New discoveries of both gas and oil are estimated since they are joint products in exploration and development activities.

An important feature of this model is that the drilling projects initiated depend on driller choice between the intensive and extensive margins. Drilling choice is modelled as a function of economic costs and producer risk aversion. The average success ratio for projects initiated is a function of this choice. The size of discovery incorporates the effects of geological depletion by depending negatively on the cumulative number of wells drilled, since better prospects are likely to be drilled first, and positively on higher gas prices, since this shifts the producer's drilling portfolio toward the extensive margin. The model also estimates changes in reserves due to extensions and revisions thereby providing a complete reserve-accounting framework.

The model determines the production of gas out of reserves by assuming exogenous prices equal to marginal costs and then by relating marginal costs to actual reserve levels and production levels.

Demand for gas by industrial, residential and commercial customers depends on the wholesale price of gas, the prices of alternative fuels and market size measuring variables such as population, income and investment levels. The wholesale price of gas is a function of the wellhead price and a pipeline markup that depends on operating and capital costs, and the regulated profits of the pipeline companies. The wholesale markets are also defined on a regional basis. The flows of natural gas between producing and consuming regions are estimated by using a network model characterised by an input-output table of flow coefficients between each of the producing and consuming regions. The difference between the production flows and demand levels in the consuming regions is a measure of the excess demand for natural gas in each region.

This model has been used extensively to analyse the effect on the U.S. natural gas industry of federal regulation of the wellhead price of gas and permissible rates of return for pipeline companies purchasing and selling gas in interstate markets.

Another energy industry model has been developed by Baughman and Joskow (1974) for the U.S. electricity industry. The authors combined an engineering supply model and an econometric demand model with the link provided by an explicit model of the regulatory process through which the price of electricity is determined. The econometric demand model forecasts regionalised electricity demands by the industrial, residential and commercial sectors as functions of the prices of electricity and alternative fuels as well as various market size determining variables. The engineering supply model covers the engineering choices involved in operating and expanding an electric utility system. It is not an intertemporal optimisation model. Instead, capacity expansion decisions are based upon single-period minimisation of the levelised annual cost of meeting the electricity demands projected by exponentially weighted moving averages of previous periods. This expected demand projection will, of course, differ from the actual consumption in any given period. Adjustments in operating capacity due to differences between projected and actual demand are assumed to take place in future optimising decisions. The regulatory model simulates the process by which electricity prices are determined based on calculations of the rate base derived from inputs from the supply model and assumptions about the rate of return permitted by the regulatory agency, the rate of depreciation and the effective tax rate.

This model was constructed to analyse policy issues affecting electricity producers, consumers, regulators and equipment vendors. In 1976, the model was used to evaluate the future of the U.S. nuclear industry (Joskow and Baughman 1976). It was concluded that the industry and the Atomic Energy Commission were substantially overestimating nuclear power growth through the end of the 20th century. Serious questions were raised regarding the future financial viability of the nuclear equipment manufacturers.

Another interesting model which can be grouped with energy industry or market models is that of Kennedy (1974). This is an international, multi-commodity model of the world oil market. The model deals with crude oil production, transportation, refining and consumption of refinery products. Alternative values are assigned to the world price of oil on the assumption that OPEC will act so as to maximise its net economic return. The model includes crude oil supply functions and also demand functions for four refined products—gasoline, kerosene, distillate fuel and residual fuel—in each of the six regions considered in the model. Cross-price elasticities are assumed to be zero. Each of the supply and demand functions are assumed to be linear. A market equilibrium is then computed by solving a quadratic programming problem for maximum net economic benefits. The net economic benefit function is defined as the gross economic benefits (the areas under individual demand curves) minus the costs of interregional and refining activities. The model determines consumption of products, production of crude oil, equilibrium prices, refinery capital structure and refinery output by region as well as trade flows of crude oil.

The model provides a convenient framework for simulating governmental policy actions both within the Persian Gulf and by other regions considered in the model. However, according to Manne, Richels and Weyant (1979) Kennedy's model suffers from two major methodological limitations. Firstly, the model is static. As a result, it excludes intertemporal phenomena such as resource depletion and the dynamics of supply and demand responses to higher prices. Secondly, the model does not allow explicitly for competition between oil and alternative fuels.

2.3 Energy System Models

Energy system models are broader in scope than energy industry or market models. In contrast to the latter models, which focus on the supply and demand sides of a specific or related set of energy products, the energy system models focus on the analysis and modelling of the overall energy system. These models encompass demand and supply of all fuels and energy forms. This type of model was stimulated by the need to develop forecasts of total energy demand.

One of the energy system models is the Brookhaven Energy System Optimisation Model (BESOM). BESOM is a linear programming model developed by the Brookhaven National Laboratory for the quantitative evaluation of U.S. energy technologies and policies within a systems framework (see Hoffman (1973) and Cherniavsky (1974)). It 'is a static model that provides a "snapshot" of the energy system configuration at a single year in time, although it may also be applied in a sequential manner for the examination of a planning horizon' (Kydes 1980, p.112).

BESOM is structured around a Reference Energy System (RES) which provides a complete physical description of the energy flows and conversion efficiencies from extraction of primary energy sources through refining and various stages of conversion from one energy form to another and through transportation, distribution and storage of energy. It also provides complete description of the energy utilising technologies which are used to satisfy demands defined on a functional basis such as space heating, process heat, transportation and so on. A typical RES is depicted in Figure 2.1. Each link in this RES represents a physical process or a mix of physical processes for a given activity. Each successive step in the supply chain is integrated along with the end-use devices.

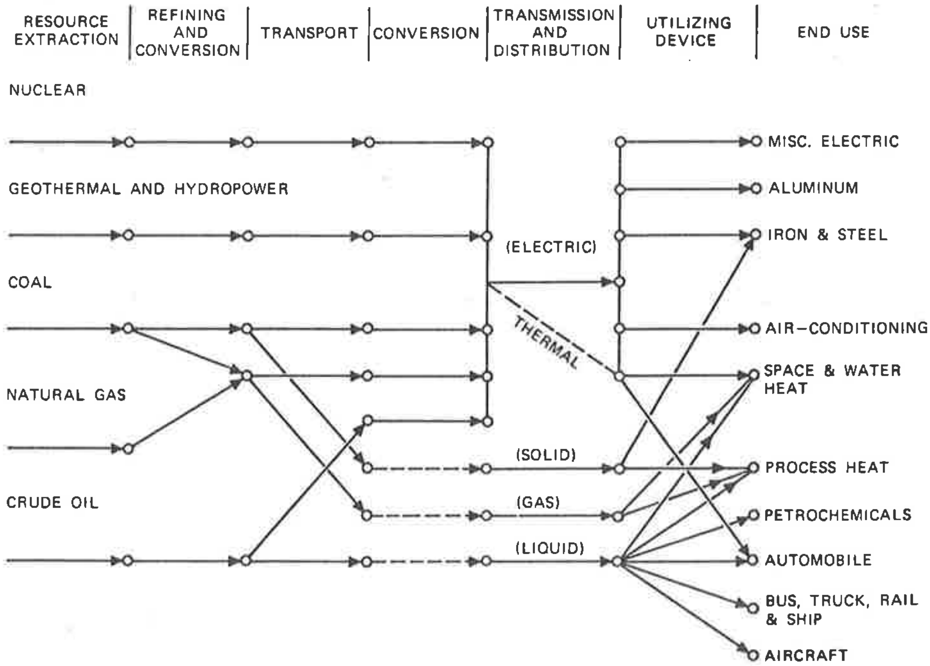

Figure 2.1: Reference Energy System (Source: Hoffman and Jorgenson (1977)).

BESOM is addressed to the problem of allocating energy supplies to energy demands so as to minimise the total system costs in a single target year subject to the demand and resource constraints. In BESOM, each energy supply-demand combination is associated with costs of extraction, refining and conversion, transportation and storage, and final utilisation. Costs per unit of operation of an energy conversion process include both capital costs and operating costs. The model includes constraints on the levels of energy conversion processes that assure that available energy supplies are not exceeded and that energy demands are met.

BESOM is designed to examine interfuel substitution in the context of constraints on the availability of competing resources and technologies and their associated costs. The model is particularly well suited to energy technology assessment and policy analysis since it emphasises technological, economic and environmental factors. Moreover, the model is flexible enough to lend itself to the investigation of alternative scenarios by minimising different objective functions such as oil imports, capital requirements, environmental effects, etc. in addition to total system cost.

BESOM has been used to study the competition among various types of fuels in specific end-uses, the feasible range of electrification of the energy system, etc. However, being a single period optimisation model, BESOM suffers from the limitation that it cannot analyse intertemporal phenomena such as resource depletion. Subsequently, a dynamic, time-phased linear programming model known as Dynamic Energy System Optimisation Model (DESOM) (see Cherniavsky, Juang and Abilock 1977) has been introduced by Brookhaven National Laboratory to overcome this inadequacy of BESOM. DESOM incorporates the same technical detail and constraints as BESOM, but treats plant expansion, exhaustible resources and capital requirements explicitly. Like its static counterpart, DESOM assumes future demands for energy services as given, and then determines the combination of energy resources and technologies to be used over time to meet those demands at minimum cost.

Another model which is closely related to DESOM, the dynamic version of BESOM, is Manne's (1976) Energy Technology Assessment (ETA) model. Like DESOM it provides a complete picture of the entire U.S. energy sector and permits energy conservation and interfuel substitution in response to changes in the relative prices of fuels.

ETA is a nonlinear programming model which maximises consumers' and producers' surplus, or equivalently, minimises costs of conservation, interfuel substitution and supply. This model has a seventy-five-year planning horizon (fifteen intervals, five years each) from 1970 to 2045. The demand side of ETA is based upon a hybrid of econometrics and of engineering process analysis. Energy demands are divided into two broad categories of secondary energy forms: electric and nonelectric. Unitary elasticity of substitution is assumed between electric and nonelectric energy. The demand curves are derived from the objective function by assuming that the U.S. economy maximises its welfare (the objective function) by allocating its expenditures optimally between energy and nonenergy items. Demand curves, so derived, are price responsive. They incorporate both own- and cross-price elasticities of demand for electric and nonelectric energy.

The supply side of ETA is handled through a conventional linear programming model. Several technologies are considered for producing electric energy. These are: coal-fired power plants, light water reactors, fast breeder reactors and an advanced electric technology (e.g., solar, fusion or an advanced breeder). Nonelectric energy (liquids and gases) are assumed to be supplied by oil, natural gas, coal- or shale-based synthetic fuels or hydrogen *via* electrolysis.

Each energy source has its own cost parameters and introduction date, but is interdependent with other components of the energy sector. For example, the amount of coal consumed in electric power plants can affect the marginal cost of production of coal which in turn can affect the cost of coal-based synthetic fuels for nonelectric energy.

The ETA model was solved for an approximate intertemporal market equilibrium by MINOS, a reduced gradient nonlinear optimisation algorithm developed by Murtag and Saunders (1977).

ETA has several advantages over DESOM. In DESOM, demand for energy is viewed as an exogenous datum and these demands are to be supplied at minimum cost. ETA improves upon this feature of process analysis models by making demands for energy price responsive. Moreover, unlike DESOM, ETA allows interdependence among various technologies. However ETA, like DESOM, fails to model the energy-economy interactions. In ETA, growth in GNP is the principal driving force for expansion of energy demands over time. But in this model GNP growth is projected on the basis of population, labour force and per capita productivity considerations. Total energy demands are then estimated by assuming that they depend on real GNP growth and energy prices. This approach, partial equilibrium in nature, does not allow for the prospect that rising energy costs and limited supplies will prevent the economy from achieving its full potential GNP growth rate, and that this in turn slows down future capital accumulation.

Energy system optimisation models have been of some interest in Australia and have been used to evaluate energy research, development and demonstration policies. One of the models used for energy system analysis in Australia is the MARKAL (MARKet ALlocation) model. MARKAL is the result of an intensive international co-operative efforts. Like all other system analysis models, it is also driven by exogenously specified energy demands. MARKAL, a dynamic linear programming model, is designed to analyse the evolution of a national energy supply/distribution systems over time. All supply availabilities, demand, technologies, etc. are assumed known for the entire time horizon. Given the set of energy demands, supplies of energy resources, characteristics of the energy extraction, conversion and utilisation technologies and some other constraints, the model chooses that mix of indigenous or imported fuels, conversion and demand technologies that minimises the total discounted system cost of installing and operating all technologies over the optimisation period.[4] An application of MARKAL to Australian energy system modelling can be found in Musgrove *et al.* (1983).

MARKAL provides an excellent tool to investigate the response of Australian energy system to a wide variety of situations. MARKAL can be used to study the effects of new technologies in meeting anticipated future energy demands, the relative attractiveness of new technologies, the sensitivity of the evolution of national energy system to efficiency improvements of technologies, the effects of long-range conservation practices on the energy sup-

[4]International Energy Agency (1980) provides an excellent description of MARKAL and its policy applications.

ply/demand distribution system, etc. However, although MARKAL is well capable of examining many issues relating to the energy system, it fails, like other process analysis models, to incorporate energy-economy interactions in the model. One important input to MARKAL is the set of energy services demands which are held fixed for a particular solution of the model. The conclusions reached by MARKAL thus crucially depend on the condition that energy demands remain constant. In fact, these demands do not remain constant. Any development in the energy sector such as introduction of a new technology, reduction in oil imports, etc. will have effects on the activities of nonenergy sectors as well as on the consumption patterns of final users of energy. As a result, demand for energy services will change. MARKAL as well as other process analysis models fail to accommodate such feedback effects.

2.4 General Equilibrium Models for Energy

While the objective in energy system models is to analyse and model the overall national energy system, the objective in general equlibrium models is to model the overall economy. Thus general equilibrium models are capable of examining the interactions between energy and nonenergy sectors as well as the impacts of various energy developments and policies on the economy including the energy system. In this sense the general equilibrium models for energy are broader in scope than the energy system models.

The interest in general equilibrium modelling in the energy area is relatively new. The first CGE model for evaluating energy policies was constructed by Hudson and Jorgenson (1974) for the U.S. economy. This model is, in fact, a combination of three models: (a) an inter-industry transactions model, (b) a consumer demand model and (d) a long-run macroeconomic model. The main innovation in this model is integration of a neo-classical model of producer behaviour with a standard input-output structure. This feature of the model allowed Hudson and Jorgenson to examine substitutability/complementarity between energy and primary factors and between energy and nonenergy inputs as well as between different fuels without sacrificing the consistency features of input-output models.

In the inter-industry transactions model the U.S. economy is divided into nine industrial groups, five of which constitute the energy sector and the remaining four the nonenergy sector. The production technology in each of the nine industrial sectors is specified by a two-level, nested average cost function, an aggregate K,L,E,M (capital, labour, energy and material) function and subaggregates for energy (an interfuel substitution model) and materials (an intermaterial substitution model). All cost functions are specified and estimated as translogs. Producer behaviour in each sector can be characterised by a set of technical coefficients giving primary and intermediate inputs per unit of output. For each sector, the technical coefficients as functions of input prices are generated in this model from the nested set of average cost functions by applying Shephard's (1953) lemma. The inter-industry transactions model also includes balance equations between supply and demand for the products of each of the nine industrial sectors. Moreover, the nested set of cost functions also ensures that the value of output of a sector is equal to the sum of the values of all primary and intermediate inputs into the sector.

Final demand for the outputs of industrial sectors is disaggregated into personal consumption, gross private investment, government consumption and net exports. Government expenditures, exports and some imports are exogenous. Total gross investment is determined in the macroeconomic model and is allocated to the industries of origin through a set of exogenously determined fixed shares. Total personal consumption expenditures is also determined in the macro model. The consumer model determines the quantities of industrial outputs purchased per person as a function of prices of all industrial products, prices of capital services and imports, and the total personal consumption expenditure per capita.

In addition to determining total gross investment and total personal consumption expenditures (in both current and constant prices), the macroeconomic model also determines the prices and supplies of capital and labour services. The growth model contains a macro production function relating the output of consumption and investment goods to the input of capital and labour services. Other relations govern the trade-off between aggregate consumption and investment in each time period. Several tax and transfer variables are included in the equations.

In the Hudson-Jorgenson model, population, labour force, unemployment and productivity trends are exogenous in addition to exports and government demands for industrial outputs.

With the prices of capital services and labour services given by the macroeconomic growth model and import prices given by exogenous forecasts, the prices of the products of all nine sectors are determined by solving their average cost functions simultaneously. Once prices of primary inputs including imports and prices of industrial products are known, the technical coefficients are also known since these are functions of these prices. Similarly, quantities purchased by the consumers can be generated from these prices in association with total personal consumption expenditures per capita supplied by the macro growth model and level of population specified exogenously. To obtain total final demand for the output of each industrial sector, the personal consumption demand is added to gross investment demand, government demand and exports.

From the quantities of final demand for the outputs of nine sectors and the matrix of technical coefficients, one can determine the output levels of all sectors. One can also determine the distribution of these outputs to intermediate users and final users as well as flows of imports, capital services and labour services into each of the sectors.

Hudson and Jorgenson computed a sequence of general market equilibria over the period 1975–2000. Beyond exogenous trends in the variables specified exogenously, the link over time is provided by the transfer of aggregate capital services from one period to another.

Hudson and Jorgenson (1974) used their model to project economic activity and energy utilisation for the period 1975 to 2000 under the assumption of no change in energy policy. The model was then employed to analyse a specific energy policy—a Btu tax designed to secure U.S. energy independence. The overall conclusion of the study was that a Btu tax could induce significant reductions in energy consumption, corresponding to even larger relative reductions in fuel imports, at the cost of comparatively minor changes in production patterns, prices or demand.

Although the model of Hudson and Jorgenson (1974) is small in size, it is still the most sophisticated model for studying the link between the energy sectors and the rest of the economy (Ulph 1980). The model allows interfuel substitution and substitution between individual materials as well as substitution between energy, capital, labour and aggregate materials in production. It also allows substitution between energy and nonenergy products in consumption. The model is well capable of analysing the impacts of alternative energy policies on the overall level of economic activity and its distribution among industry groups or groups of consumers. However, the model does not provide satisfactory treatment of new technologies. In fact, 'this approach is infeasible for the study of technologies that are not already in use or for the study of consumer preferences for commodities not already in existence' (Jorgenson 1982, p.10).

2.5 Integrated Energy-Economic Models

Recently, there has been increasing research activity in integrating energy system models with models of the overall economy such as CGE, macroeconomic and input-output models. In reviewing the energy system models it is noticed that these models require the energy demands to be specified exogenously as input parameters. While these models allow events in the rest of the economy to have repercussions in the energy system, they fail to recognise that events in the energy system may have important repercussions in the rest of the economy and in turn in the energy system. The recognition of the importance of modelling such two-way linkage between the energy sector and the rest of the economy has stimulated the energy modellers to construct hybrid models for energy by coupling energy system models with models of the overall economy. The coupled energy-economic models reviewed here involve those that are used for analysis of the role of energy as a driving force and constraint on economic development.

To examine the extent of two-way linkage between the energy sector and the balance of the U.S. economy Manne (1977) has integrated his ETA model with a macroeconomic (MACRO) growth model. The integrated model has been nicknamed ETA-MACRO. ETA-MACRO simulates a market economy over time, assuming that producers and consumers are sufficiently farsighted to anticipate future scarcities. Supplies, demands and prices are matched through a dynamic, nonlinear programming model. The higher that prices rise, the greater the amount of future supplies that are likely to become available, and the greater the inducements for consumers to conserve energy.

Figure 2.2 provides an overview of the principal static linkages between the ETA model and the MACRO model. Electric and nonelectric energy are supplied by the energy sector to the rest of the economy. Gross output depends on the inputs of capital, labour and energy (electric and nonelectric). In turn, output is allocated between current consumption, investment and current payments for energy costs.

The aggregate production function employed in the MACRO model provides for substitution among the inputs of capital, labour, electric energy and nonelectric energy. The form of the production function is constant elasticity

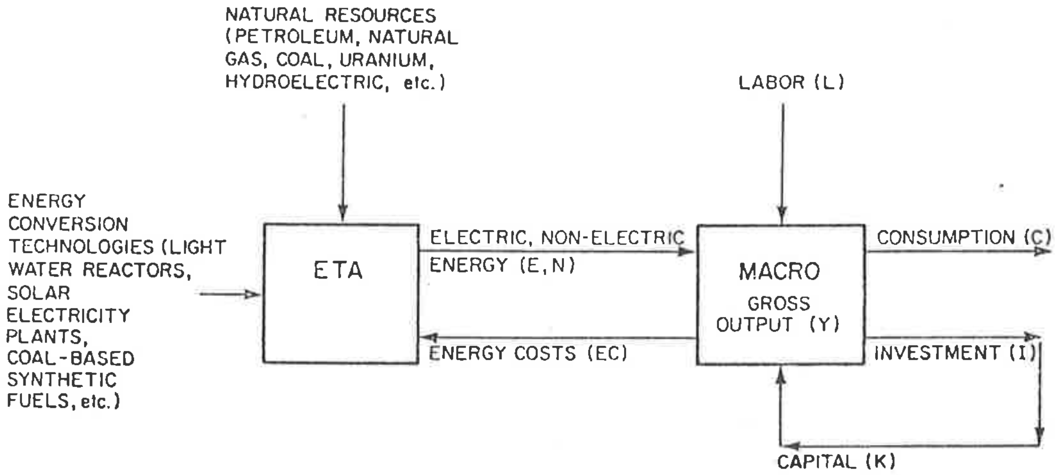

Figure 2.2: An Overview of ETA-MACRO (Source: Manne (1977)).

of substitution (CES) between a capital-labour component and an electric-nonelectric component, and nested inside the CES are two Cobb-Douglas production functions expressing unitary elasticity of substitution between capital and labour, and between electric and nonelectric energy.

To distinguish between short- and long-run responses to higher energy prices Manne assumes that there is no flexibility with respect to the method of operation of the initial (1970) energy-using stocks and life-style habits, but that there is full flexibility with respect to capital goods accumulated after 1970. Thus the production technology assumed is putty-clay in type. Investment augments capital stocks; an average two year lag between investment and usable capital stocks has been assumed.

The MACRO growth model is driven by three key parameters: (a) the discount rate in the objective function, the key determinant of the savings-investment accumulation process; (b) the labour force growth index; and (c) the elasticity of substitution between energy and nonenergy inputs, the principal determinant of the economy's ability to cope with higher energy prices. The ETA part of ETA-MACRO in its broad outlines follows the original version in Manne (1976).

Although ETA-MACRO is small in size, it is elegant in its approach. By bringing energy directly into the macroeconomic production function and by focusing on energy-economy interactions in terms of a single easily understood parameter, the elasticity of substitution, it permits the exploration of those macroeconomic issues that are of particular interest to energy policy and technology assessment.

The methodology of integration of the Hudson-Jorgenson (H-J) model (Hudson and Jorgenson 1974) and BESOM involving an integrated inter-industry transactions model and an iterative solution process is described in Hoffman and Jorgenson (1977). The combined model is a single-period model like BESOM. However, the combined model allows two-way interactions between the energy sector and the rest of the economy. Moreover, the combined model can assess the impacts of both old and new technologies, even of future technologies, on the energy sector as well as on the whole economy.

Both the H-J model and BESOM have been discussed before. So here attention will be focused on the methodology which has been used to integrate the H-J model and BESOM and the solution technique used to solve the integrated model.

The integration of the H-J model and BESOM is achieved with the help of an integrated inter-industry transactions model. The inter-industry transactions model is based on a system of inter-industry accounts which is an expansion of the system used in the H-J model. The expanded system has four final demand components, three primary inputs and four nonenergy sectors as in the H-J system. The five energy sectors of the H-J system are now disaggregated into eleven energy resource sectors, twenty energy conversion processes and sixteen secondary energy forms and energy products sectors (see Hoffman and Jorgenson (1977) for detail), which correspond to the supply constraints, conversion processes and demand constraints in BESOM.

Each iteration of the solution procedure involves three steps. In the first step of the solution process, the H-J model and BESOM are solved separately. The initial solution of the H-J model provides information on the final demands for the outputs of four nonenergy sectors, sixteen energy products, and inventory accumulation and exports of energy resources in the integrated inter-industry model. The solution of the H-J model also provides the technical coefficients for the four nonenergy sectors of the integrated inter-industry transactions model. Technical coefficients for the forty-seven energy sectors of the integrated model are obtained from the solution of BESOM. Using the set of technical coefficients and final demands generated from the solutions of the H-J model and BESOM, one can then obtain the levels of output of all fifty-one sectors of the integrated model. Given the prices of primary inputs and nonenergy industrial products from the H-J model, energy resource prices, energy conversion costs and energy product prices from BESOM, one can then convert the array of inter-industry transactions, final demands and primary inputs into current prices.

In the second step of the solution process an input data set is generated for BESOM from the integrated model. Levels of energy resource supplies and demands for energy products are obtained from the integrated model to be used in BESOM. Moreover, the integrated model also supplies information on unit conversion costs of conversion technologies of BESOM. Given the unit costs, the energy product demands and the energy resource supplies, BESOM then generates a new set of cost minimising levels for the energy conversion processes and shadow prices associated with energy supplies and demand.

In the third step of the solution process, prices of the outputs of the five energy sectors which appear in the H-J model are determined from the shadow prices of fuels generated by BESOM in step two of the solution process. Given these prices of the outputs of the five energy sectors of the H-J model, the prices of primary inputs and the levels of productivity in each of the four nonenergy sectors of the H-J model, the prices of the outputs of the four nonenergy sectors are determined from their average cost functions. From energy and nonenergy prices and the prices of primary inputs, technical coefficients for the four nonenergy sectors of the integrated model can be obtained from the H-J model. A new set of final demands is also obtained for the integrated model from the H-J model on the basis of these prices.

The three steps outlined above generate a new set of data to initiate the next iteration of the solution process. The sequence of these three steps are repeated until the data employed to initiate the process are generated as a solution of the integrated model.

From the discussion above, it becomes evident that the integrated model obtained by coupling the H-J model and BESOM permits one to capture energy-economy interactions. Moreover, this integrated model provides far more information than ETA-MACRO on the impacts of energy policies on the rest of the economy. However, this integrated model is static in nature, while ETA-MACRO is dynamic. To achieve a dynamic integrated model, the H-J model has been coupled with DESOM, the dynamic version of BESOM, with the help of an input-output model. A version of this dynamic integrated model is reported in Behling *et al.* (1977).

Inspired by the work of Brookhaven National Laboratory and Manne, James *et al.* (1983) constructed an integrated energy-economic model of Australia by linking MARKAL to an input-output model MERG (named after the Macquarie Energy Resource Group) through an energy make matrix and an energy absorption matrix. In MERG, the economy is divided into 49 sectors of which 9 are energy producing sectors and the remaining 40 are nonenergy sectors. The energy make matrix shows the production of 22 energy commodities by the energy sectors and the energy absorption matrix shows the distribution of the 22 energy commodities to the 49 sectors of the economy as well as to final demand categories comprising households, net exports and stock changes. To implement MERG, input-output coefficients for inputs of the energy sectors to the energy and nonenergy sectors are obtained from the energy make and energy absorption matrices through some transformation process (see James *et al.* 1983). Final demands for the outputs of the energy sectors are also obtained from these matrices. Input-output coefficients for inputs of the nonenergy sectors to the energy and nonenergy sectors as well as final demands for the outputs of nonenergy sectors are obtained from conventional input-output tables.

An iterative solution procedure is used to solve the integrated model MERG-MARKAL. In the first step of the iteration, MERG is solved independently given the levels of final demands for the outputs of energy and nonenergy sectors. In the second step, the MERG solutions are translated into useful energy demands to be used as inputs into MARKAL. MARKAL is solved in this step. In the third step, energy make and absorption matrices are updated on the basis of MARKAL solutions. Input-output coefficients in MERG for inputs of the energy sectors to the energy and nonenergy sectors as well final demands for the outputs of energy sectors are updated using the new set of energy make and energy absorption matrices. MERG is solved again and a new set of useful energy demands is constructed for use in MARKAL. The solution algorithm returns to step two. This process continues until convergence is achieved.

Thus the integration of MERG and MARKAL now enables the useful energy demands in MARKAL, and sectoral input-output coefficients for energy inputs and final demands for energy outputs in MERG to vary in response to changes in the energy system. But this integrated model, although an improvement over MARKAL, falls short of the calibre of models such as ETA-MACRO, and the integrated H-J model and BESOM (or DESOM). In the integrated MERG-MARKAL model, sectoral input-output coefficients for nonenergy inputs and final demands for nonenergy outputs cannot change in response to changes in the energy system represented by MARKAL. This means that while the integrated MERG-MARKAL model can allow interfuel substitution it fails to allow substitution between energy and nonenergy inputs and between energy and primary factors in production. By the same token, it fails to capture substitution between energy and nonenergy products in the final demand sector. Thus the solutions provided by integrated MERG-MARKAL are not general equilibrium in nature.

2.6 Conclusion

This review of energy models illustrates the scope, application, methodology and content of energy models used for forecasting future energy market conditions and in the formation and analysis of energy policy. The existence of a variety of energy models reviewed here suggests that a broad-ranging capability exists for supporting energy forecasting, planning and analysis studies. Energy models may be simple or complex depending on the purpose for which they are formulated. According to the scope of analysis, these models can be classified into five broad groups: (a) energy demand or supply models which focus on either the demand side or the supply side of a specific type of energy; (b) energy industry or market models which focus on both the demand and supply sides of a specific or related set of energy products; (c) energy system models which focus on the overall energy system of an economy; (d) general equilibrium energy models which focus on the overall economy including the energy system; and (e) integrated energy-economic models which permit two-way interactions between the energy system and the rest of the economy.

Chapter 3

THEORETICAL STRUCTURES OF THE MODELS

One of the objectives of this chapter is to derive the structural equations of a computable general equilibrium (CGE) energy model and its variants which can be used in a later stage to analyse the effects of Australian energy policies on a wide variety of economic variables. As pointed out by Dixon *et al.* (1982, p.13), such a model consists of several sets of equations. These are:

(i) a set of demand equations for intermediate and primary factor inputs;

(ii) a set of equations representing household and other final demands for commodities;

(iii) a set of pricing equations relating commodity prices to costs;

(iv) a set of market clearing equations for primary factors and commodities; and

(v) a set of miscellaneous equations defining some macroeconomic variables.

Another objective of this chapter is to express the structural equations in terms of percentage changes in the variables. Schematically, a CGE model containing m equations and n variables can be written as

$$\begin{aligned} F_1(X_1, X_2, \ldots, X_n) &= 0 \\ F_2(X_1, X_2, \ldots, X_n) &= 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots & \ldots \ldots \\ F_m(X_1, X_2, \ldots, X_n) &= 0 \end{aligned} \tag{3.1}$$

Since the system (3.1) can be very large and can consist of a wide variety of nonlinear relationships among variables, from a computational point of view it may be quite intractable. In the present study, a system of equations like (3.1) is specified and then solved by Johansen's (1960) linearisation approach. Johansen's approach involves transforming (3.1) into linear form in which variables are changes or percentage changes or changes in the logarithms of original variables and, then, solving the linearised version of the model.

The linearised version of (3.1) which is used in Johansen style computation can be obtained by first totally differentiating each equation in (3.1) to obtain

$$\begin{bmatrix} \frac{\delta F_1}{\delta X_1} & \frac{\delta F_1}{\delta X_2} & \cdots & \frac{\delta F_1}{\delta X_n} \\ \frac{\delta F_2}{\delta X_1} & \frac{\delta F_2}{\delta X_2} & \cdots & \frac{\delta F_2}{\delta X_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\delta F_m}{\delta X_1} & \frac{\delta F_m}{\delta X_2} & \cdots & \frac{\delta F_m}{\delta X_n} \end{bmatrix} \begin{bmatrix} dX_1 \\ dX_2 \\ \vdots \\ dX_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{3.2}$$

where $\delta F_i/\delta X_j$ is the first-order partial derivative of function F_i $(i = 1, 2, \ldots, m)$ with respect to variable X_j $(j = 1, 2, \ldots, n)$. Then assuming that zero is not a relevant value for any of the variables included in the model, (3.2) can be rewritten as

$$\begin{bmatrix} \frac{\delta F_1}{\delta X_1} & \frac{\delta F_1}{\delta X_2} & \cdots & \frac{\delta F_1}{\delta X_n} \\ \frac{\delta F_2}{\delta X_1} & \frac{\delta F_2}{\delta X_2} & \cdots & \frac{\delta F_2}{\delta X_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\delta F_m}{\delta X_1} & \frac{\delta F_m}{\delta X_2} & \cdots & \frac{\delta F_m}{\delta X_n} \end{bmatrix} \begin{bmatrix} X_1 & 0 & \ldots & 0 \\ 0 & X_2 & \ldots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \ldots & X_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{3.3}$$

where lower-case x's denote percentage changes in the variables represented by the upper-case X's. In simpler notation, (3.3) can be written as

$$Av = 0 \tag{3.4}$$

where $v = (x_1 \ x_2 \ \ldots \ x_n)'$ and A is an $m \times n$ matrix. (3.4) represents (3.1) in linearised form where the variables are percentage changes of the original variables.

The next step of a Johansen style computation is to evaluate the matrix A at initial values of X's which are called base-period values. The base-period values are obtained from input-output tables.

The third step of a Johansen style computation is to divide the vector v into two sub-vectors of endogenous and exogenous variables, viz., v_1 and v_2 respectively. Generally, in a system of equations like (3.1) or (3.4) the number of variables n is greater than the number of equations m. So to achieve a solution $(n - m)$ variables must be declared exogenous. In the light of this discussion, (3.4) can be rewritten as

$$A_1 v_1 + A_2 v_2 = 0 \tag{3.5}$$

where A_1 is an $m \times m$ matrix and $v_1 = (x_1 \ x_2 \ \ldots \ x_m)'$; and A_2 is an $m \times (n - m)$ matrix and $v_2 = (x_{m+1} \ x_{m+2} \ \ldots \ x_n)'$.

Finally, the solution for v_1 in terms of v_2 can be obtained as

$$v_1 = -A_1^{-1} A_2 v_2$$

or

$$v_1 = E v_2 \tag{3.6}$$

where E can be defined as a matrix of elasticities of dimension $m \times (n - m)$ where an element e_{ij} measures the elasticity of the i^{th} endogenous variable with respect to j^{th} exogenous variable.

This chapter is organised in the following way. In Section 3.1, the production technology of each sector is specified and structural equations of demand for intermediate and primary factors are derived on the assumption that producers minimise their costs of production. While Section 3.1 deals with producers involved in current production, Section 3.2 deals with producers involved in producing capital goods. This section, like Section 3.1, is concerned with specifying production technology for capital goods and deriving structural equations of demand for intermediate inputs used in the production of capital goods. Section 3.3 deals with utility maximising theory and the derivation of structural equations for household demands for commodities. Structural equations for government demands for commodities are derived in Section 3.4. Section 3.5 deals with the foreign sector. Structural equations for demand for domestically produced goods as well as imports are derived in this section. Foreign demand for Australian exports is also discussed in this section. Pricing equations relating prices and costs of producing commodities are specified in Section 3.6. Section 3.7 deals with the investment theory incorporated in the present CGE models and, also, with the allocation of investment across industries. While Section 3.8 is concerned with the specification of market clearing equations, Section 3.9 deals with aggregate imports, exports and balance of trade. Section 3.10 is concerned with some useful macroeconomic variables such as aggregate capital stock, price indexes, etc. Finally, the chapter is concluded in Section 3.11 where the models specified in this chapter are compared with those discussed in Chapter 2. Note that in all sections, structural equations which are included in the CGE models have been transformed into linear percentage change form. Lower-case roman letters are used to denote percentage changes in the variables represented by upper-case roman letters.

Before proceeding to describe the structural equations of the CGE energy model and its variants, it should be noted that the notational conventions used in the ORANI model have been followed in this work with appropriate deviations. The notational conventions used here are:

(i) $X_{ij}^{(k)c}$ will denote the demand for effective good i in sector j for purpose k. Here the superscript c is used to denote an effective good. The subscript i runs from 0 to 9. When $i = 0$, the good concerned is non-competing imports. But $i = 1$ implies a good of the type produced by sector 1 (agriculture, mining and construction), $i = 2$ implies a good of the type produced by sector 2 (manufacturing), and so on. The subscript j runs from 1 to 9 implying sector 1, sector 2, and so on. The superscript k runs from 1 to 4; $k = 1$ implies that the good is used in the production of current goods, $k = 2$ implies the good is used in the production of capital goods, $k = 3$ implies the good is used in the household sector and $k = 4$ implies the good is used in the government sector. Note that when $k = 3$ or 4, the subscript j is superfluous.

(ii) $X_{(ts)}^{c}$ will denote the demand for product t of type s used in the production of effective good t ($t = 1, 2, \ldots, 9$). Here the subscript s takes the values 1 and 2. When $s = 1$, the product is a domestic product and when $s = 2$ the product is an imported product.

(iii) $X_{(j1)}^{0}$ will denote the output of sector j. The superscript 0 is used to denote output.

(iv) $X_{(j1)}^{(5)}$ will denote the export of domestic good j. The superscript (5) denotes that this variable relates to export.

The same notational conventions have been used in association with other roman letters to denote some other variables. For example, $P_{(j1)}$ will denote the price of domestic good j, P_i^c will denote the price of effective good i, etc. There are other notations used as well which do not obey the conventions noted above. These notations will be explained in due course.

3.1 Production Functions for Current Output

The production side of the model involves disaggregation of the Australian business sector into nine industries; five of these are energy producing industries and the remaining four are nonenergy producing sectors. Disaggregating the business sector in this way gives special emphasis to production and use of energy in the Australian economy, while preserving enough detail on other sectors to record major reallocations of resources among them. The nine industries are:

1. agriculture, non-fuel mining and construction;
2. manufacturing, excluding petroleum refining;
3 transportation;
4. communications, trade and services;
5. coal;
6. crude oil;
7. petroleum and coal products;
8. electricity; and
9. gas utilities.

The basic behavioural assumption underlying the production models is that producers maximise profits. Each industry produces a single output and uses capital, labour and intermediate inputs in the production of its output. The technological constraints of each sector can be represented by a well-behaved neo-classical production function. Finally, it is assumed that production in each sector exhibits constant returns to scale. Under these conditions the technological possibilities and the behaviour of producers can be neatly summarised by a unit cost function. Letting $P_{(j1)}$ denote the basic price or unit cost of current output of sector j, $X^0_{(j1)}$, the unit cost function can be specified in general terms as

$$P_{(j1)} = P_{(j1)}(P^c_0, P^c_1, P^c_2, \ldots, P^c_9, P^{(1)}_{Kj}, P^{(1)}_L), \;\; j = 1, 2, \ldots, 9, \tag{3.7}$$

where $P^{(1)}_{Kj}$ is the user cost of capital in sector j; $P^{(1)}_L$ is the wage rate which is assumed to be same in all sectors; P^c_0 is the basic price of non-competitive imports and P^c_i, $i = 1, 2, \ldots, 9$, is the basic price of 'effective' good i used as intermediate input in sector j. P^c_i's are assumed to be the same in all sectors. A unit of an effective good i is defined as an aggregate of units of domestically produced good i, and units of imported good i used to produce it. The aggregation procedure for forming a unit of effective good i, $i = 1, 2, \ldots, 9$, is discussed in Section 3.5 in detail.

Furthermore, the production function underlying (3.7) is assumed weakly separable in four aggregates—capital, labour, energy and aggregate materials input—where energy and aggregate materials input are linear homogenous functions of the individual fuels and individual material inputs respectively. In other words, it is assumed that the production function underlying (3.7) can be written as a nested set of production functions as follows:

$$X^0_{(j1)} = X^0_{(j1)}(K^{(1)}_j, L^{(1)}_j, E^{(1)}_j, M^{(1)}_j), \tag{3.8}$$

$$E^{(1)}_j = E^{(1)}_j(X^{(1)c}_{5j}, X^{(1)c}_{6j}, \ldots, X^{(1)c}_{9j}), \tag{3.9}$$

$$M^{(1)}_j = M^{(1)}_j(X^{(1)c}_{0j}, X^{(1)c}_{1j}, \ldots, X^{(1)c}_{4j}), \tag{3.10}$$

where $X^0_{(j1)}$ is the output of domestic sector j, $K^{(1)}_j$, $L^{(1)}_j$ and $X^{(1)c}_{0j}$ are capital, labour and non-competitive imports respectively and $X^{(1)c}_{ij}$, $(i = 1, 2, \ldots, 9)$, is the input of effective good i used in sector j for current production. Under these assumptions of weak separability and homotheticity, the average cost function of sector j, defined by (3.7), can be equivalently represented by the following nested set of unit cost functions:

$$P_{(j1)} = P_{(j1)}(P_{Kj}^{(1)}, P_L^{(1)}, P_{Ej}^{(1)}, P_{Mj}^{(1)}), \ \ j = 1, 2, \ldots, 9; \qquad (3.11)$$

$$P_{Ej}^{(1)} = P_{Ej}^{(1)}(P_5^c, P_6^c, P_7^c, P_8^c, P_9^c), \ \ j = 1, 2, \ldots, 9; \qquad (3.12)$$

$$P_{Mj}^{(1)} = P_{Mj}^{(1)}(P_0^c, P_1^c, P_2^c, P_3^c, P_4^c), \ \ j = 1, 2, \ldots, 9. \qquad (3.13)$$

Here equation (3.11) defines the price of output of sector j, $P_{(j1)}$, as a function of the prices of four aggregate inputs, i.e., prices of capital ($P_{Kj}^{(1)}$), labour ($P_L^{(1)}$), energy ($P_{Ej}^{(1)}$) and aggregate materials ($P_{Mj}^{(1)}$). Equation (3.12) defines the unit cost or price of energy in sector j, $P_{Ej}^{(1)}$, as a function of the prices of the five types of fuels included in the model, i.e., prices of coal (P_5^c), crude oil (P_6^c), petroleum and coal products (P_7^c), electricity (P_8^c), and gas utilities (P_9^c). Equation (3.13) defines the price of aggregate materials input in sector j, $P_{Mj}^{(1)}$, as a function of the prices of the five types of nonenergy inputs, i.e., prices of non-competitive imports (P_0^c), agriculture, mining and construction inputs (P_1^c), manufactured inputs (P_2^c), transportations (P_3^c), and communications (P_4^c).

Following Fuss (1977), it can be argued that the assumptions of weak separability of the production function and homotheticity of the aggregates justify the construction of separate submodels for energy inputs, material inputs and for the aggregates. In other words, three separate submodels can be specified for (3.11), (3.12) and (3.13). The producers' problem in each sector can be decomposed into two stages: first the determination of the optimal mix for each aggregate and then the optimal choice of aggregates.

For the present study, it is assumed that the production possibilities and producers behaviour in each sector can be summarised by a nested set of cost functions of the type (3.11)–(3.13). The main advantage of such an assumption is to reduce greatly the estimation burden of the parameters of the overall unit cost function.

For the purpose of deriving the set of structural equations of demand for intermediate and primary inputs in each sector as well as estimation one must employ specific functional forms for (3.11)–(3.13). Since the main purpose of the present study is to examine the sensitivity of the model results to alternative technological specifications for current production, three different types of functional forms have been specified for these cost functions. In the first case, hereafter Case A, the average cost functions (3.11), (3.12) and (3.13) are specified as

$$
\begin{aligned}
T_j^{(1)}P_{(j1)} &= a_{Vj}[\frac{1}{\bar{B}_j}\{\theta_j^{\sigma_j}(P_L^{(1)})^{(1-\sigma_j)} + (1-\theta_j)^{\sigma_j}(P_{Kj}^{(1)})^{(1-\sigma_j)}\}^{1/(1-\sigma_j)}] \\
&\quad + a_{Ej}P_{Ej}^{(1)} + a_{Mj}P_{Mj}^{(1)}, \;\; j = 1,2,\ldots,9, \qquad (3.14) \\
P_{Ej}^{(1)} &= \sum_{i=5}^{9} a_{ij}P_i^c, \;\; j = 1,2,\ldots,9, \qquad (3.15) \\
P_{Mj}^{(1)} &= \sum_{t=0}^{4} a_{tj}P_t^c, \;\; j = 1,2,\ldots,9, \qquad (3.16)
\end{aligned}
$$

respectively. In (3.14), (3.15) and (3.16), $T_j^{(1)}$ is one minus the rate of production tax in sector j while $P_L^{(1)}$, $P_{Kj}^{(1)}$, $P_{Ej}^{(1)}$, $P_{Mj}^{(1)}$ and P_i^c, $(i = 0, 1, \ldots, 9)$, are defined as before. The parameters a_{Vj}, a_{Ej} and a_{Mj} respectively define the requirements of aggregate primary factor, energy and aggregate materials per unit of current output of sector j; a_{ij}, $i = 5, 6, \ldots, 9$, defines the requirement of i^{th} effective good for the formation of one unit of energy input in sector j; and a_{tj}, $t = 0, 1, \ldots, 4$, defines the requirement of t^{th} effective good in the production of one unit of aggregate materials input in sector j. The function included in the pair of third brackets in (3.14) defines the unit cost of producing one unit of aggregate primary factor, a composite of labour and capital, in sector j. The parameters $\bar{B}_j$, θ_j and σ_j appearing in this function are respectively technical efficiency, distribution and substitution parameters of the underlying production function for aggregate primary factor. The set of average cost functions so defined specifies a production technology for sector j which allows substitution only between primary factors, labour and capital, and thus rules out substitution possibilities among individual fuels and among individual materials. This production technology also rules out substitution possibilities among aggregate primary factor, energy and aggregate materials input. This type of production technology is similar to what has been implemented in ORANI (see Dixon *et al.* 1982).

In the second case, hereafter Case B, the average cost functions (3.11), (3.12) and (3.13) are assumed to be of the Cobb-Douglas type. Average cost functions, in this case, take the following forms:

$$\begin{aligned}
\ln(T_j^{(1)} P_{(j1)}) &= \ln A_j + \sum_r \delta_{rj} \ln P_{rj}^{(1)}, \quad r = K, L, E, M, \\
&\qquad j = 1, 2, \ldots, 9, && (3.17) \\
\ln P_{Ej}^{(1)} &= \ln A_j^E + \sum_{s=5}^{9} \delta_{sj}^E \ln P_s^c, \quad j = 1, 2, \ldots, 9, && (3.18) \\
\ln P_{Mj}^{(1)} &= \ln A_j^M + \sum_{t=0}^{4} \delta_{tj}^M \ln P_t^c, \quad j = 1, 2, \ldots, 9, && (3.19)
\end{aligned}$$

where the variables $T_j^{(1)}$, $P_{(j1)}$, $P_{rj}^{(1)}$, P_s^c and P_t^c are defined as before while A_j, A_j^E, A_j^M, δ_{rj}, δ_{sj}^E and δ_{tj}^M are parameters of the production functions underlying the average cost functions. The production technology specified by this nested set of average cost functions allows substitution among individual fuels, individual materials and among capital, labour, energy and aggregate materials. This type of production technology is more flexible in respect of allowing substitution among all factors and inputs in production. However, this models rules out the possibility of complementarity between factors or inputs and restricts the elasticity of substitution to unity for all pairs of inputs or factors.

In the third case, hereafter Case C, the functional forms specified for the average cost functions (3.11), (3.12) and (3.13) are translog in nature. Several factors led to the choice of the translog functional form. First, the translog form is very general; it has been shown to provide a second-order approximation to any cost function (see Christensen, Jorgenson and Lau 1973). This implies that it is consistent with a wide range of production relationships.

Secondly, in contrast to some restrictive forms such as Cobb-Douglas and CES, it does not rule out complementarity between inputs. A number of studies (Berndt and Wood 1975, Field and Grebenstein 1980, Truong 1985) suggest that energy is a complement to certain key factors—in particular capital—and it has been urged that this complementarity is of fundamental importance to the way higher energy prices influence economic growth. Thirdly, the translog form allows, in contrast to CES or Cobb-Douglas functional forms, the elasticity of substitution to vary from input pair to input pair. However, a variety of other functional forms such as the generalised Leontief (Diewert 1971) and the generalised Cobb-Douglas (Diewert 1973, Magnus 1979) also enjoy the virtues of the translog form. It is not, however, possible to discriminate and choose among the three forms on theoretical grounds. The choice for the translog cost functions in this study is, therefore, somewhat arbitrary.

The translog forms of the cost functions (3.11), (3.12) and (3.13) can be specified as

$$\begin{aligned}
\ln(T_j^{(1)}P_{(j1)}) &= \beta_{0j} + \sum_r \beta_{rj} \ln P_{rj}^{(1)} + \frac{1}{2}\sum_r\sum_s \beta_{rs,j} \ln P_{rj}^{(1)} \ln P_{sj}^{(1)} \\
& \quad r,s = K,L,E,M; \;\; j = 1,2,\ldots,9; \qquad (3.20) \\
\ln P_{Ej}^{(1)} &= \beta_{0j}^E + \sum_m \beta_{mj}^E \ln P_m^c + \frac{1}{2}\sum_m\sum_n \beta_{mn,j}^E \ln P_m^c \ln P_n^c, \\
& \quad m,n = 5,6,\ldots,9, \;\; j = 1,2,\ldots,9; \qquad (3.21) \\
\ln P_{Mj}^{(1)} &= \beta_{0j}^M + \sum_u \beta_{uj}^M \ln P_u^c + \frac{1}{2}\sum_u\sum_v \beta_{uv,j}^M \ln P_u^c \ln P_v^c, \\
& \quad u,v = 0,1,\ldots,4, \;\; j = 1,2,\ldots,9; \qquad (3.22)
\end{aligned}$$

where the β's are parameters of the underlying production functions and the variables are defined as before.

The usual assumptions of neoclassical production theory ensure that these cost functions are concave and increasing functions of the respective set of prices. The estimation burden of (3.20), (3.21) and (3.22) can be greatly reduced by recognising that the parameters appearing in them can be assumed to satisfy the symmetry and linear homogeneity conditions. Symmetry conditions imply that $\beta_{rs,j} = \beta_{sr,j}$, for $r \neq s$ in (3.20)[1]; $\beta^E_{mn,j} = \beta^E_{nm,j}$, for $m \neq n$ in (3.21); and $\beta^M_{uv,j} = \beta^M_{vu,j}$, for $u \neq v$ in (3.22). To illustrate the restrictions on the parameters of (3.20)–(3.22) imposed by the linear homogeneity assumption, equation (3.20) is chosen and the restrictions meant for (3.21) and (3.22) are deduced from those of (3.20).

Linear homogeneity requires that

$$V_j(\lambda P^{(1)}_{\cdot j}) = \lambda V_j(P^{(1)}_{\cdot j}), \quad j = 1, 2, \ldots, 9,$$

where $P^{(1)}_{\cdot j} = (P^{(1)}_{rj}, \quad r = K, L, E, M)$. Equivalently, this requires that

$$\ln V_j(\lambda P^{(1)}_{\cdot j}) = \ln V_j(P^{(1)}_{\cdot j}) + \ln \lambda, \quad j = 1, 2, \ldots, 9.$$

Increasing all prices by λ ($\lambda > 0$), (3.20) gives

$$\begin{aligned} \ln V_j(\lambda P^{(1)}_{\cdot j}) &= \beta_{0j} + \sum_r \beta_{rj} \ln(\lambda P^{(1)}_{rj}) + \frac{1}{2} \sum_r \sum_s \beta_{rs,j} \ln(\lambda P^{(1)}_{rj}) \ln(\lambda P^{(1)}_{sj}) \\ & \quad r, s = K, L, E, M; \quad j = 1, 2, \ldots, 9. \end{aligned} \tag{3.23}$$

Since

$$\ln(\lambda P_k) = \ln \lambda + \ln P_k,$$

for all k and

$$\beta_{rs,j} = \beta_{sr,j},$$

[1] Let B_j be the 4×4 matrix of $\beta_{rs,j}$'s ($r, s = K, L, E, M$). If B_j were not symmetric, then it would be possible to rewrite (3.20) with the initial B_j matrix replaced by the symmetric matrix $\frac{1}{2}(B_j + B_j')$. Therefore, no loss of generality occurs in assuming that B_j is a symmetric matrix.

for all $r \neq s$, equation (3.23) may be expanded as

$$\begin{aligned}\ln V_j(\lambda P_{\cdot j}^{(1)}) &= \ln V_j(P_{\cdot j}^{(1)}) + (\ln \lambda)\sum_r \beta_{rj} + (\ln \lambda)\sum_r (\ln P_{rj}^{(1)}) \sum_s \beta_{rs,j} \\ &+ \frac{1}{2}(\ln \lambda)^2 \sum_r \sum_s \beta_{rs,j}.\end{aligned} \quad (3.24)$$

Hence the necessary and sufficient conditions for (3.20) to be linearly homogenous in the prices of inputs are:

$$\sum_r \beta_{rj} = 1, \;\; r = K, L, E, M; \;\; j = 1, 2, \ldots, 9 \quad (3.25)$$

and

$$\sum_s \beta_{rs,j} = 0, \;\; s = K, L, E, M, \quad (3.26)$$

for all r, $r = K, L, E, M$ and $j = 1, 2, \ldots, 9$.

The restrictions on the parameters of (3.21) and (3.22) imposed by the linear homogeneity assumption can be deduced from (3.25) and (3.26). These restrictions for (3.21) can be written as

$$\sum_m \beta_{mj}^E = 1, \;\; m = 5, 6, \ldots, 9; \;\; j = 1, 2, \ldots, 9 \quad (3.27)$$

and

$$\sum_n \beta_{mn,j}^E = 0, \quad (3.28)$$

for all m,where $m, n = 5, 6, \ldots, 9$ and $j = 1, 2, \ldots, 9$. The homogeneity restrictions on the parameters of (3.22) can be written as

$$\sum_u \beta_{uj}^M = 1, \;\; u = 0, 1, \ldots, 4; \;\; j = 1, 2, \ldots, 9; \quad (3.29)$$

and

$$\sum_v \beta^M_{uv,j} = 0, \tag{3.30}$$

for all u, where $u, v = 0, 1, \ldots, 4$ and $j = 1, 2, \ldots, 9$.

Concavity of the cost function requires that its Hessian matrix be negative semi-definite. Consider cost function (3.20)[2] and let

$$Z = \mathbf{w}\mathbf{w}' - diag.\mathbf{w} \tag{3.31}$$

where

$$\mathbf{w} = \begin{bmatrix} \beta_{Kj} + \sum_s \beta_{Ks,j} \ln P^{(1)}_{sj} \\ \beta_{Lj} + \sum_s \beta_{Ls,j} \ln P^{(1)}_{sj} \\ \beta_{Ej} + \sum_s \beta_{Es,j} \ln P^{(1)}_{sj} \\ \beta_{Mj} + \sum_s \beta_{Ms,j} \ln P^{(1)}_{sj} \end{bmatrix}$$

The elements of $\mathbf{w}$ can be interpreted as cost shares of the inputs. The Hessian matrix, H, for the cost function (3.20) is then

$$H = R(B + Z)R \tag{3.32}$$

where

$$R = \begin{bmatrix} 1/P_K & 0 & 0 & 0 \\ 0 & 1/P_L & 0 & 0 \\ 0 & 0 & 1/P_E & 0 \\ 0 & 0 & 0 & 1/P_M \end{bmatrix}$$

and

$$B = \begin{bmatrix} \beta_{KK} & \beta_{KL} & \beta_{KE} & \beta_{KM} \\ \beta_{LK} & \beta_{LL} & \beta_{LE} & \beta_{LM} \\ \beta_{EK} & \beta_{EL} & \beta_{EE} & \beta_{EM} \\ \beta_{MK} & \beta_{ML} & \beta_{ME} & \beta_{MM} \end{bmatrix} \tag{3.33}$$

[2]The discussion relating concavity is equally applicable to the other two average cost functions, i.e., cost functions (3.21) and (3.22).

The concavity restrictions can be imposed *via* (3.31) to (3.33). This is discussed further in Chapter 4, Section 4.3.

Once the set of average cost functions (3.11)–(3.13) are specified it is straightforward to derive the input demand equations for current production by applying Shephard's (1953) lemma. Shephard's lemma states that the input demand functions are partial derivatives of the total cost function with respect to prices of inputs, i.e.,

$$X_{ij} = X^0_{(j1)} \delta P_{(j1)} / \delta P_i, \tag{3.34}$$

where X_{ij} is the amount of input i demanded in sector j for current production; $X^0_{(j1)}$ is the level of output of sector j; $P_{(j1)}$ is the unit cost of producing current output in sector j; and P_i is the price of input i.

Input demand equations in Case A: Applying Shephard's lemma, i.e., the result in (3.34), to average cost function (3.14), the demand functions for capital, labour, energy and aggregate materials can be obtained as

$$\begin{aligned} K_j^{(1)} &= \frac{a_{Vj}}{\bar{B}_j}[\theta_j\{\theta_j^{\sigma_j}(P_L^{(1)})^{(1-\sigma_j)} + \\ &\quad (1-\theta_j)^{\sigma_j}(P_{Kj}^{(1)})^{(1-\sigma_j)}\}^{1/(1-\sigma_j)}/P_{Kj}^{(1)}]^{\sigma_j} X^0_{(j1)} && (3.35) \\ L_j^{(1)} &= \frac{a_{Vj}}{\bar{B}_j}[(1-\theta_j)\{\theta_j^{\sigma_j}(P_L^{(1)})^{(1-\sigma_j)} + \\ &\quad (1-\theta_j)^{\sigma_j}(P_{Kj}^{(1)})^{(1-\sigma_j)}\}^{1/(1-\sigma_j)}/P_L^{(1)}]^{\sigma_j} X^0_{(j1)} && (3.36) \\ E_j^{(1)} &= a_{Ej} X^0_{(j1)} && (3.37) \\ M_j^{(1)} &= a_{Mj} X^0_{(j1)} && (3.38) \end{aligned}$$

where $K_j^{(1)}$, $L_j^{(1)}$, $E_j^{(1)}$ and $M_j^{(1)}$ represent demands for capital, labour, energy and aggregate materials respectively.

The input demand equations for individual 'effective' fuels, i.e., coal, crude oil, petroleum and coal products, electricity, and gas utilities for sector j can be obtained from the average cost function (3.15) by applying Shephard's lemma. These input demand equations are:

$$X_{sj}^{(1)c} = a_{sj}E_j^{(1)}, \quad s = 5, 6, \ldots, 9 \tag{3.39}$$

where $X_{sj}^{(1)c}$ denotes the demand for effective fuel of type s by sector j for current production. When $s = 5$, the fuel is coal; when $s = 6$, the fuel is crude oil; and so on.

The input demand equations for individual effective materials, i.e., non-competing imports, agriculture, mining and construction, manufactured, transportations and communications inputs, can be obtained from average cost function (3.16) in the same way, i.e., by applying Shephard's lemma. These input demand equations are obtained as

$$X_{tj}^{(1)c} = a_{tj}M_j^{(1)}, \quad t = 0, 1, \ldots, 4 \tag{3.40}$$

where $X_{tj}^{(1)c}$ denotes the demand for effective material of type t ($t = 0$ denotes non-competing imports, $t = 1$ denotes agriculture, mining and construction input, and so on) by sector j for current production.

Since Johansen's type of algorithm will be used to solve the CGE models, all structural equations of the models must be expressed in linear form. To linearise equation (3.35), let

$$Q_j = \{\theta_j^{\sigma_j}(P_L^{(1)})^{(1-\sigma_j)} + (1-\theta_j)^{\sigma_j}(P_{Kj}^{(1)})^{(1-\sigma_j)}\}^{1/(1-\sigma_j)}. \tag{3.41}$$

Equation (3.35) then can be written as

$$K_j^{(1)} = (a_{Vj}/\bar{B}_j)(\theta_j Q_j / P_{Kj}^{(1)})^{\sigma_j} X_{(j1)}^0 \tag{3.42}$$

which, when expressed in terms of percentage changes in the variables, becomes

$$k_j^{(1)} = x_{(j1)}^0 - \sigma_j p_{kj}^{(1)} + \sigma_j q_j, \tag{3.43}$$

where the lower-case symbols denote percentage changes in the variables represented by the corresponding upper-case symbols in (3.42). Now, recognising the fact that

$$Q_j = \bar{B}_j P_{Vj}^{(1)} \tag{3.44}$$

where $P_{Vj}^{(1)}$ is the unit cost of producing aggregate primary factor in sector j. $P_{Vj}^{(1)}$ is defined in (3.14) as

$$P_{Vj}^{(1)} = \frac{1}{\bar{B}_j}\{\theta_j^{\sigma_j}(P_L^{(1)})^{(1-\sigma_j)} + (1-\theta_j)^{\sigma_j}(P_{Kj}^{(1)})^{(1-\sigma_j)}\}^{1/(1-\sigma_j)}. \tag{3.45}$$

Expressing (3.44) and (3.45) in terms of percentage changes gives the equations

$$q_j = p_{Vj}^{(1)} \tag{3.46}$$

and

$$p_{Vj}^{(1)} = S_{Lj}^{\prime(1)} p_L^{(1)} + S_{Kj}^{\prime(1)} p_{Kj}^{(1)}, \tag{3.47}$$

where lower-case symbols represent percentage changes in the variables denoted by the upper-case symbols; and $S_{Lj}^{\prime(1)}$ and $S_{Kj}^{\prime(1)}$ denote the shares of labour and capital in the total primary factor cost of sector j respectively. Using equations (3.46) and (3.47), equation (3.43) can be written as

$$k_j^{(1)} = x_{(j1)}^0 - \sigma_j(p_{Kj}^{(1)} - \sum_{t=K,L} S_{tj}^{\prime(1)} p_{tj}^{(1)}), \quad j = 1, 2, \ldots, 9, \tag{3.48}$$

which is linear in the percentage changes in the variables concerned. Similarly, the demand equation for labour, i.e., equation (3.36), when expressed in terms of percentage changes in the variables can be written as

$$l_j^{(1)} = x_{(j1)}^0 - \sigma_j(p_L^{(1)} - \sum_{t=K,L} S_{tj}^{\prime(1)} p_{tj}^{(1)}), \ \ j = 1, 2, \ldots, 9. \qquad (3.49)$$

Equations (3.37)–(3.40) when expressed in terms of percentage changes can be written as

$$e_j^{(1)} = x_{(j1)}^0, \ \ j = 1, 2, \ldots, 9, \qquad (3.50)$$

$$m_j^{(1)} = x_{(j1)}^0, \ \ j = 1, 2, \ldots, 9, \qquad (3.51)$$

$$x_{sj}^{(1)c} = x_{(j1)}^0, \ \ s = 5, 6, \ldots, 9, \ \ j = 1, 2, \ldots, 9, \qquad (3.52)$$

$$x_{tj}^{(1)c} = x_{(j1)}^0, \ \ t = 0, 1, \ldots, 4, \ \ j = 1, 2, \ldots, 9, \qquad (3.53)$$

respectively; where lower-case symbols denote percentage changes in the variables represented by the upper-case symbols.

Equations (3.48)–(3.53) form a part of the first variant of the CGE energy model. This variant will be called CES-FC model or CES-Fixed Coefficient model since CES and fixed coefficients type of functions have been used to specify the production technology for current production in this variant. Equations (3.48)–(3.53) are amenable to easy interpretation. ***Ceteris paribus***, a one percent increase in the current output level of sector j leads to a one percent increase in the requirements for all inputs in that sector. Other things remaining the same, an increase in the cost to sector j of any particular primary factor leads to substitution away from that factor in favour of the other primary factor but does not affect the requirements of intermediate inputs in that sector. In fact, the demands for intermediate inputs are not directly responsive to any price changes; they respond only to a change in the activity level of sector j. This is the result of the inflexible production technology assumed for current production in Case A which allows substitution only between the primary factors, capital and labour, but assumes fixed input-output relationships for intermediate inputs.

Input demand functions in Case B: Sectoral input demand functions for current production in Case B can be obtained from the set of average cost functions (3.17)–(3.19) by applying Shephard's lemma. Thus the demand functions for capital, labour, energy and aggregate materials for sector j can be obtained from the average cost function (3.17) as

$$K_j^{(1)} = \delta_{Kj} T_j^{(1)} P_{(j1)} X_{(j1)}^0 / P_{Kj}^{(1)}, \; j = 1, 2, \ldots, 9, \tag{3.54}$$

$$L_j^{(1)} = \delta_{Lj} T_j^{(1)} P_{(j1)} X_{(j1)}^0 / P_L^{(1)}, \; j = 1, 2, \ldots, 9, \tag{3.55}$$

$$E_j^{(1)} = \delta_{Ej} T_j^{(1)} P_{(j1)} X_{(j1)}^0 / P_{Ej}^{(1)}, \; j = 1, 2, \ldots, 9, \tag{3.56}$$

$$M_j^{(1)} = \delta_{Mj} T_j^{(1)} P_{(j1)} X_{(j1)}^0 / P_{Mj}^{(1)}, \; j = 1, 2, \ldots, 9, \tag{3.57}$$

where the variables and parameters are defined as before. Similarly, the input demand functions for individual effective fuels for sector j can be obtained from the average cost function (3.18) as

$$X_{sj}^{(1)c} = \delta_{sj}^E P_{Ej}^{(1)} E_j^{(1)} / P_s^c, \; s = 5, 6, \ldots, 9, \; j = 1, 2, \ldots, 9, \tag{3.58}$$

where the variables and parameters are defined as before. The input demand functions for individual effective materials can be obtained from the average cost function (3.19) as

$$X_{tj}^{(1)c} = \delta_{tj}^M P_{Mj}^{(1)} M_j^{(1)} / P_t^c, \; t = 0, 1, \ldots, 4, \; j = 1, 2, \ldots, 9, \tag{3.59}$$

where the variables and parameters are defined as before.

Expressing (3.54)–(3.57) in terms of percentage changes in the variables gives the following set of equations:

$$k_j^{(1)} = x_{(j1)}^0 + p_{(j1)} + t_j^{(1)} - p_{Kj}^{(1)} \tag{3.60}$$

$$l_j^{(1)} = x_{(j1)}^0 + p_{(j1)} + t_j^{(1)} - p_L^{(1)} \tag{3.61}$$

$$e_j^{(1)} = x_{(j1)}^0 + p_{(j1)} + t_j^{(1)} - p_{Ej}^{(1)} \tag{3.62}$$

$$m_j^{(1)} = x_{(j1)}^0 + p_{(j1)} + t_j^{(1)} - p_{Mj}^{(1)} \tag{3.63}$$

where lower-case symbols denote percentage changes in the variables represented by the upper-case symbols. Expressing (3.17) in terms of percentage changes in the variables gives

$$p_{(j1)} = \sum_r S_{rj}^{(1)} p_{rj}^{(1)} - t_j^{(1)}, \quad r = K, L, E, M, \tag{3.64}$$

where the lower-case letters represent percentage changes in the variables and $S_{rj}^{(1)}$ represents the share of factor r ($r = K, L, E, M$) in the total expenditures (excluding production taxes) of sector j for current production. Finally, substituting (3.64) into (3.60)–(3.63) and re-organising the equations, the input demand equations for capital, labour, energy and aggregate materials can be written in percentage change form as follows

$$k_j^{(1)} = x_{(j1)}^0 - (p_{Kj}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}), \quad j = 1, 2, \ldots, 9, \tag{3.65}$$

$$l_j^{(1)} = x_{(j1)}^0 - (p_L^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}), \quad j = 1, 2, \ldots, 9, \tag{3.66}$$

$$e_j^{(1)} = x_{(j1)}^0 - (p_{Ej}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}), \quad j = 1, 2, \ldots, 9, \tag{3.67}$$

$$m_j^{(1)} = x_{(j1)}^0 - (p_{Mj}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}), \quad j = 1, 2, \ldots, 9, \tag{3.68}$$

where the variables and coefficients are defined as before.

Following the same procedure, the input demand equations for individual effective fuels and for individual effective materials, i.e., equations (3.58) and (3.59) respectively, can be written in percentage change form as follows:

$$x_{sj}^{(1)c} = e_j^{(1)} - (p_s^c - \sum_{k=5}^{9} S_{kj}^{(1)E} p_k^c), \quad s = 5, 6, \ldots, 9, \quad j = 1, 2, \ldots, 9, \tag{3.69}$$

$$x_{tj}^{(1)c} = m_j^{(1)} - (p_t^c - \sum_{q=0}^{4} S_{qj}^{(1)M} p_q^c), \quad t = 0, 1, \ldots, 4, \quad j = 1, 2, \ldots, 9, \tag{3.70}$$

where the lower-case letters denote percentage changes in the variables; $S_{kj}^{(1)E}$

represents the share of effective fuel of type k ($k = 5, 6, \ldots, 9$) in the total energy cost of sector j; and $S_{qj}^{(1)M}$ represents the share of effective material of type q ($q = 0, 1, \ldots, 4$) in the total material cost of sector j for current production.

Equations (3.65)–(3.70) constitute a part of the second variant of the CGE energy model. This variant will be called CD model or Cobb-Douglas model since Cobb-Douglas production functions have been used to describe sectoral production technologies for current production.

As in Case A, the input demand equations (3.65)–(3.70) obtained in Case B are amenable to easy interpretation. This set of equations suggest that a one percent increase in the current output level of sector j, other things remaining the same, will lead to a one percent increase in the requirements of all inputs in that sector. This feature of the equations can be ascribed to the assumption of constant returns to scale in production as in Case A. *Ceteris paribus*, if the cost of a factor or input to sector j increases relative to a weighted average of the costs of all factors/inputs in a nest to which this particular factor or input belongs, then there will be substitution away from this factor or input in favour of other factors or inputs in the nest. Contrasting the set of input demand equations in Case B to that in Case A, it can be seen that the intermediate inputs are no longer independent of prices of inputs. In fact, an increase in the cost of a factor or input to sector j, *ceteris paribus*, will induce the sector to readjust its optimal mix of all inputs both primary and intermediate.

Input demand functions in Case C: As in Case A and Case B, the sectoral input demand functions for current production in Case C can be derived from the set of average cost functions (3.20)–(3.22) by applying Shephard's lemma. The demand functions for capital, labour, energy and aggregate materials for sector j can be derived from the average cost function (3.20) as

$$\begin{aligned}
K_j^{(1)} &= X_{(j1)}^0 T_j^{(1)} P_{(j1)} (\beta_{Kj} + \sum_r \beta_{Kr,j} \ln P_{rj}^{(1)}) / P_{Kj}^{(1)}, \\
&\quad r = K, L, E, M, \;\; j = 1, 2, \ldots, 9, && (3.71) \\
L_j^{(1)} &= X_{(j1)}^0 T_j^{(1)} P_{(j1)} (\beta_{Lj} + \sum_r \beta_{Lr,j} \ln P_{rj}^{(1)}) / P_{Lj}^{(1)}, \\
&\quad r = K, L, E, M, \;\; j = 1, 2, \ldots, 9, && (3.72) \\
E_j^{(1)} &= X_{(j1)}^0 T_j^{(1)} P_{(j1)} (\beta_{Ej} + \sum_r \beta_{Er,j} \ln P_{rj}^{(1)}) / P_{Ej}^{(1)}, \\
&\quad r = K, L, E, M, \;\; j = 1, 2, \ldots, 9, && (3.73) \\
M_j^{(1)} &= X_{(j1)}^0 T_j^{(1)} P_{(j1)} (\beta_{Mj} + \sum_r \beta_{Mr,j} \ln P_{rj}^{(1)}) / P_{Mj}^{(1)}, \\
&\quad r = K, L, E, M, \;\; j = 1, 2, \ldots, 9, && (3.74)
\end{aligned}$$

where the variables and parameters are defined as before. The input demand equations for individual effective fuels can be derived from the average cost function (3.21) as follows

$$\begin{aligned}
X_{hj}^{(1)c} &= E_j^{(1)} P_{Ej}^{(1)} (\beta_{hj}^E + \sum_{s=5}^{9} \beta_{hs,j}^E \ln P_s^c) / P_h^c, \;\; h = 5, 6, \ldots, 9, \\
&\quad j = 1, 2, \ldots, 9, && (3.75)
\end{aligned}$$

where $X_{hj}^{(1)c}$ represents the demand for effective fuel of type h ($h = 5, 6, \ldots, 9$) in sector j for current production and other variables and parameters are defined as before. The input demand equations for individual effective materials for sector j can be derived from (3.22) as

$$\begin{aligned}
X_{ij}^{(1)c} &= M_j^{(1)} P_{Mj}^{(1)} (\beta_{ij}^M + \sum_{q=0}^{4} \beta_{iq}^M \ln P_q^c) / P_i^c, \\
&\quad i = 0, 1, \ldots, 4, \;\; j = 1, 2, \ldots, 9, && (3.76)
\end{aligned}$$

where $X_{ij}^{(1)c}$ denotes the demand for effective material of type i ($i = 0, 1, \ldots, 4$) in sector j for current production and other variables and parameters are defined as before.

It is not difficult to derive the percentage change forms of the input demand equations (3.71)–(3.76). The procedure used to do this is illustrated below in relation to equation (3.71).

Let

$$Q_{Kj} = \beta_{Kj} + \sum_r \beta_{Kr,j} \ln P_{rj}^{(1)}, \quad r = K, L, E, M, \tag{3.77}$$

then (3.71) can be written as

$$K_j^{(1)} = X_{(j1)}^0 T_j^{(1)} P_{(j1)} Q_{Kj} / P_{Kj}^{(1)}. \tag{3.78}$$

Expressing (3.78) in logarithmic form, gives

$$\ln K_j^{(1)} = \ln X_{(j1)}^0 + \ln T_j^{(1)} + \ln P_{(j1)} + \ln Q_{Kj} - \ln P_{Kj}^{(1)}. \tag{3.79}$$

Total differential of (3.79) can be written as

$$\begin{aligned} (1/K_j^{(1)})dK_j^{(1)} &= (1/X_{(j1)}^0)dX_{(j1)}^0 + (1/T_j^{(1)})dT_j^{(1)} + (1/P_{(j1)})dP_{(j1)} \\ &\quad + (1/Q_{Kj})dQ_{Kj} - (1/P_{Kj}^{(1)})dP_{Kj}^{(1)}. \end{aligned} \tag{3.80}$$

Multiplying both sides of (3.80) by 100, the percentage change form of (3.78) can be obtained as

$$k_j^{(1)} = x_{(j1)}^0 + t_j^{(1)} + p_{(j1)} + q_{Kj} - p_{Kj}^{(1)} \tag{3.81}$$

where lower-case letters represent percentage changes in the variables denoted by upper-case letters.

Now, differentiating (3.77) totally gives

$$dQ_{Kj} = \sum_r \beta_{Kr,j}(1/P_{rj}^{(1)})dP_{rj}^{(1)}, \quad r = K, L, E, M. \tag{3.82}$$

Multiplying both sides of (3.82) by $(100/Q_{Kj})$ and using the fact that Q_{Kj} is the share of capital in the total cost of sector j net of production taxes, the percentage change form of (3.77) can be written as

$$q_{Kj} = \sum_r (\beta_{Kr,j}/S_{Kj}^{(1)}) p_{rj}^{(1)}, \quad r = K, L, E, M, \tag{3.83}$$

where $S_{Kj}^{(1)}$ is the share of capital in the total expenditure of sector j net of production taxes for current production. Then, substituting (3.83) into (3.81) one obtains the equation

$$\begin{aligned} k_j^{(1)} &= x_{(j1)}^0 + t_j^{(1)} + p_{(j1)} + \sum_r (\beta_{Kr,j}/S_{Kj}^{(1)}) p_{rj}^{(1)} - p_{Kj}^{(1)}, \\ & \quad r = K, L, E, M. \end{aligned} \tag{3.84}$$

One can remove $t_j^{(1)}$ and $p_{(j1)}$ from (3.84) by expressing the average cost function (3.20) in percentage change form and substituting it into (3.84). Taking total differential of (3.20) gives

$$(1/T_j^{(1)})dT_j^{(1)} + (1/P_{(j1)})dP_{(j1)} = \sum_r S_{rj}^{(1)} (1/P_{rj}^{(1)}) dP_{rj}^{(1)}, \tag{3.85}$$

where $S_{rj}^{(1)}$, $r = K, L, E, M$, is the share of r^{th} factor in the total expenditure (excluding production taxes) of sector j for current production. Multiplying both sides of (3.85) by 100 and rearranging give the percentage change form of (3.20) as

$$p_{(j1)} = \sum_r S_{rj}^{(1)} p_{rj}^{(1)} - t_j^{(1)}, \quad r = K, L, E, M. \tag{3.86}$$

Finally, substituting (3.86) into (3.84) and rearranging the terms one gets the percentage change form of (3.71) as

$$\begin{aligned} k_j^{(1)} &= x_{(j1)}^0 - (p_{Kj}^{(1)} - \sum_r S_{Kr,j}^{*(1)} p_{rj}^{(1)}), \quad r = K, L, E, M, \\ & \quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.87}$$

where

$$S^{*(1)}_{Kr,j} = S^{(1)}_{rj} + (\beta_{Kr,j}/S^{(1)}_{Kj}). \tag{3.88}$$

$S^{*(1)}_{Kr,j}$ can be interpreted as the 'modified' cost share of factor r ($r = K, L, E, M$) appearing in the demand equation of capital, K, for sector j when written in percentage change form. It should be noted that $\sum_r S^{*(1)}_{Kr,j} = 1$ since $\sum_r \beta_{Kr,j} = 0$ for $r = K, L, E, M$.

Following the same procedure described above, the percentage change forms of the input demand equations (3.72)–(3.74) can be derived as

$$\begin{aligned} l^{(1)}_j &= x^0_{(j1)} - (p^{(1)}_L - \sum_r S^{*(1)}_{Lr,j} p^{(1)}_{rj}), \quad r = K, L, E, M, \\ &\quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.89}$$

where

$$S^{*(1)}_{Lr,j} = S^{(1)}_{rj} + (\beta_{Lr,j}/S^{(1)}_{Lj}); \tag{3.90}$$

$$\begin{aligned} e^{(1)}_j &= x^0_{(j1)} - (p^{(1)}_{Ej} - \sum_r S^{*(1)}_{Er,j} p^{(1)}_{rj}), \quad r = K, L, E, M, \\ &\quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.91}$$

where

$$S^{*(1)}_{Er,j} = S^{(1)}_{rj} + (\beta_{Er,j}/S^{(1)}_{Ej}); \tag{3.92}$$

and

$$\begin{aligned} m^{(1)}_j &= x^0_{(j1)} - (p^{(1)}_{Mj} - \sum_r S^{*(1)}_{Mr,j} p^{(1)}_{rj}), \quad r = K, L, E, M, \\ &\quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.93}$$

where

$$S^{*(1)}_{Mr,j} = S^{(1)}_{rj} + (\beta_{Mr,j}/S^{(1)}_{Mj}); \tag{3.94}$$

respectively. In (3.89)–(3.94), the lower-case symbols represent percentage changes in the variables concerned, $S^{(1)}_{rj}$ represents the share of factor r ($r = K, L, E, M$) in the total cost of sector j net of production taxes and $S^{*(1)}_{tr,j}$ is the modified total cost share (net) of factor r ($r = K, L, E, M$) appearing in the demand equation of factor t ($t = L, E, M$) of sector j when expressed in percentage change form.

Similarly, the linear percentage change forms of (3.75) and (3.76) can be written as

$$\begin{aligned} x^{(1)c}_{hj} &= e^{(1)}_j - (p^c_h - \sum_{s=5}^{9} S^{*(1)E}_{hs,j} p^c_s), \quad h = 5, 6, \ldots, 9, \\ & \quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.95}$$

where

$$S^{*(1)E}_{hs,j} = S^{(1)E}_{sj} + (\beta^E_{hs,j}/S^{(1)E}_{hj}); \tag{3.96}$$

and

$$\begin{aligned} x^{(1)c}_{ij} &= m^{(1)}_j - (p^c_i - \sum_{q=0}^{4} S^{*(1)M}_{iq,j} p^c_q), \quad i = 0, 1, \ldots, 4, \\ & \quad j = 1, 2, \ldots, 9, \end{aligned} \tag{3.97}$$

where

$$S^{*(1)M}_{iq,j} = S^{(1)M}_{qj} + (\beta^M_{iq,j}/S^{(1)M}_{ij}), \tag{3.98}$$

respectively. In (3.95) and (3.96), the lower-case letters represent percentage changes in the variables concerned, $S^{(1)E}_{sj}$ represents the share of effective fuel of type s ($s = 5, 6, \ldots, 9$) in the total energy cost of sector j for current production and $S^{*(1)E}_{hs,j}$ represents modified energy cost share of effective fuel of type s ($s = 5, 6, \ldots, 9$) appearing in the demand equation of effective fuel of type h ($h = 5, 6, \ldots, 9$) of sector j when expressed in percentage change form. In (3.97) and (3.98), the lower-case letters represent percentage changes, as before, in the variables concerned, $S^{(1)M}_{qj}$ represents the share of effective material of type q ($q = 0, 1, \ldots, 4$) in the total material cost of sector j for current production and $S^{*(1)M}_{iq,j}$ represents modified material cost share of effective material of type q ($q = 0, 1, \ldots, 4$) appearing in the demand equation of effective material of type i ($i = 0, 1, \ldots, 4$) of sector j when expressed in percentage change form.

As in Case A and Case B, input demand equations (3.87), (3.89), (3.91), (3.93), (3.95) and (3.97) in Case C pose no problem for interpretation. This set of input demand equations suggests that a one percent increase in the current output level of sector j, ***ceteris paribus***, will lead to a one percent increase in the requirements of all inputs in that sector. Thus this set of input demand equations reflects the assumption of constant returns to scale in current production. In contrast to Case A but as in Case B, this set of input demand equations also suggests that an increase in the cost of any input to sector j, ***ceteris paribus***, will lead to readjustment of the optimal mix of all inputs, both primary and intermediate, in that sector. Although this interpretation of the input demand equations in Case C sounds the same as what has been provided in the context of corresponding equations in Case B, there are major differences between these two sets of input demand equations. These are:

(i) The weights given to percentage changes in input prices are cost shares in Case B while they are modified cost shares in Case C.

(ii) These weights in Case B remain constant across input demand equations in a nest. But the weights used in Case C vary across input demand equations in a nest.

(iii) In Case B, substitutability between inputs has been assumed but complementarity between inputs has been ruled out. This assumption results in positive weights for percentage changes in all input prices. As a result, an increase in the price of one input in a nest leads to an increase in the demand for other inputs in the nest. Since translog cost functions allow complementarity between inputs, all of the weights need not be positive in Case C. If, for example, $\beta_{KE,j}$ is sufficiently negative, then $S^{*(1)}_{KE,j}$ (modified cost share of energy appearing in the capital demand equation) will be negative and an increase in the price of energy, $P^{(1)}_{Ej}$, *ceteris paribus*, will reduce the demand for capital rather than increasing it. Similar cases may arise with respect to other pairs of inputs.

Due to these differences between input demand equations in Case B and those in Case C, the third variant of the CGE energy model which contains input demand equations obtained in Case C will provide different results from those provided by the second variant of the CGE model which contains input demand equations of Case B. The third variant of the CGE energy model will be called TL model or Translog model since it utilises translog functions to describe the sectoral production technologies for current production.

3.2 Demands for Inputs for Capital Goods Production

In this section, the demand functions for inputs required for the creation of capital goods are discussed. It is assumed that producers of capital goods are competitive and efficient like the producers involved in current goods production. They are also assumed to experience constant returns to scale in the creation of capital. However, a point of contrast between the technologies for current production and those for capital creation is that capital creation requires no inputs of capital and labour. The use of labour and capital associated with capital goods creation is recognised through the inputs of construction, i.e., the construction industries use labour and capital and the production of capital goods requires heavy inputs of construction. Under these assumptions, the technological constraints and producers behaviour in capital goods production can be represented by a nested set of average cost functions similar to those for current production.

Choosing translog form, these unit cost functions can be specified as

$$\begin{aligned}
\ln(T_j^{(2)} P_{Ij}) &= \alpha_{0j} + \sum_r \alpha_{rj} \ln P_{rj}^{(2)} + \frac{1}{2}\sum_r \sum_s \alpha_{rs,j} \ln P_{rj}^{(2)} \ln P_{sj}^{(2)} \\
& \quad r, s = E, M, \;\; j = 1, 2, \ldots, 9; \qquad (3.99) \\
\ln P_{Ej}^{(2)} &= \alpha_{0j}^E + \sum_m \alpha_{mj}^E \ln P_m^c + \frac{1}{2}\sum_m \sum_n \alpha_{mn,j}^E \ln P_m^c \ln P_n^c \\
& \quad m, n = 5, 6, \ldots, 9, \;\; j = 1, 2, \ldots, 9; \qquad (3.100) \\
\ln P_{Mj}^{(2)} &= \alpha_{0j}^M + \sum_u \alpha_{uj}^M \ln P_u^c + \frac{1}{2}\sum_u \sum_v \alpha_{uv,j}^M \ln P_u^c \ln P_v^c \\
& \quad u, v = 0, 1, \ldots, 4, \;\; j = 1, 2, \ldots, 9, \qquad (3.101)
\end{aligned}$$

where $T_j^{(2)}$ is the one minus the rate of production tax in sector j for capital goods production; P_{Ij} is the basic price of the capital good produced by sector j; $P_{rj}^{(2)}$, is the unit cost of aggregate input r ($r = E$ is energy and $r = M$ is aggregate materials input) to sector j which uses that input for capital production; P_i^c is the basic price of effective good i, $i = 0, 1, \ldots, 9$, used in capital production in sector j; and α's are parameters of the translog cost functions for capital production.

Now applying Shephard's lemma to (3.99)–(3.101), the demands for effective inputs for capital goods creation in sector j can be specified as

$$\begin{aligned}
E_j^{(2)} &= I_j T_j^{(2)} P_{Ij}(\alpha_{Ej} + \sum_s \alpha_{Es,j} \ln P_{sj}^{(2)}) / P_{Ej}^{(2)}, \\
& \quad s = E, M, \;\; j = 1, 2, \ldots, 9; \qquad (3.102) \\
M_j^{(2)} &= I_j T_j^{(2)} P_{Ij}(\alpha_{Mj} + \sum_s \alpha_{Ms,j} \ln P_{sj}^{(2)}) / P_{Mj}^{(2)}, \\
& \quad s = E, M, \;\; j = 1, 2, \ldots, 9; \qquad (3.103)
\end{aligned}$$

$$X_{hj}^{(2)c} = E_j^{(2)} P_{Ej}^{(2)} (\alpha_{hj}^E + \sum_{r=5}^{9} \alpha_{hr,j}^E \ln P_r^c)/P_h^c,$$
$$h = 5, 6, \ldots, 9, \;\; j = 1, 2, \ldots, 9; \qquad (3.104)$$
$$X_{ij}^{(2)c} = M_j^{(2)} P_{Mj}^{(2)} (\alpha_{ij}^M + \sum_{q=0}^{4} \alpha_{iq,j}^M \ln P_q^c)/P_i^c,$$
$$i = 0, 1, \ldots, 4, \;\; j = 1, 2, \ldots, 9; \qquad (3.105)$$

where I_j is the amount of capital goods produced in sector j; $E_j^{(2)}$ is the demand for energy, $M_j^{(2)}$, the demand for aggregate materials, $X_{hj}^{(2)c}$, the demand for effective fuel of type h, $(h = 5, 6, \ldots, 9)$, and $X_{ij}^{(2)c}$, the demand for effective material of type i, $(i = 0, 1, \ldots, 4)$ in sector j for capital goods creation; and other variables are defined as before.

Following the procedure adopted in connection with current production in Case C, the linear percentage change forms of (3.102)–(3.105) can be written as

$$e_j^{(2)} = i_j - (p_{Ej}^{(2)} - \sum_r S_{Er,j}^{*(2)} p_{rj}^{(2)}), \;\; r = E, M, \;\; j = 1, 2, \ldots, 9, \qquad (3.106)$$

where

$$S_{Er,j}^{*(2)} = S_{rj}^{(2)} + (\alpha_{Er,j}/S_{Ej}^{(2)}); \qquad (3.107)$$

$$m_j^{(2)} = i_j - (p_{Mj}^{(2)} - \sum_r S_{Mr,j}^{*(2)} p_{rj}^{(2)}), \;\; r = E, M, \;\; j = 1, 2, \ldots, 9, \qquad (3.108)$$

where

$$S_{Mr,j}^{*(2)} = S_{rj}^{(2)} + (\alpha_{Mr,j}/S_{Mj}^{(2)}); \qquad (3.109)$$

$$x_{hj}^{(2)c} = e_j^{(2)} - (p_h^c - \sum_{t=5}^{9} S_{ht,j}^{*(2)E} p_t^c), \quad h = 5, 6, \ldots, 9,$$
$$j = 1, 2, \ldots, 9, \qquad (3.110)$$

where

$$S_{ht,j}^{*(2)E} = S_{tj}^{(2)E} + (\alpha_{ht,j}^{E} / S_{hj}^{(2)E}); \qquad (3.111)$$

and

$$x_{ij}^{(2)c} = m_j^{(2)} - (p_i^c - \sum_{q=0}^{4} S_{iq,j}^{*(2)M} p_q^c), \quad i = 0, 1, \ldots, 4,$$
$$j = 1, 2, \ldots, 9, \qquad (3.112)$$

where

$$S_{iq,j}^{*(2)M} = S_{qj}^{(2)M} + (\alpha_{iq,j}^{M} / S_{ij}^{(2)M}); \qquad (3.113)$$

respectively. In equations (3.106)–(3.113), the lower-case symbols denote percentage changes in the variables represented by the upper-case symbols; $S_{rj}^{(2)}$, $r = E, M$, is the share of r^{th} aggregate input in the total cost of sector j, net of production taxes, for capital formation; $S_{Er,j}^{*(2)}$, $r = E, M$, is the modified cost share of r^{th} aggregate input appearing in the energy demand equation of sector j; $S_{Mr,j}^{*(2)}$, $r = E, M$, is the modified cost share of r^{th} aggregate input appearing in the aggregate materials demand equation of sector j; $S_{tj}^{(2)E}$, $t = 5, 6, \ldots, 9$, is the share of t^{th} fuel in the total energy cost of sector j for capital formation; $S_{ht,j}^{*(2)E}$, $h, t = 5, 6, \ldots, 9$, is the modified energy cost share of fuel t appearing in the demand equation of fuel h of sector j; $S_{qj}^{(2)M}$, $q = 0, 1, \ldots, 4$, is the share of q^{th} individual material in the total material cost of sector j for capital formation; and $S_{iq,j}^{*(2)M}$, $i, q = 0, 1, \ldots, 4$, is the modified material cost share of material q appearing in the demand equation of material i of sector j. Input demand equations (3.106), (3.108), (3.110) and

(3.112) have similar interpretations as those obtained for current production in Case C except that these equations relate to capital goods production.

So far, it is not explained how the investment level in sector j, I_j, ($j = 1, 2, \ldots, 9$) will be determined in the models. This is done in Section 3.7. However, given the level of investment in sector j, I_j, the derived demand functions (3.102)–(3.105) will determine the cost minimising input levels used for capital creation in sector j.

3.3 Household Demands for Commodities

The structural equations for household demands for commodities are derived from a utility maximising model. In specifying the model, it is assumed that consumers derive utility from effective goods which are aggregates of domestic and matching foreign goods. The process of aggregation is discussed in Section 3.5. Moreover, it is assumed that consumer demands can be treated as if they arise from the maximisation of a single utility function subject to a budget constraint. In other words, it is assumed that aggregation across consumers is legitimate.

Let Q be the number of households and $X_i^{(3)c}$ be the number of units of effective good i, $i = 0, 1, \ldots, 9$,[3] consumed by the household sector. Then the utility maximising model determines the consumption bundle of effective goods for the average household, $X_i^{(3)c}/Q$, so as to maximise

$$U = U(\bar{X}_0^{(3)c}, \bar{X}_1^{(3)c}, \ldots, \bar{X}_9^{(3)c}) \tag{3.114}$$

subject to

$$\sum_{i=0}^{9} \bar{P}_i^{(3)c} \bar{X}_i^{(3)c} = C^{(3)}, \tag{3.115}$$

[3]Note that when $i = 0$, the effective good is non-competing imports.

where

$$\bar{X}_i^{(3)c} = X_i^{(3)c}/Q, \quad i = 0, 1, \ldots, 9, \tag{3.116}$$

and

$$\bar{P}_i^{(3)c} = P_i^{(3)c}Q, \quad i = 0, 1, \ldots, 9, \tag{3.117}$$

where $P_i^{(3)c}$ is the price of effective good i, $i = 0, 1, \ldots, 9$, paid by the household sector; $C^{(3)}$ is the aggregate consumer expenditure; and other variables are defined as above. Note that the price paid by the household sector for the effective good i differs from its basic price by an amount which is equal to the basic price times the rate of consumption tax. Consumer prices are defined in Section 3.6.

The first-order conditions for a solution of the problem specified by equations (3.114) and (3.115) can be written as

$$\frac{\delta U}{\delta \bar{X}_i^{(3)c}} - \Lambda \bar{P}_i^{(3)c} = 0, \quad i = 0, 1, \ldots, 9, \tag{3.118}$$

and

$$\sum_{i=0}^{9} \bar{P}_i^{(3)c} \bar{X}_i^{(3)c} = C^{(3)}, \tag{3.119}$$

where Λ is the Lagrangian multiplier.

Solving the first-order conditions gives

$$\bar{X}_i^{(3)c} = \bar{X}_i^{(3)c}(\bar{P}_0^{(3)c}, \bar{P}_1^{(3)c}, \ldots, \bar{P}_9^{(3)c}, C^{(3)}), \quad i = 0, 1, \ldots, 9. \tag{3.120}$$

The percentage change form of (3.120) can be written as

$$\bar{x}_i^{(3)c} = \varepsilon_i c^{(3)} + \sum_{k=0}^{9} \eta_{ik} \bar{p}_k^{(3)c}, \quad i = 0, 1, \ldots, 9, \tag{3.121}$$

where ε_i, η_{ik}, $i, k = 0, 1, \ldots, 9$, can be interpreted as expenditure and own- and cross-price elasticities satisfying the usual restrictions—homogeneity, symmetry and Engel's aggregation. Finally, substituting percentage change forms of (3.116) and (3.117), i.e.,

$$\bar{x}_i^{(3)c} = x_i^{(3)c} - q$$

and

$$\bar{p}_i^{(3)c} = p_i^{(3)c} + q$$

respectively, into (3.121) gives the relationships for unbarred variables as

$$x_i^{(3)c} = q + \varepsilon_i(c^{(3)} - q) + \sum_{k=0}^{9} \eta_{ik} p_k^{(3)c}, \quad i = 0, 1, \ldots, 9. \tag{3.122}$$

In deriving (3.122), the homogeneity restriction has been taken into account, which says

$$\sum_{k=0}^{9} \eta_{ik} = -\varepsilon_i. \tag{3.123}$$

To assign numerical values to the elasticities in (3.122), one will have to estimate a system of demand equations derived from an explicitly specified utility function. In this regard, one can draw on the extensive literature on the systems approach to applied demand theory. (See Powell (1974) for a survey of both economic theory and econometrics of the systems approach to applied demand theory.) An illustration can be provided in this regard by utilising an explicit utility function of the Klein-Rubin form (Klein and Rubin 1948-49), i.e.,

$$U = \sum_{i=0}^{9} \delta_i \ln(\bar{X}_i^{(3)c} - \theta_i) \tag{3.124}$$

where δ_i and θ_i, $i = 0, 1, \ldots, 9$, are parameters with $\delta_i > 0$ for all i and $\sum_i \delta_i = 1$. Utility functions of the form (3.124) are also known as Stone-Geary utility functions in recognition of the contributions of Stone (1954) and Geary (1950-51).

Solving the first-order conditions of utility maximisation, (3.118) and (3.119), in the context of utility function (3.124) gives the system of demand equations

$$\bar{X}_i^{(3)} = \theta_i + \delta_i(C^{(3)} - \sum_{k=0}^{9} P_k^{(3)c}\theta_k)/P_i^{(3)c}, \quad i = 0, 1, \ldots, 9. \tag{3.125}$$

Once the system of equations (3.125) is estimated, one can proceed to estimate

$$\varepsilon_i = \hat{\delta}_i / S_i^{(3)c}, \quad i = 0, 1, \ldots, 9, \tag{3.126}$$

$$\eta_{ik} = -\hat{\delta}_i S_k^{*(3)c} / S_i^{(3)c}, \quad \textit{for all } i \neq k, \tag{3.127}$$

and

$$\eta_{ii} = -\varepsilon_i - \sum_{k \neq i} \eta_{ik}, \tag{3.128}$$

where

$$S_i^{(3)c} = P_i^{(3)c} \bar{X}_i^{(3)c} / \sum_k P_k^{(3)c} \bar{X}_k^{(3)c}, \quad i = 0, 1, \ldots, 9, \tag{3.129}$$

and

$$S_i^{*(3)c} = P_i^{(3)c} \hat{\theta}_i / \sum_k P_k^{(3)c} \bar{X}_k^{(3)c}, \quad i = 0, 1, \ldots, 9. \tag{3.130}$$

In (3.126)–(3.130), $\hat{\delta}$'s and $\hat{\theta}$'s are estimates of the parameters appearing in the system of equations (3.125); $S_i^{(3)c}$ can be interpreted as the share of household expenditure devoted to effective good i; $S_i^{*(3)c}$ can be interpreted as 'modified' expenditure share; and other variables are defined as before.

Before concluding this section, it should be emphasised that one can always improve on the present demand specification by implementing a nonadditive utility function instead of the additive form (3.124). One implication of the additive specification (3.124) is that

$$\frac{\delta^2 U}{\delta \bar{X}_i^{(3)c} \delta \bar{X}_j^{(3)c}} = 0, \quad for \ all \ i \neq j,$$

i.e., marginal utility of good i to a consumer is independent of his consumption of good j for all $i \neq j$ which is theoretically restrictive.

Another point to note is that one could improve upon the present model by including different types of consumers in the model. However, Dixon *et al.* (1982) have argued that the payoff for doing that in terms of more accurate simulation of aggregate consumer behaviour might be quite small unless there is large demographic change or major redistribution of income in the economy. Their view in this regard has empirical support from Dixon, Harrower and Vincent (1978) and Dixon (1975, Ch. 2).

3.4 Government Demands for Commodities

In deriving government demand functions for commodities, it is assumed that government preferences for them can be represented by a Cobb-Douglas utility function which can be specified as

$$\ln U = \sum_{i=0}^{9} \alpha_i^{(4)c} \ln X_i^{(4)c}, \qquad \sum_i \alpha_i^{(4)c} = 1 \tag{3.131}$$

In (3.131), $X_i^{(4)c}$ represents units of effective good i, $i = 0, 1, \ldots, 9$, used in the government sector; U represents the utility level; and α's are parameters of the utility function.

It is further assumed that the government determines $X_i^{(4)c}$ so that its utility, defined by (3.131), is maximised subject to the budget constraint

$$C^{(4)} = \sum_{i=0}^{9} P_i^c X_i^{(4)c}, \tag{3.132}$$

where $C^{(4)}$ is the aggregate government expenditure and other variables are defined as above. The first-order conditions for this maximisation problem are:

$$(\alpha_i^{(4)c}/X_i^{(4)c})U - \Lambda P_i^c = 0, \quad i = 0, 1, \ldots, 9, \tag{3.133}$$

$$C^{(4)} = \sum_{i=0}^{9} P_i^c X_i^{(4)c}, \tag{3.134}$$

where Λ is the Lagrangian multiplier.

Solving (3.133) and (3.134), the government demand functions for effective good i, $X_i^{(4)c}$, can be obtained as

$$X_i^{(4)c} = (\alpha_i^{(4)c} C^{(4)}/P_i^c) F_i^{(4)c}, \quad i = 0, 1, \ldots, 9, \tag{3.135}$$

where the multiplicative $F_i^{(4)c}$ is added to take care of exogenous shifts in government demand.

In percentage change form (3.135) can be written as

$$x_i^{(4)c} = c^{(4)} - p_i^c + f_i^{(4)c}, \quad i = 0, 1, \ldots, 9, \tag{3.136}$$

where lower-case symbols denote percentage changes in the variables concerned. The restrictiveness of the Cobb-Douglas function in representing consumer preferences is reflected in the demand fuctions (3.136). From (3.136) it is obvious that Cobb-Douglas type of utility functions impose the restrictions that expenditure and own-price elasticities of demand are unity and cross-price elasticities are zero. These restrictions are neither theoretically nor empirically plausibile.

3.5 Foreign Sector

In this section, Australian demand for imports and foreign demand for Australian exports are discussed. Moreover, the processes of forming effective goods are also discussed here. Subsection 3.5.1 is concerned with the derivation of demand functions for domestically produced commodities and imported commodities. Note that in this study it is assumed that producers and consumers do not directly use domestic and competing imports. They use effective goods and effective goods are produced by combining domestic and matching imported goods. Subsection 3.5.2 is devoted to the derivation of foreign demand functions for Australian exports.

3.5.1 Demand for domestic and imported goods

International trade and trade policies can be incorporated in a multi-sector general equilibrium model by making few simplifying assumptions. One of the assumptions often made in international trade theory is the standard small-country assumption. The small-country assumption is, as a matter of fact, a combination of two other assumptions: (a) the share of a country in the world market is very small, and (b) consumers do not differentiate products by country or region of origin. This assumption further implies that a small country behaves like a small firm in a competitive market, i.e., it is a price taker and cannot affect the terms at which it trades.

Although the small-country assumption allows a clear-cut analysis of links between foreign trade and domestic economy, it is very hard to reconcile it with observed facts. As Dervis, *et al.* (1982) argue, the small-country assumption coupled with an assumption of constant returns to scale on the production side leads to a tendency toward extreme specialisation in production that does not fit empirical evidence. The assumption of perfect substitutability in use between goods of domestic and foreign origins rules out the possibility of two-way trade if one assumes away existence of inter-country transportation and storage costs. A good is either exported or imported but never both. Moreover, the assumption of perfect substitutability implies "the law of one price". In other words, world prices determine the domestic prices of tradables, and a given product has the same price irrespective of whether it is produced domestically or imported from a foreign country. These implications—extreme specialisation in production, one-way trade and one price for domestic and foreign goods—are quite inconsistent with empirical observations. In reality, two-way trade can be observed in trade statistics even when products are classified in extremely disaggregated form. Grubel and Lloyd (1975) have found significant two-way trade even at a seven digit standard industrial trade classification level.

Considering the implications of the small-country assumption, as noted above, it is hard to justify the use of such an assumption in applied multisector general equilibrium models especially when the model deals with fairly aggregated sectors. Making the small-country assumption for an aggregated sector, say agriculture, implies that there is no product differentiation between agricultural imports and domestic agricultural products, that agricultural goods will either be imported or exported but never both and that changes in world prices, exchange rates and tariffs are fully translated into changes in domestic prices. Thus in a country where agricultural imports consist largely of cereal grains and the domestic agricultural sector produces mainly beef cattle, the small-country assumption implies that a 40 percent decrease in the import price of cereal grains will lead to a 40 percent decrease in the price of beef cattle.

As a matter of fact, the assumption of perfect substitutability included in the small-country assumption greatly exaggerates the power that trade policy has over the domestic price system and domestic economic structure. Accordingly, the small-country assumption in its pure form is quite untenable as a workable approximation particularly in the context of building applied, fairly aggregated, multi-sector general equilibrium models. No doubt, disaggregation definitely helps but it is empirically quite impossible to implement a general equilibrium model at such a level of disaggregation that will avoid completely the problems of perfect substitutability.

Another assumption, opposite to the perfect substitutability assumption, has often been made in planning literature, particularly in "two-gap" models.

According to this assumption, imports are treated as "noncompetitive", and the degree of substitutability between domestic and foreign goods is assumed to be zero. In other words, imports are treated as if they are perfect complements to domestic commodities. This assumption introduces a great deal of rigidity into the models. In particular, changes in relative prices induced by trade policies can have no, or only a very indirect, effect on the structure of the domestic economy. "This rigidity leads to foreign exchange "gaps" that cannot be alleviated by trade and exchange rate policy" (Dervis *et al.* 1982).

The two assumptions discussed above do not represent real world phenomena. Reality is obviously somewhere in between. For any given level of aggregation, foreign and domestic goods are not identical, may have different prices, and may be characterised by a degree of substitutability that varies across sectors. To capture these features, some studies (Dixon, *et al.* 1982, Petri 1976, Dervis *et al.* 1982 and Whalley 1977) have introduced product differentiation by country of origin into the structure of demand for commodities.

This approach which allows one to keep aggregate commodity categories but introduces product differentiation by country of origin into the structure of demand was originally proposed by Armington (1969, 1970). It has been very useful for building trade-oriented applied general equilibrium models. The formulation suggested by Armington allows a flexible and intermediate specification representing a useful compromise between the extreme assumptions of perfect substitution and perfect complementarity.

In the present study, imports are classified into two categories: (a) non-competitive imports and (b) competitive imports. Non-competitive imports are those imports for which there are no matching domestic products. Competitive imports are those imports for which there are matching domestic products. It has been assumed that these types of imports are imperfectly substitutable in use with domestic products. In Sections 3.1–3.4, it has been assumed that producers involved in the production of current and capital goods and consumers as well as government use effective goods which are aggregates of domestic and matching imported goods. It is not explained there how these effective goods are formed.

Following Armington, an effective good, X_i^c, is defined as a CES function of commodities produced abroad, $X_{(i2)}^c$, and commodities produced domestically, $X_{(i1)}^c$. That is,

$$\begin{aligned} X_i^c &= \bar{A}_i[\mu_i(X_{(i1)}^c)^{-\rho_i} + (1-\mu_i)(X_{(i2)}^c)^{-\rho_i}]^{-\frac{1}{\rho_i}}, \\ & i = 1, 2, \ldots, 9, \end{aligned} \tag{3.137}$$

where $\bar{A}_i$, μ_i and ρ_i are technical efficiency, distribution and trade-substitution parameters respectively. (In such a formulation, the demands for imports and domestically produced goods become derived demands, in just the same way as the demands for factor inputs are derived demands in a traditional production model.) Given the prices for the imported and domestic goods, the problem facing the user or buyer is mathematically equivalent to that facing the firm wishing to produce a specified level of output at minimum cost. The demand functions for imports and domestic goods can be derived from the first-order conditions of cost minimisation.

An equivalent but easier way to derive the demand functions for domestically produced goods and imports is to derive them from the unit cost functions of effective goods by applying Shephard's lemma. Under the assumption of cost minimisation, the unit cost function for effective good i corresponding to the CES aggregation function can be defined as

$$\begin{aligned} P_i^c &= \frac{1}{\bar{A}_i}[\mu_i^{\sigma_i^c} P_{(i1)}^{(1-\sigma_i^c)} + (1-\mu_i)^{\sigma_i^c} P_{(i2)}^{(1-\sigma_i^c)}]^{\frac{1}{1-\sigma_i^c}} \\ & i = 1, 2, \ldots, 9, \end{aligned} \tag{3.138}$$

where P_i^c is the average cost or price of effective good i; $P_{(i1)}$ and $P_{(i2)}$ are basic prices of domestic good i and imported good i respectively; $\bar{A}_i$ and μ_i

are defined as above; and σ_i^c is the 'trade-substitution elasticity' parameter or Armington elasticity. Applying Shephard's lemma to (3.138) gives

$$X_{(i1)}^c = \frac{1}{\bar{A}_i}[\mu_i\{\mu_i^{\sigma_i^c} P_{(i1)}^{(1-\sigma_i^c)} + (1-\mu_i)^{\sigma_i^c} P_{(i2)}^{(1-\sigma_i^c)}\}^{\frac{1}{1-\sigma_i^c}} / P_{(i1)}]^{\sigma_i^c} X_i^c \quad i = 1,2,\ldots,9, \tag{3.139}$$

and

$$X_{(i2)}^c = \frac{1}{\bar{A}_i}[(1-\mu_i)\{\mu_i^{\sigma_i^c} P_{(i1)}^{(1-\sigma_i^c)} + (1-\mu_i)^{\sigma_i^c} P_{(i2)}^{(1-\sigma_i^c)}\}^{\frac{1}{1-\sigma_i^c}} / P_{(i2)}]^{\sigma_i^c} X_i^c \quad i = 1,2,\ldots,9, \tag{3.140}$$

where the variables and parameters are defined as before.

If it is further assumed that the aggregation function for effective good i, $i = 1,2,\ldots,9$, is the same for all users, the variable X_i^c can be considered as total demand for or supply of effective good i. $X_{(i1)}^c$ and $X_{(i2)}^c$ then represent total requirements of domestic and imported goods respectively for the production of X_i^c.

The percentage change forms of (3.139) and (3.140) can be obtained easily by following the procedure described in the context of deriving percentage change forms of capital and labour demand equations in Case A of current production. That is, substituting the percentage change form of (3.138) into the percentage forms of (3.139) and (3.140) and simplifying one can finally write the percentage change forms of (3.139) and (3.140) as

$$x_{(i1)}^c = x_i^c - \sigma_i^c(p_{(i1)} - \sum_{t=1}^{2} S_{(it)}^c p_{(it)}), \quad i = 1,2,\ldots,9, \tag{3.141}$$

and

$$x_{(i2)}^c = x_i^c - \sigma_i^c(p_{(i2)} - \sum_{t=1}^{2} S_{(it)}^c p_{(it)}), \quad i = 1,2,\ldots,9, \tag{3.142}$$

respectively. In (3.141) and (3.142), the lower-case symbols denote percentage changes in the variables concerned and $S_{(i1)}^c$ and $S_{(i2)}^c$ represent the shares of domestic good i and imported good i respectively in the total cost of producing effective good i.

If other things remain the same, equations (3.141) and (3.142) imply that a one percent increase in the output of effective good i will lead to a one percent increase in the requirements of both domestic and imported goods in its production. Moreover, these equations suggest that an increase in the cost of domestic good i, *ceteris paribus*, relative to the cost of imported good i will lead to substitution away from the domestic good in favour of the imported good in the production of effective good i.

3.5.2 Foreign demand for Australian exports

In the present study, it has been assumed that all exports are domestically produced , i.e., no imports are exported without flowing through a domestic industry. The foreign demand function for the domestic good i is specified as

$$P^{w}_{(i1)} = \Psi_i(X^{(5)}_{(i1)})F^{w}_{(i1)}, \quad i = 1, 2, \ldots, 9, \tag{3.143}$$

where $P^{w}_{(i1)}$ is the f.o.b. price of export good i in foreign currency. Ψ_i is a non-increasing function of $X^{(5)}_{(i1)}$ and $X^{(5)}_{(i1)}$ is the volume of exports of good i. Finally, $F^{w}_{(i1)}$ is a shift variable which models exogenous shifts in foreign demand for domestic good i. $F^{w}_{(i1)}$ increases if there is an exogenous increase in the foreign demand for export good i.

Expressing in percentage change form, (3.143) becomes

$$p^{w}_{(i1)} = -\gamma_i x^{(5)}_{(i1)} + f^{w}_{(i1)}, \quad i = 1, 2, \ldots, 9, \tag{3.144}$$

where

$$-\gamma_i = \frac{\delta \Psi_i}{\delta X^{(5)}_{(i1)}} \frac{X^{(5)}_{(i1)}}{\Psi_i}$$

i.e., γ_i is non-negative and can be interpreted as the reciprocal of the foreign elasticity of demand for Australian export good i, $i = 1, 2, \ldots, 9$.

Equation (3.144) is flexible and can be used to model different situations in export markets. For example, if Australia's share in world market for a particular export good i is relatively small, then, γ_i can be set equal to zero which has the implication that the foreign currency f.o.b. price of export good i is independent of the volume of Australian exports of good i. If the export volume and price of an export good i is determined by government agreement, then such situation can be handled by setting γ_i at zero and fixing $f^w_{(i1)}$ and $x^{(5)}_{(i1)}$ exogenously. For a commodity enjoying well-developed world market in which Australia has a major share, e.g., wool, the γ_i can be set at a value other than zero.

3.6 Pricing Equations

In specifying the price systems in the economy three initial assumptions are made. Firstly, there are no pure profits in any activity, e.g., in producing current products and capital goods, exporting, importing, etc. Secondly, basic prices are assumed uniform across users and across producing industries in the case of domestic goods and importers in the case of foreign goods. Finally, it is assumed that economic actors are responsive to the basic prices of the inputs and commodities save the households which are assumed to be responsive to the consumers' prices of effective goods. This is not a good assumption because relative costs of inputs or commodities to an economic agent are best signalled by the set of purchasers' prices rather by the basic prices. The difference between the cost of an input or commodity to a purchaser and the basic price is composed of margins such as transport and storage services, wholesale and retail margins, etc. If these differences between purchasers' prices and basic prices are negligible, then the assumption that economic agents base their decisions regarding the choice of the optimal mix of inputs or mix of commodities will not lead to significant distortions in the results.

The final assumption noted above is made to avoid modelling the margins separately as is done in the ORANI model. In this study, it is assumed that the direct flows and margins (i.e., flows facilitating the transactions of direct flows) from a sector are perfect substitutes for each other. As pointed out by Dixon *et al.* (1982), such a treatment of the margins is likely to introduce some strange distortions in the results. Since the margins are treated just as other goods, an increase in the price of agricultural products, for example, will lead to an increased use of transportation products both as direct and margin flows by all users of this product. However, a more plausible outcome of the increase in the price of agricultural products is likely to be an increase in the use of transport products as direct flows but a decrease in the use of transport products as margins associated with the flows of agricultural products. One possible way to model the margins and purchasers' prices satisfactorily is also demonstrated and implemented by Dixon *et al.* (1982). They have modelled the margins separately by specifying a set of equations which relate margins to the direct flows with which they are associated. *Ceteris paribus*, changes in the direct flows of commodities lead to proportionate changes in the requirements for margins. But their model is also capable of simulating the effects of changes in the amounts of margin service associated with various commodity flows. Although it is important to model the margins separately because of their different nature from direct flows, it is not done in this study in order to keep the models small and simple. The objective of the present study, as has been mentioned before, is to examine the sensitivity of model results to alternative specifications of production technologies for current production. If distortions are introduced for not modelling margins separately, they will affect all three variants of the CGE energy model equally and, as a result, the examination of the sensitivity of the results is not likely to be hampered.

Under the assumptions noted above, the zero-pure-profit conditions for current production of sector j can be defined as

$$
\begin{aligned}
T_j^{(1)} P_{(j1)} X_{(j1)}^0 &= P_{Kj}^{(1)} K_j^{(1)} + P_L^{(1)} L_j^{(1)} + P_{Ej}^{(1)} E_j^{(1)} + P_{Mj}^{(1)} M_j^{(1)}, \\
& \quad j = 1, 2, \ldots, 9, & (3.145) \\
P_{Ej}^{(1)} E_j^{(1)} &= \sum_{h=5}^{9} X_{hj}^{(1)c} P_h^c, \;\; j = 1, 2, \ldots, 9, & (3.146) \\
P_{Mj}^{(1)} M_j^{(1)} &= \sum_{i=0}^{4} X_{ij}^{(1)c} P_i^c, \;\; j = 1, 2, \ldots, 9, & (3.147)
\end{aligned}
$$

where the variables are defined as before. Equation (3.145) defines the zero-pure-profit condition in the production of current goods in sector j by equating total revenue net of taxes to the total payment for inputs; equation (3.146) defines zero-pure-profit condition in the creation of energy input in sector j; and equation (3.147) defines zero-pure-profit condition in the creation of aggregate materials input in sector j. When expressed in terms of percentage changes in the variables, these equations take the following forms:

$$
\begin{aligned}
p_{(j1)} &= S_{Kj}^{(1)}(p_{Kj}^{(1)} + k_j^{(1)}) + S_{Lj}^{(1)}(p_L^{(1)} + l_j^{(1)}) + S_{Ej}^{(1)}(p_{Ej}^{(1)} + e_j^{(1)}) + \\
& \quad S_{Mj}^{(1)}(p_{Mj}^{(1)} + m_j^{(1)}) - x_{(j1)}^0 - t_j^{(1)}, & (3.148) \\
p_{Ej}^{(1)} &= \sum_{h=5}^{9} S_{hj}^{(1)E}(p_h^c + x_{hj}^{(1)c}) - e_j^{(1)}, & (3.149) \\
p_{Mj}^{(1)} &= \sum_{i=0}^{4} S_{ij}^{(1)M}(p_i^c + x_{ij}^{(1)c}) - m_j^{(1)}, & (3.150)
\end{aligned}
$$

where the lower-case symbols denote percentage changes in the variables represented by the upper-case symbols and $S_{rj}^{(1)}$, $r = K, L, E, M$, $S_{hj}^{(1)E}$ and $S_{ij}^{(1)M}$ are cost shares defined as before.

Substituting equations (3.87)–(3.94) into (3.148), (3.95) and (3.96) into (3.149), and (3.97) and (3.98) into (3.150), taking considerations of symmetry and homogeneity restrictions on the second-order parameters of translog cost functions and, finally, simplifying one can get rid of quantity terms from equations (3.148)–(3.150) and write them as[4]

$$p_{(j1)} = \sum_r S_{rj}^{(1)} p_{rj}^{(1)} - t_j^{(1)}, \quad r = K, L, E, M, \quad j = 1, 2, \ldots, 9; \tag{3.151}$$

$$p_{Ej}^{(1)} = \sum_{h=5}^{9} S_{hj}^{(1)E} p_h^c, \quad j = 1, 2, \ldots, 9; \tag{3.152}$$

$$p_{Mj}^{(1)} = \sum_{i=0}^{4} S_{ij}^{(1)M} p_i^c, \quad j = 1, 2, \ldots, 9; \tag{3.153}$$

respectively. The disappearance of the quantity terms from (3.148)–(3.150) can be ascribed to the assumption of constant returns to scale in the production of current goods, in the creation of energy input and in the creation of aggregate materials input for current production. Under constant returns to scale cost per unit of activity is independent of the activity level.

Equations (3.151)–(3.153) make obvious intuitive sense. If it is assumed that there is no change in $T_j^{(1)}$, i.e., $t_j^{(1)} = 0$, then equation (3.151) suggests that the percentage change in the basic price of the output of sector j is a weighted average of the percentage changes in the prices of capital, labour, energy and aggregate materials, the weights being the shares of these inputs in the total cost of sector j, net of production taxes, for current production. Similar interpretations can be offered for equations (3.152) and (3.153).

Analogous to the zero-pure-profit conditions for current production in sector j, the zero-pure-profit conditions for capital formation in sector j can be specified as follows

$$T_j^{(2)} P_{Ij} I_j = P_{Ej}^{(2)} E_j^{(2)} + P_{Mj}^{(2)} M_j^{(2)}, \quad j = 1, 2, \ldots, 9, \tag{3.154}$$

$$P_{Ej}^{(2)} E_j^{(2)} = \sum_{h=5}^{9} X_{hj}^{(2)c} P_h^c, \quad j = 1, 2, \ldots, 9, \tag{3.155}$$

$$P_{Mj}^{(2)} M_j^{(2)} = \sum_{i=0}^{4} X_{ij}^{(2)c} P_i^c, \quad j = 1, 2, \ldots, 9, \tag{3.156}$$

[4]Note that same set of pricing equations in percentage change form could be derived by substituting percentage change forms of input demand equations of Case A and Case B into (3.148)–(3.150). Thus these pricing equations are quite general and the same in all three variants of the CGE energy model.

where the variables are defined as before. Equation (3.154) defines the zero-pure-profit condition in the production of capital goods in sector j; equation (3.155) defines the zero-pure-profit condition in the creation of aggregate energy input from individual fuels in sector j for capital formation; and equation (3.156) defines the zero-pure-profit condition in the creation of aggregate materials input used for capital formation in sector j. The percentage change forms of (3.154)–(3.156) can be written as

$$p_{Ij} = \sum_{r=E,M} S_{rj}^{(2)} p_{rj}^{(2)} - t_j^{(2)}, \quad j = 1, 2, \ldots, 9; \tag{3.157}$$

$$p_{Ej}^{(2)} = \sum_{h=5}^{9} S_{hj}^{(2)E} p_h^c, \quad j = 1, 2, \ldots, 9; \tag{3.158}$$

$$p_{Mj}^{(2)} = \sum_{i=0}^{4} S_{ij}^{(2)M} p_i^c, \quad j = 1, 2, \ldots, 9; \tag{3.159}$$

where the lower-case symbols denote percentage changes in the variables concerned and $S_{rj}^{(2)}$, $S_{hj}^{(2)E}$ and $S_{ij}^{(2)M}$ are cost shares of inputs in capital goods production and are defined before. The derivation procedure of equations (3.157)–(3.159) from (3.154)–(3.156) is similar to that of equations (3.151)–(3.153) from (3.145)–(3.147). The interpretations of equations (3.157)–(3.159) are similar to those of equations (3.151)–(3.153) except that the former set of equations relates to capital formation.

The zero-pure-profit conditions in the production of effective goods can be specified as

$$P_i^c X_i^c = P_{(i1)} X_{(i1)}^c + P_{(i2)} X_{(i2)}^c, \quad i = 1, 2, \ldots, 9, \tag{3.160}$$

where the variables are defined as before. Equation (3.160) states that total value of effective good i is equal to the total payments for domestic good i and foreign good i used in its production. Expressing equation (3.160) in terms of percentage changes in the variables gives

$$p_i^c = \sum_{t=1}^{2} S_{(it)}^c (p_{(it)} + x_{(it)}^c) - x_i^c, \tag{3.161}$$

where lower-case symbols denote percentage changes in the variables concerned; and $S^c_{(i1)}$ and $S^c_{(i2)}$ denote shares of domestic good i and foreign good i respectively in the total cost of production of effective good i. Finally, substituting equations (3.141) and (3.142) into (3.161) and simplifying one can get rid of quantity terms and write equation (3.161) as

$$p^c_i = S^c_{(i1)}p_{(i1)} + S^c_{(i2)}p_{(i2)}, \quad i = 1, 2, \ldots, 9. \tag{3.162}$$

The disappearance of quantity terms from (3.161) can be ascribed to the assumption of constant returns to scale in the production of effective goods. Equation (3.162) implies that the percentage change in the unit cost of effective good i is a weighted average of the percentage changes in the prices of inputs used in its production where the weights are input cost shares.

The set of price equations which guarantees zero-pure-profit conditions in importing can be defined as

$$P_{(i2)} \quad = \quad P^w_{(i2)}\Phi T_{(i2)}, \quad i = 1, 2, \ldots, 9, \tag{3.163}$$

where $P_{(i2)}$ is the basic price of imported good i, i.e., the price received by the importers including import duties; $P^w_{(i2)}$ is the foreign currency c.i.f. price of imports; Φ is the exchange rate, i.e., \$A per unit of foreign currency; and $T_{(i2)}$ is one plus the rate of *ad valorem* tariff applicable to good i.

In percentage change form, (3.163) can be written as

$$p_{(i2)} \quad = \quad p^w_{(i2)} + \phi + t_{(i2)}, \quad i = 1, 2, \ldots, 9, \tag{3.164}$$

where lower-case symbols denote percentage changes in the variables concerned. Analogous to equation (3.164), the zero-pure-profit condition in importing non-competing imports can be written in percentage change form as

$$p^c_0 \quad = \quad p^w_{(02)} + \phi + t_{(02)}, \tag{3.165}$$

where p_0^c denotes the percentage change in the basic price of non-competing imports; $p_{(02)}^w$, the percentage change in the foreign currency price of non-competing imports; ϕ, the percentage change in the exchange rate; and $t_{(02)}$, the percentage change in $T_{(02)}$ which is one plus the rate of *ad valorem* tax applicable to non-competing imports.

The set of price equations guaranteeing zero-pure-profit in exporting can be written as

$$P_{(i1)} \quad = \quad P_{(i1)}^w \Phi T_{(i1)}^{(5)}, \quad i = 1, 2, \ldots, 9, \tag{3.166}$$

where $P_{(i1)}$ is the basic price of domestic good i, $P_{(i1)}^w$ is the foreign currency f.o.b. price of export good i, $T_{(i1)}^{(5)}$ is one plus the rate of subsidy applicable to export good i. In percentage change form, (3.166) can be written as

$$p_{(i1)} \quad = \quad p_{(i1)}^w + \phi + t_{(i1)}^{(5)}, \quad i = 1, 2, \ldots, 9, \tag{3.167}$$

where lower-case symbols denote percentage changes in the variables appearing in equation (3.166). The subscript range in (3.167) is allowed to cover all commodities. However, $t_{(i1)}^{(5)}$ is treated as an endogenous variable in the event a commodity is nontradable. Then equation (3.167) has no effect in the determination of the domestic price, $p_{(i1)}$. This is determined by domestic demand and supply.

The final set of equations defining consumers' prices for effective goods can be specified as

$$P_i^{(3)c} = T_i^{(3)c} P_i^c, \quad i = 0, 1, \ldots, 9, \tag{3.168}$$

where all variables have been defined before except $T_i^{(3)c}$ which is one plus the *ad valorem* tax on the effective consumer good i ($i = 0$ implies non-competing imports). Expressing equation (3.168) in percentage change form gives

$$p_i^{(3)c} = t_i^{(3)c} + p_i^c, \quad i = 0, 1, \ldots, 9, \tag{3.169}$$

where lower-case symbols denote percentage changes in the variables concerned. If it is assumed that $t_i^{(3)c} = 0$, then equation (3.169) implies that the percentage change in the consumer price of effective good i is equal to the percentage change in the basic price of the effective good i.

3.7 Allocation of Investment Across Industries

In describing the technology for creating capital goods in Section 3.2, the question of how many capital goods will be produced for each industry was left open. In this section, the theory of allocating investment across industries is described.

There are several approaches to tackle the problem of investment allocation. One possible approach to the problem of investment allocation is to set the I_j's exogenously (see, for example, Dervis, *et al.* 1982, Taylor and Black 1974). Another approach may be to determine I_j's endogenously while leaving the determination of total investment expenditure exogenous. Dixon *et al.* (1982) have followed the second approach and the present study closely follows the theory of investment implented in the ORANI model by Dixon *et al.*

The investment theory incorporated in this study is based on six simplifying assumptions. The first assumption is that the current net rate of return on fixed capital in industry j, $R_j(0)$, can be defined as

$$R_j(0) \quad = \quad \frac{P_{Kj}^{(1)}}{P_{Ij}} - d_j, \qquad (3.170)$$

where $P_{Kj}^{(1)}$ and P_{Ij} are respectively the rental value and price of capital and d_j is the rate of depreciation (assumed fixed) in sector j.

The second assumption is that it takes one period to install new capital in sector j. Since the present study is not dynamic in nature, it is not important to associate a period with an exact calendar time.

The third assumption is that the expected rate-of-return schedule of sector j in one period's time will have the form

$$R_j(1) = R_j(0)\{K_j(1)/K_j(0)\}^{-\beta_j},$$

where β_j is a positive parameter; $K_j(0)$ and $K_j(1)$ are capital stocks in the current period and at the end of one period respectively; and $R_j(1)$ is the rate of return on capital which the producers in sector j expect to prevail after one period. The implications of this assumption can be illustrated diagrammatically. Figure 3.1 illustrates the schedule. If at the end of one period sector j maintained capital stock at the existing level, then expected rate of return would be the current rate of return, $R_j(0)$. However, if the investment plans in sector j were set so that $K_j(1)/K_j(0)$ would reach the level A, then businessmen would behave as if they expected the rate of return to fall to B.

The fourth assumption is that total private investment expenditure, $C^{(2)}$, is allocated across sectors so as to equate the sectoral expected rates of return to a unique rate of return Ω. That is,

$$\{K_j(1)/K_j(0)\}^{-\beta_j} R_j(0) \quad = \quad \Omega, \quad j \in J, \tag{3.171}$$

where J is the subset of sectors for which investments, I_j's, are explained endogenously.

The fifth assumption is that

$$K_j(1) \quad = \quad K_j(0)(1-d_j) + I_j, \quad j = 1, 2, \ldots, 9, \tag{3.172}$$

and

$$C^{(2)} \quad = \quad \sum_{j \in J} P_{Ij} I_j. \tag{3.173}$$

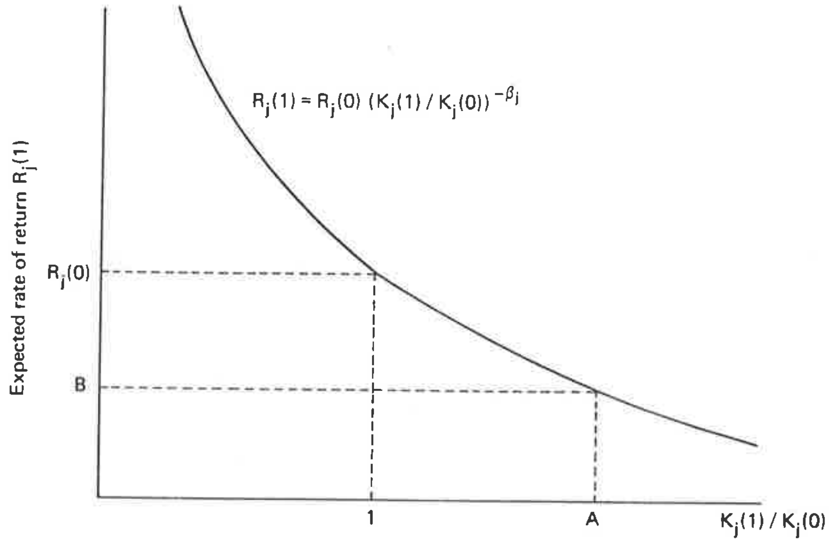

Figure 3.1: Expected Rate of Return Schedule for Sector j (Source: Dixon *et al.* (1982)).

The variables in (3.172) and (3.173) are defined as above. Equation (3.172) implies that the capital stock at the end of one period is influenced only by the current capital stock and the current level of investment. It is assumed that the effects of past investment decisions are fully incorporated in the current capital stock. Equation (3.173) simply defines the private investment budget as the sum of investment expenditures across those industries j, for which $j \in J$.

The sixth assumption involves the determination of investment in those industries ($j \notin J$) for which the rate of return theory is considered inappropriate. For those industries it is assumed that

$$I_j \quad = \quad (C_R^{(2)})^{h_j^{(2)}} F_j^{(2)}, \quad j \notin J, \qquad (3.174)$$

where

$$C_R^{(2)} \quad = \quad C^{(2)}/\Xi^{(2)}. \qquad (3.175)$$

In (3.174) and (3.175), $C_R^{(2)}$ is the real level of private investment, $\Xi^{(2)}$ is the capital-goods price index and $F_j^{(2)}$ is a shift variable. If the parameter $h_j^{(2)}$ is equal to one in (3.174), then the percentage changes in $F_j^{(2)}$ reflect the growth in investment in sector j relative to that of the entire private sector.

Equations (3.170)–(3.175) describe the theory of allocation of investment across industries. On the one hand, investment in sector $j \in J$ is allowed to be affected by what the model implies about relative rates of return. On the other hand, investment in sector $j \notin J$ can be specified exogenously or determined mechanically according to a rule which forces I_j to be a simple function of $C_R^{(2)}$.

In percentage change form, equations (3.170)–(3.175) can be written as

$$r_j(0) = Q_j(p_{Kj}^{(1)} - p_{Ij}), \ \ j = 1, 2, \ldots, 9, \tag{3.176}$$

$$-\beta_j\{k_j(1) - k_j(0)\} + r_j(0) = \omega, \ \ j \in J, \tag{3.177}$$

$$k_j(1) = k_j(0)(1 - G_j) + i_j G_j, \ \ j = 1, 2, \ldots, 9, \tag{3.178}$$

$$\sum_{j \in J}(p_{Ij} + i_j)\Upsilon_j = (\sum_{j \in J}\Upsilon_j)c^{(2)} \tag{3.179}$$

$$i_j = h_j^{(2)} c_R^{(2)} + f_j^{(2)}, \ \ j \notin J, \tag{3.180}$$

and

$$c_R^{(2)} = c^{(2)} - \xi^{(2)}, \tag{3.181}$$

where

$$Q_j = \{R_j(0) + d_j\}/R_j(0),$$

i.e., Q_j is the ratio of the gross rate of return to the net rate of return in sector j; $G_j = I_j/K_j(1)$ is the ratio of gross investment in sector j to its 'after-one-period' capital stock; $\Upsilon_j = I_j P_{Ij}/\sum_{j=1}^{9} I_j P_{Ij}$ is the share of total aggregate investment accounted for by sector j. Note that $\sum \Upsilon_j = 1$ over all j, not just over $j \in J$. It is convenient to make Υ_j independent of user-determined choice of the elements in J.

3.8 Market Clearing Equations

This section deals with equations which set demands equal to supplies in all markets. The equations involve markets for effective goods, domestically produced goods, imported goods and primary factors.

The equations which set total supplies of effective goods equal to total demands are:

$$X_i^c = \sum_{j=1}^{9} X_{ij}^{(1)c} + \sum_{j=1}^{9} X_{ij}^{(2)c} + X_i^{(3)c} + X_i^{(4)c}, \quad i = 1, 2, \ldots, 9, \qquad (3.182)$$

where total supply of effective good i is denoted by X_i^c. The total demand for effective good i comes from producers of current goods and capital goods, the household sector and the government. For effective good i, the total demand from producers producing current goods is $\sum_j X_{ij}^{(1)c}$; the total demand from capital goods' producers is $\sum_j X_{ij}^{(2)c}$; the demand from the household sector is $X_i^{(3)c}$ and the government sector's demand is $X_i^{(4)c}$.

In percentage change form, (3.182) can be written as

$$x_i^c = \sum_{j=1}^{9} H_{ij}^{(1)c} x_{ij}^{(1)c} + \sum_{j=1}^{9} H_{ij}^{(2)c} x_{ij}^{(2)c} + H_i^{(3)c} x_i^{(3)c} + H_i^{(4)c} x_i^{(4)c},$$
$$i = 1, 2, \ldots, 9, \qquad (3.183)$$

where $H_{ij}^{(1)c}$ is the share of sector j's demand for effective good i for current production purposes in the total demand for effective good i; $H_{ij}^{(2)c}$ is the share of sector j's demand for effective good i for capital formation purposes in the total demand for effective good i; $H_i^{(3)c}$ is the share of households in the total demand for effective good i and $H_i^{(4)c}$ is the share of government in the total demand for effective good i.

The market clearing equations for domestically produced goods can be specified as

$$X_{(j1)}^0 = X_{(j1)}^c + X_{(j1)}^{(5)}, \quad j = 1, 2, \ldots, 9, \qquad (3.184)$$

where $X^0_{(j1)}$ denotes total supply of domestically produced good j, $X^c_{(j1)}$ is the demand for domestically produced good j in the production of effective good j, X^c_j, and $X^{(5)}_{(j1)}$ is the demand for domestic good j from the foreigners. In other words, $X^{(5)}_{(j1)}$ is the amount of exports of domestic good j.

In percentage change form, (3.184) can be specified as

$$x^0_{(j1)} = B^c_{(j1)}x^c_{(j1)} + B^{(5)}_{(j1)}x^{(5)}_{(j1)}, \quad j = 1, 2, \ldots, 9, \tag{3.185}$$

where $B^c_{(j1)}$ is the share of total demand for domestic good j accounted for by the demand for domestic good j for the creation of effective good j and $B^{(5)}_{(j1)}$ is the share of total demand for domestic good j accounted for by exports of good j.

The market clearing equations for competing imports are:

$$X_{(i2)} = X^c_{(i2)}, \quad i = 1, 2, \ldots, 9, \tag{3.186}$$

where $X_{(i2)}$ is the supply of imported good i and $X^c_{(i2)}$ is the demand for imported good i in the creation of effective good i, X^c_i. In percentage change form, (3.186) can be expressed as

$$x_{(i2)} = x^c_{(i2)}, \quad i = 1, 2, \ldots, 9. \tag{3.187}$$

The market clearing equation for non-competitive imports is

$$X^c_0 = \sum_{j=1}^{9} X^{(1)c}_{0j} + \sum_{j=1}^{9} X^{(2)c}_{0j} + X^{(3)c}_0 + X^{(4)c}_0, \tag{3.188}$$

where X^c_0 is the total supply of non-competitive imports; $\sum_j X^{(1)c}_{0j}$ is the demand from producers of current goods; $\sum_j X^{(2)c}_{0j}$ is the demand from producers of capital goods; $X^{(3)c}_0$ is the demand from the household sector; and $X^{(4)c}_0$ is the demand from the government sector for non-competitive imports.

In percentage change form, (3.188) can be written as

$$x^c_0 = \sum_{j=1}^{9} H^{(1)c}_{0j}x^{(1)c}_{0j} + \sum_{j=1}^{9} H^{(2)c}_{0j}x^{(2)c}_{0j} + H^{(3)c}_0 x^{(3)c}_0 + H^{(4)c}_0 x^{(4)c}_0, \tag{3.189}$$

where $H_{0j}^{(1)c}$ is the share of total demand for non-competitive imports accounted for by the demand for these imports in sector j for current production; $H_{0j}^{(2)c}$ is the share of total demand for non-competitive imports accounted for by the demand for these imports in sector j for capital creation; and $H_0^{(3)c}$ and $H_0^{(4)c}$ are shares of total demand for non-competitive imports accounted for by the demands for these imports by the household and government sectors respectively.

The market clearing equations for exports are:

$$X_{(i1)5} \quad = \quad X_{(i1)}^{(5)}, \quad i = 1, 2, \ldots, 9, \tag{3.190}$$

where $X_{(i1)5}$ is the supply of exports and $X_{(i1)}^{(5)}$ is the demand for exports of good i. In percentage change form, (3.190) can be specified as

$$x_{(i1)5} \quad = \quad x_{(i1)}^{(5)}, \quad i = 1, 2, \ldots, 9. \tag{3.191}$$

For capital, the market clearing equations are:

$$K_j(0) \quad = \quad K_j^{(1)}, \quad j = 1, 2, \ldots, 9, \tag{3.192}$$

where $K_j(0)$ and $K_j^{(1)}$ are supply of and demand for capital respectively in sector j. Note that in (3.192) capital is assumed to be industry-specific or non-shiftable between industries. This assumption implies that it is not possible to dismantle capital units and allocate the components to other industries. The non-shiftability assumption is unlikely to distort model results significantly except in the simulation of policies which could produce very rapid declines in the outputs of some industries; large-scale shifting of capital from one industry to other industries will occur only if that particular industry is declining at a faster rate than is allowed by depreciation (Dixon *et al.* 1982, p.123). The assumption of non-shiftability of capital stock has been popular in other models emphasising issues of foreign trade (e.g., Evans 1972, Taylor and Black 1974, Dixon *et al.* 1982).

In percentage change form, (3.192) can be expressed as

$$k_j(0) \;=\; k_j^{(1)}, \;\; j = 1, 2, \ldots, 9. \tag{3.193}$$

The market clearing equation for labour can be defined as

$$L \;=\; \sum_{j=1}^{9} L_j^{(1)}, \tag{3.194}$$

where L represents supply of labour and $\sum_j L_j^{(1)}$ represents the total demand for labour. Unlike capital, labour is assumed homogenous and is shiftable between industries. Regarding the labour market it is further assumed that the wage rate moves with the consumer price index, i.e.,

$$P_L^{(1)} \;=\; (\Xi^{(3)})^h F_L, \tag{3.195}$$

where $P_L^{(1)}$ is the nominal wage rate, $\Xi^{(3)}$ is the consumer price index, defined in Section 3.10, F_L is the wage-shift variable and h is the wage indexation parameter. In other words, it could be assumed that the nominal wage rate is indexed to the consumer price index rather being determined in the labour market by the forces of demand and supply. If the parameter h is set at unity and the wage-shift variable, F_L, is held constant, then the model will simulate a situation of 100 percent wage indexation. Partial wage indexation can be simulated by setting h at less than one. Exogenous shifts in real wages can be introduced through changes in F_L.

In percentage form, (3.194) and (3.195) can be written as

$$l \;=\; \sum_{j=1}^{9} B_{Lj}^{(1)} l_j^{(1)}, \tag{3.196}$$

and

$$p_L^{(1)} \;=\; h\xi^{(3)} + f_L \tag{3.197}$$

respectively. $B_{Lj}^{(1)}$, in (3.196), is the share of total employment accounted for by sector j. Lower-case symbols in equations (3.196) and (3.197) denote percentage changes in the variables concerned.

3.9 Aggregate Imports, Exports and Balance of Trade

The foreign currency value of aggregate imports can be calculated as

$$M = P^w_{(02)} X^c_0 + \sum_{i=1}^{9} P^w_{(i2)} X^c_{(i2)}, \tag{3.198}$$

where M is the foreign currency cost of aggregate imports; $P^w_{(02)} X^c_0$, the foreign currency cost of non-competitive imports; and $\sum_i P^w_{(i2)} X^c_{(i2)}$, the foreign currency cost of competitive imports. In percentage change form, (3.198) can be written as

$$m = M_{(02)}(x^c_0 + p^w_{(02)}) + \sum_{i=1}^{9} M_{(i2)}(x^c_{(i2)} + p^w_{(i2)}), \tag{3.199}$$

where $M_{(02)}$ is the share of non-competitive imports in the aggregate foreign currency cost of commodity imports, while $M_{(i2)}$ is the share of competitive import good i, $i = 1, 2, \ldots, 9$, in the total foreign currency cost of commodity imports.

The total foreign currency receipts for exports, E, is given by

$$E = \sum_{i=1}^{9} P^w_{(i1)} X^{(5)}_{(i1)}, \tag{3.200}$$

where $P^w_{(i1)} X^{(5)}_{(i1)}$ denotes the total foreign currency receipts from exports of good i, $i = 1, 2, \ldots, 9$. In percentage change form, (3.200) can be written as

$$e = \sum_{i=1}^{9} D^{(5)}_{(i1)}(x^{(5)}_{(i1)} + p^w_{(i1)}), \tag{3.201}$$

where $D^{(5)}_{(i1)}$ is the share of export good i in the total foreign currency receipts for exports.

Finally, the balance of trade, B, on commodity account can be defined as

$$B = E - M. \tag{3.202}$$

This gives

$$100\Delta B \quad = \quad Ee - Mm, \tag{3.203}$$

where ΔB is the change in B (not percentage change). So ΔB is a variable which requires units. E and M are as defined before; and e and m are percentage changes in E and M respectively.

3.10 Miscellaneous Equations

The objective in this section is to define some variables which appeared in previous sections but were not defined there. Such variables are $C^{(3)}$, $C^{(4)}$, $\Xi^{(2)}$ and $\Xi^{(3)}$. In addition to these, some other useful macro variables will be defined here and included in the CGE models.

Before defining $C^{(3)}$, aggregate household expenditure, one must define total income of the household sector. The total income of the household sector is defined as

$$Y^{(3)} \quad = \quad P_L^{(1)} \sum_{j=1}^{9} L_j^{(1)} + \sum_{j=1}^{9} P_{Kj}^{(1)} K_j^{(1)}, \tag{3.204}$$

where $Y^{(3)}$ is the total income of the household sector and $P_L^{(1)}$, $L_j^{(1)}$, $P_{Kj}^{(1)}$ and $K_j^{(1)}$ are defined as before. In defining $Y^{(3)}$, it is assumed that the household sector owns all primary factors and earns income by letting them be used by the sectors involved in current production.

The aggregate household expenditure, then, can be defined as

$$C^{(3)} \quad = \quad Q^{(3)} Y^{(3)} (1 - T^H), \tag{3.205}$$

where $Q^{(3)}$ is the average propensity to consume of the household sector and T^H is the rate of household income tax.

In percentage change form, (3.204) and (3.205) can be written as

$$y^{(3)} \quad = \quad \sum_{j=1}^{9} G_j^L (p_L^{(1)} + l_j^{(1)}) + \sum_{j=1}^{9} G_j^K (p_{Kj}^{(1)} + k_j^{(1)}), \tag{3.206}$$

and

$$c^{(3)} = q^{(3)} + y^{(3)} - \{T^H/(1-T^H)\}t^H, \tag{3.207}$$

respectively. In (3.206), G_j^L is the share of gross (before tax) household income accounted for by wages received by households from sector j and G_j^K is the share of gross household income accounted for by capital income earned by households from sector j. Lower-case symbols in (3.206) and (3.207) denote percentage changes in the variables concerned and T^H is defined as above.

Total government income net of subsidy, $Y^{(4)}$, can be defined as

$$\begin{aligned} Y^{(4)} = {} & \sum_{j=1}^{9}(1-T_j^{(1)})P_{(j1)}X^0_{(j1)} + \sum_{j=1}^{9}(1-T_j^{(2)})P_{Ij}I_j + \\ & \sum_{i=1}^{9}(T_{(i2)}-1)P^w_{(i2)}\Phi X^c_{(i2)} + (T_{(02)}-1)P^w_{(02)}\Phi X^c_0 - \\ & \sum_{i=1}^{9}(T^{(5)}_{(i1)}-1)P^w_{(i1)}\Phi X^{(5)}_{(i1)} + T^H Y^{(3)} + \\ & \sum_{i=0}^{9}(T_i^{(3)c}-1)P^c_i X_i^{(3)c}, \end{aligned} \tag{3.208}$$

where the variables are defined as before. Total government expenditure is, then, defined by

$$C^{(4)} = Q^{(4)}Y^{(4)}, \tag{3.209}$$

where $Q^{(4)}$ is the average propensity to consume of the government sector.

In percentage change form, (3.208) and (3.209) becomes

$$\begin{aligned} y^{(4)} = {} & \sum_{j=1}^{9}R^{(1)}_{(j1)}(p_{(j1)} + x^0_{(j1)}) - \sum_{j=1}^{9}G^{(1)}_{(j1)}t_j^{(1)} + \sum_{j=1}^{9}R_j^{(2)}(p_{Ij}+i_j) - \\ & \sum_{j=1}^{9}G_j^{(2)}t_j^{(2)} + \sum_{i=1}^{9}G_{(i2)}t_{(i2)} + \sum_{i=1}^{9}J_{(i2)}(p^w_{(i2)} + \phi + x^c_{(i2)}) + \\ & G_{(02)}t_{(02)} + J_{(02)}(p^w_{(02)} + \phi + x^c_0) - \sum_{i=1}^{9}G^{(5)}_{(i1)}t^{(5)}_{(i1)} - \\ & \sum_{i=1}^{9}J^{(5)}_{(i1)}(p^w_{(i1)} + \phi + x^{(5)}_{(i1)}) + J^H(t^H + y^{(3)}) + \\ & \sum_{i=0}^{9}G_i^{(3)c}t_i^{(3)c} + \sum_{i=0}^{9}J_i^{(3)c}(p^c_i + x_i^{(3)c}) \end{aligned} \tag{3.210}$$

and

$$c^{(4)} = q^{(4)} + y^{(4)} \tag{3.211}$$

respectively. In (3.210), $R^{(1)}_{(j1)}$ is the ratio of total production tax paid by current goods' producers in sector j ($j = 1, 2, \ldots, 9$) to the total government income net of subsidy, $Y^{(4)}$; $G^{(1)}_{(j1)}$, ($j = 1, 2, \ldots, 9$) is the value of current output of sector j net of production taxes divided by $Y^{(4)}$; $R^{(2)}_j$ is the ratio of total tax paid for capital goods' production by sector j to $Y(4)$; $G^{(2)}_j$ is the value of output of capital goods (net of production taxes) produced by sector j divided by $Y(4)$; $G_{(i2)}$ is the value of imports of commodity i ($i = 0, 1, \ldots, 9$) including the tariff divided by $Y^{(4)}$; $J_{(i2)}$ is the total tariff paid by importers of commodity i divided by $Y^{(4)}$; $G^{(5)}_{(i1)}$ is the value of exports of commodity i ($i = 1, 2, \ldots, 9$) including subsidy divided by $Y_{(4)}$; $J^{(5)}_{(i1)}$ is the total government subsidy paid to exporters of commodity i divided by $Y^{(4)}$; J^H is the share of $Y^{(4)}$ accounted for by tax on household income; $G^{(3)c}_i$ is the total household expenditure on effective good i ($i = 0, 1, \ldots, 9$) including tax divided by $Y(4)$ and $J^{(3)c}_i$ is the total consumption tax paid by the household sector for effective good i divided by $Y(4)$.

The consumer price index, $\Xi^{(3)}$, the government price index, $\Xi^{(4)}$, and the capital goods price index, $\Xi^{(2)}$, are defined as

$$\Xi^{(3)} = \prod_{i=0}^{9} (P^{(3)c}_i)^{w^{(3)}_i}, \tag{3.212}$$

$$\Xi^{(4)} = \prod_{i=0}^{9} (P^c_i)^{w^{(4)}_i}, \tag{3.213}$$

and

$$\Xi^{(2)} = \prod_{j=1}^{9} (P_{Ij})^{w^{(2)}_j}, \tag{3.214}$$

respectively. In (3.212)–(3.214), $w^{(3)}_i$'s are household consumption weights, $w^{(4)}_i$'s are government expenditure weights and $w^{(2)}_j$'s are investment expenditure weights. In percentage change form, (3.212)–(3.214) can be written as

$$\xi^{(3)} = \sum_{i=0}^{9} w_i^{(3)} p_i^{(3)c}, \tag{3.215}$$

$$\xi^{(4)} = \sum_{i=0}^{9} w_i^{(4)} p_i^{c} \tag{3.216}$$

and

$$\xi^{(2)} = \sum_{j=1}^{9} w_j^{(2)} p_{Ij} \tag{3.217}$$

respectively.

Other useful macroeconomic equations included in the present CGE models are related to aggregate capital stock in base-period value units, real household expenditure, real government expenditure and macro allocation of aggregate expenditure.

Aggregate capital stock in base-period value units is calculated as

$$K = \sum_{j=1}^{9} K_j(0)\bar{P}_{Kj}, \tag{3.218}$$

where K is the aggregate capital stock in base-period value units, $K_j(0)$ is the current supply of capital in sector j, and $\bar{P}_{Kj}$ is a parameter whose value is fixed at the price of a unit of capital for sector j in the initial situation. In percentage change form, (3.218) can be written as

$$k = \sum_{j=1}^{9} B_{Kj} k_j(0), \tag{3.219}$$

where B_{Kj}, $j = 1, 2, \ldots, 9$, is the share of economy's total capital stock, K, accounted for by sector j's capital stock and lower-case letters represent percentage changes in the variables concerned.

The real household expenditure is calculated as

$$C_R^{(3)} = C^{(3)}/\Xi^{(3)}, \tag{3.220}$$

where $C_R^{(3)}$ is real household expenditure, $C^{(3)}$ and $\Xi^{(3)}$ are defined as before. In percentage change form, (3.220) can be written as

$$c_R^{(3)} = c^{(3)} - \xi^{(3)}. \qquad (3.221)$$

Real government expenditure, $C_R^{(4)}$, is calculated as

$$C_R^{(4)} = C^{(4)}/\Xi^{(4)}. \qquad (3.222)$$

In percentage change form, (3.222) becomes

$$c_R^{(4)} = c^{(4)} - \xi^{(4)}. \qquad (3.223)$$

Macro allocation of aggregate expenditure is modelled by the following three equations:

$$C^{(4)} = C^{(3)}F_{43}, \qquad (3.224)$$

$$C^{(4)} = C^{(2)}F_{42} \qquad (3.225)$$

and

$$C^{(2)} = C^{(3)}F_{23}. \qquad (3.226)$$

where F_{43}, F_{42} and F_{23} are variables allowing exogenous treatment of the macro allocation of aggregate expenditure. In percentage change form, equations (3.224)–(3.226) can be written as

$$c^{(4)} = c^{(3)} + f_{43}, \qquad (3.227)$$

$$c^{(4)} = c^{(2)} + f_{42} \qquad (3.228)$$

and

$$c^{(2)} = c^{(3)} + f_{23} \qquad (3.229)$$

respectively; where lower-case symbols denote percentage changes in the variables concerned.

3.11 Conclusion

Three alternative CGE energy models have been specified and the theories underlying their specifications have been discussed in this chapter. These models, being constructed in a general equilibrium framework, capture the interactions among all product and factor markets including interactions between energy and nonenergy markets. Thus these models, unlike energy models constructed in a partial equilibrium framework (such as energy demand or supply models, energy industry or market models and energy system models), take into account energy-economy feedbacks in evaluating changing energy conditions, energy policy issues, energy price shocks, etc. However, these models differ from one another in allowing substitution among inputs in current production but they share the same characteristics in other aspects of modelling, i.e., modelling consumer preferences, foreign trade, capital goods production, etc. The first model, CES-FC, allows substitution only between capital and labour and assumes fixed input-output relationships for intermediate inputs including fuels. The second model, CD, allows substitution between aggregate factors—capital, labour, energy and aggregate materials—and between individual fuels as well as individual materials. But this model suffers from the restrictive assumption of Cobb-Douglas production functions that the elasticity of substitution between any two inputs is unity. To overcome this restriction, translog cost functions have been used in the third model, TL, to describe the production technologies for current production. As in the CD model, interfactor and interfuel as well as intermaterial substitutions are allowed in this model. But in contrast to the CD model, where all inputs are substitutes, a pair of inputs can be either substitutes or complements for each other in this model and, moreover, the elasticity of substitution can vary from input pair to input pair. From the viewpoint of allowing substitution among inputs in production, the CD and TL models (like integrated energy-economic models) are more general than energy system models. Energy system models, like BESOM and MARKAL, allow substitution among different fuels but fail to take into account the substitution possibilities among nonenergy intermediate inputs as well as between energy and other factors of production. But both the CD and TL models, as specified here, allow substitutions not only among various fuels but also among various materials as well as between energy and other factors of production.

Chapter 4

NUMERICAL SPECIFICATIONS OF THE MODELS

In the previous chapter, the theoretical foundations and the structural equations of the CGE models have been discussed. In this chapter, the objective is to specify the models numerically so that they can be used for policy analysis. In other words, the purpose is to assign numerical values to the various share coefficients and parameters associated with the equations included in the models. Two sets of values are required. The first set of values are related to the share coefficients such as cost shares, sales shares, revenue shares, budget shares, etc. The second set of values consists of elasticities of substitution, the second-order parameters of the translog cost functions, indexation parameters, foreign elasticity of demand for Australian exports, etc. The share coefficients have been derived from a base-period input-output data set; the base-period data set and the derivation procedures of the values of these coefficients are discussed in Section 4.1 and Section 4.2 respectively. The assignment of numerical values to the parameters is discussed in Section 4.3.

4.1 Base-Period Input-Output Data Set

The base-period input-output data set used to derive the share coefficients of the models has been obtained by adapting the 1977–78 balanced ORANI data base to the needs of the present study. The ORANI data base which has been used for the present study is, in fact, an updated version of the previous ones. While the non-agricultural components of the data base were drawn from 1977–78 input-output data (see ABS (1983)), the agricultural components were drawn from the typical year agricultural data base prepared by Higgs (1985). The procedures adopted to integrate these two sets of data to obtain the 1977–78 ORANI balanced data base with the typical year agricultural sector implemented are discussed in Higgs (1986), and the overall data base is documented in Blampied (1985) and Bruce (1985).

The base-period input-output data base implemented for the present study, however, differs from the 1977–78 balanced ORANI input-output data base in some respects. The major differences between these two data sets are as follows.

(i) In the ORANI input-output data base the flows from a margin industry to the users are classified into two groups: (a) direct usage and (b) margin usage. The flows from a margin industry to the users are grouped into direct usage if these flow directly from the margin industry to the users. The flows from a margin industry are grouped into margin usage if these are associated with direct flows. In the present input-output data base no such distinction is maintained. All flows from the margin industries are direct flows.

(ii) The ORANI input-output data base describes commodity flows to different users. But the present base-period input-output data base shows flows of industrial outputs to different users. The ORANI data base shows distribution of 114 commodities to 112 industries and other final users. To make this data base useful for the present study, the first 111 ORANI industries have been aggregated into 9 industrial sectors and the first 113 commodities have been aggregated into 9 industrial outputs. The correspondence between the present 9 industrial sectors and their outputs and the ORANI industries and commodities is shown in Table 4.1. In aggregating the ORANI industries the 112^{th} ORANI industry, which is a non-competing imports industry, has been simply ignored. The 114^{th} ORANI commodity which is non-competing imports has been considered as a separate product which is used as an input into the production of current and capital goods by the 9 industrial sectors and as a commodity by the household and government sectors.

(iii) In the ORANI input-output data base there are three types of primary inputs—labour, capital and agricultural land—while in the present case there are only two types of primary inputs: (a) labour, and (b) capital. Moreover, there is only one category of labour in the present data base in contrast to 10 skill-categories of labour in the ORANI data base.

For convenience, the base-period input-output data base for the present study is organised into several matrices. Forms of these matrices are illustrated in Figure 4.1. The first matrix in Figure 4.1, $\tilde{A}$, shows the 1977–78 flows of domestic goods into the production processes of the domestic industries. Matrix $\tilde{B}$ shows the flows of domestic goods into capital formation and vectors $\tilde{C}$, $\tilde{D}$ and $\tilde{E}$ show the flows to household, government and export sectors respectively. The flows of goods contained in the matrices $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, $\tilde{D}$ and $\tilde{E}$ are valued at basic prices, i.e., prices received by producers excluding margins and sales taxes. Notationally, these matrices can be specified as

$$\begin{aligned}
\tilde{A} &= [\tilde{a}_{ij}] = [P_{(i1)}X^{(1)}_{(i1)j}]_{9\times 9}, \\
\tilde{B} &= [\tilde{b}_{ij}] = [P_{(i1)}X^{(2)}_{(i1)j}]_{9\times 9}, \\
\tilde{C} &= [\tilde{c}_{i}] = [P_{(i1)}X^{(3)}_{(i1)}]_{9\times 1}, \\
\tilde{D} &= [\tilde{d}_{i}] = [P_{(i1)}X^{(4)}_{(i1)}]_{9\times 1},
\end{aligned}$$

Table 4.1: Correspondence between the 9 Industries in the Present Study and the ORANI Industries.

Industry/Output	ORANI industry code	ORANI commodity code
1. Agriculture, mining and construction	1–13, 16,17, 87,88	1–15, 18,19, 89,90
2. Manufacturing	18–55, 57–83	20–57, 59–85
3. Transportation	93–96	95–98
4. Communications, trade and services	86, 89–92, 97–111	88, 91–94, 99–113
5. Coal	14	16
6. Crude oil	15	17
7. Petroleum and coal products	56	58
8. Electricity	84	86
9. Gas utilities	85	87

and

$$\tilde{E} = [\tilde{e}_i] = [P_{(i1)}X^{(5)}_{(i1)}]_{9\times 1},$$

where $\tilde{a}_{ij}$, $\tilde{b}_{ij}$, $\tilde{c}_i$, $\tilde{d}_i$ and $\tilde{e}_i$ are elements of the respective matrices; $P_{(i1)}$ is the basic price of the output of the i^{th} sector; $X^{(1)}_{(i1)j}$ is the flow of output from sector i to sector j for current production; $X^{(2)}_{(i1)j}$ is the flow of output from sector i to sector j for capital formation; $X^{(3)}_{(i1)}$, $X^{(4)}_{(i1)}$ and $X^{(5)}_{(i1)}$ are flows of output of sector i to the household, government and foreign sectors respectively.

The first four non-zero matrices in the second row of Figure 4.1, $\tilde{F}$, $\tilde{G}$, $\tilde{H}$ and $\tilde{J}$ contain flows of competing imports valued at basic prices. The basic price of an imported good is defined as its c.i.f., duty-paid price. The typical elements of these matrices can be specified as

$$\begin{aligned}\tilde{F} &= [\tilde{f}_{ij}] = [P_{(i2)}X^{(1)}_{(i2)j}]_{9\times 9},\\ \tilde{G} &= [\tilde{g}_{ij}] = [P_{(i2)}X^{(2)}_{(i2)j}]_{9\times 9},\\ \tilde{H} &= [\tilde{h}_i] = [P_{(i2)}X^{(3)}_{(i2)}]_{9\times 1},\end{aligned}$$

and

$$\tilde{J} = [\tilde{j}_i] = [P_{(i2)}X^{(4)}_{(i2)}]_{9\times 1},$$

where $\tilde{f}_{ij}$, $\tilde{g}_{ij}$, $\tilde{h}_i$ and $\tilde{j}_i$ are elements of the respective matrices; $P_{(i2)}$ is the basic price of the i^{th} imported good; $X^{(1)}_{(i2)j}$ is the flow of imported good i to sector j for current production; $X^{(2)}_{(i2)j}$ is the flow of imported good i to sector j for capital formation; $X^{(3)}_{(i2)}$ and $X^{(4)}_{(i2)}$ are flows of imported good i to the household and government sectors respectively. The fifth matrix, $\underline{O}$, in the second row is a vector of zeros reflecting the assumption that no imports are simply exported without being processed in a domestic industry. The final matrix, $\tilde{Z}$, in the row which is also a vector shows the import duties paid on imports. When one adds across the rows of $\tilde{F}$, $\tilde{G}$, $\tilde{H}$, $\tilde{J}$ and $-\tilde{Z}$, one obtains the vector of competing imports valued at c.i.f. prices.

	Domestic industries (current production)	Final Demands: Domestic industries (capital production)	Final Demands: House-hold cons'n	Final Demands: Govern-ment cons'n	Final Demands: Exports		
	← 9 →	← 9 →	← 1 →	← 1 →	← 1 →		
Domestic outputs	↑ 9 ↓ $\tilde{A}$	$\tilde{B}$	$\tilde{C}$	$\tilde{D}$	$\tilde{E}$	Row sums=total usage of domes-tic goods	
Competing imports	↑ 9 ↓ $\tilde{F}$	$\tilde{G}$	$\tilde{H}$	$\tilde{J}$	$\underline{\underline{0}}$	−Duty $-\tilde{Z}$	Row sums =total imports (c.i.f.)
Noncom-peting imports	↑ 1 ↓ $\tilde{K}$	$\tilde{L}$	$\tilde{M}$	$\tilde{N}$	$\underline{\underline{0}}$	$-\tilde{P}$	Row sum =total imports (c.i.f.)
Tax	↑ 9 ↓ $\tilde{Q}$	$\tilde{R}$	$\tilde{S}$	$\underline{\underline{0}}$	$\tilde{T}$	Row sums=total tax on sales of effective goods	
Labour	↑ 1 ↓ $\tilde{U}$	$\underline{\underline{0}}$	$\underline{\underline{0}}$	$\underline{\underline{0}}$	$\underline{\underline{0}}$		
Capital	↑ 1 ↓ $\tilde{V}$						
	Column sums= outputs of domestic industries at basic values	Column sums= investment expenditure by industry	Column sum= total house-hold expen-diture	Column sum= total govt. expen-diture	Column sum= total exports		

Figure 4.1: Input-Output Data Base for the Models.

The first four non-zero vectors in the third row of Figure 4.1, $\tilde{K}$, $\tilde{L}$, $\tilde{M}$ and $\tilde{N}$, contain flows of non-competing imports to various users valued at basic prices. The fifth vector, $\underline{Q}$, in the row contains a single element of zero since non-competing imports, like competing imports, are not exported without being processed in the domestic economy. $\tilde{P}$ contains duty on non-competing imports. Adding all elements in $\tilde{K}$, $\tilde{L}$, $\tilde{M}$, $\tilde{N}$ and $-\tilde{P}$ gives the value of non-competing imports at c.i.f. price.

Matrices $\tilde{Q}$ and $\tilde{R}$ in the fourth row of Figure 4.1 show the taxes (or subsidies if negative) associated with the flows of effective goods to different sectors for current production and capital formation respectively. The vector $\tilde{S}$ shows the taxes (or subsidies if negative) associated with the consumption of effective goods by the household sector. The vector $\underline{Q}$ contains zeros since the government sector does not pay any tax or receive subsidy for the use of effective goods. Finally, the vector $\tilde{T}$ shows taxes (or subsidies if negative) associated with exports of domestic goods.

The last group of matrices in Figure 4.1, $\tilde{U}$ and $\tilde{V}$, provide a breakdown of value added in each sector. The elements of $\tilde{U}$, which is a row vector, are the 1977–78 purchases of labour by different sectors. The row vector $\tilde{V}$ contains the rental value of each industry's fixed capital.

The data values contained in the matrices or files described above are reported in Appendix B.

4.2 Derivation of the Share Coefficients

The share coefficients which must be assigned numerical values have been listed in Table 4.2. The objective in this section is to discuss how these share coefficients have been derived from the matrices described in Section 4.1. The discussion follows the sequence of appearances of the share coefficients in Table 4.2.

Table 4.2: Share Coefficients and Parameters of the CGE Models.

Coefficient or parameter	Description	Appearance in equations
$S'^{(1)}_{tj}$	Share of factor t ($t = K, L$) in the total primary factor cost of sector j for current production.	(3.48), (3.49)
$S^{(1)}_{rj}$	Share of input r ($r = K, L, E, M$) in the total factor cost of sector j ($j = 1, 2, \ldots, 9$) for current production.	(3.65)–(3.68), (3.151)
$S^{*(1)}_{rs,j}$	Modified share of input r ($r = K, L, E, M$) in the total factor cost of sector j for current production. The additional subscript s indicates that the share coefficient appears in the demand equation for input s ($s = K, L, E, M$).	(3.87), (3.89), (3.91), (3.93)
$S^{(1)E}_{hj}$	Share of effective fuel of type h ($h = 5, 6, \ldots, 9$) in the total energy cost of sector j for current production.	(3.69), (3.152)
$S^{*(1)E}_{hr,j}$	Modified share of effective fuel of type h ($h = 5, 6, \ldots, 9$) in the total energy cost of sector j for current production. The additional subscript r suggests that the coefficient appears in the demand equation for fuel r, ($r = 5, 6, \ldots, 9$).	(3.95)
$S^{(1)M}_{ij}$	Share of effective material input of type i ($i = 0, 1, \ldots, 4$) in the total material cost of sector j for current production.	(3.70), (3.153)
$S^{*(1)M}_{iq,j}$	Modified share of effective material input of type i ($i = 0, 1, \ldots, 4$) in the total material cost of sector j for current production. The additional subscript q indicates that the coefficient appears in the demand equation for material input q ($q = 0, 1, \ldots, 4$).	(3.97)
$S^{(2)}_{rj}$	Share of input r ($r = E, M$) in the total factor cost of capital formation in sector j ($j = 1, 2, \ldots, 9$).	(3.157)
$S^{*(2)}_{rs,j}$	Modified share of input r ($r = E, M$) in the total factor cost of capital formation in sector j. The additional subscript s indicates that the share coefficient appears in the demand equation for input s ($s = E, M$).	(3.106), (3.108)

....continued

Table 4.2: (*continued*)

Coefficient or parameter	Description	Appearance in equations
$S_{hj}^{(2)E}$	Share of effective fuel of type h ($h = 5, 6, \ldots, 9$) in the total energy cost of sector j for capital formation.	(3.158)
$S_{hr,j}^{*(2)E}$	Modified share of effective fuel of type h ($h = 5, 6, \ldots, 9$) in the total energy cost of sector j for capital formation. The additional subscript r indicates that the coefficient appears in the demand equation for fuel r ($r = 5, 6, \ldots, 9$).	(3.110)
$S_{ij}^{(2)M}$	Share of effective material input of type i ($i = 0, 1, \ldots, 4$) in the total material cost of sector j for capital formation.	(3.159)
$S_{iq,j}^{*(2)M}$	Modified share of effective material input of type i ($i = 0, 1, \ldots, 4$) in the total material cost of sector j for capital formation. The additional subscript q indicates that the coefficient appears in the demand equation for material q ($q = 0, 1, \ldots, 4$).	(3.112)
$S_{(it)}^{c}$	Cost shares of domestic good ($t = 1$) and imported good ($t = 2$) in the creation of effective good i.	(3.141), (3.142), (3.162)
Υ_j	Share of total investment accounted for by sector j.	(3.179)
$H_{ij}^{(1)c}$	Share of total sales of effective good i ($i = 1, 2, \ldots, 9$) which is absorbed by sector j as an input for current production.	(3.183)
$H_{ij}^{(2)c}$	Share of total sales of effective good i which is absorbed by sector j as an input for capital formation.	(3.183)
$H_{i}^{(3)c}$	Share of total sales of effective good i which is consumed by the household sector.	(3.183)
$H_{i}^{(4)c}$	Share of total sales of effective good i which is consumed by the government sector.	(3.183)
$B_{(i1)}^{c}$	Share of the total sales of domestic good i ($i = 1, 2, \ldots, 9$) which is used in the domestic sector.	(3.185)

....*continued*

Table 4.2: (*continued*)

Coefficient or parameter	Description	Appearance in equations
$B^{(5)}_{(i1)}$	Share of the total sales of domestic good i which is exported.	(3.185)
$H^{(1)c}_{0j}$	Share of the non-competing imports which is used in sector j as an input for current production.	(3.189)
$H^{(2)c}_{0j}$	Share of the non-competing imports which is used in sector j as an input for capital formation.	(3.189)
$H^{(3)c}_{0}$	Share of the non-competing imports which is consumed by the household sector.	(3.189)
$H^{(4)c}_{0}$	Share of the non-competing imports which is consumed by the government sector.	(3.189)
$M_{(02)}$	Share of non-competing imports in the total foreign currency costs of imports.	(3.199)
$M_{(i2)}$	Share of competing import good i ($i = 1, 2, \ldots, 9$) in the total foreign currency cost of imports.	(3.199)
$D^{(5)}_{(i1)}$	Share of export good i in the total foreign currency value of exports.	(3.201)
M	Total foreign currency value of imports.	(3.203)
E	Total foreign currency value of exports.	(3.203)
G^L_j	Share of gross household income which is accounted for by wages received from sector j.	(3.206)
G^K_j	Share of gross household income which is accounted for by capital income from sector j.	(3.206)
$R^{(1)}_{(j1)}$	Ratio of the total sales tax paid for current production by industry j to total government income net of subsidy.	(3.210)

....*continued*

Table 4.2: (*continued*)

Coefficient or parameter	Description	Appearance in equations
$G^{(1)}_{(j1)}$	Ratio of the value of current output net of production taxes in sector j to net government income.	(3.210)
$R^{(2)}_j$	Ratio of the total sales tax paid for capital production by industry j to net government income.	(3.210)
$G^{(2)}_j$	Ratio of the value of capital output net of production taxes in sector j to net government income.	(3.210)
$G_{(i2)}$	Ratio of the value of imports i ($i = 0, 1, \ldots, 9$) including tariffs to net government income.	(3.210)
$J_{(i2)}$	Ratio of the total tariff imposed on import good i ($i = 0, 1, \ldots, 9$) to net government income.	(3.210)
$G^{(5)}_{(i1)}$	Ratio of the value of exports of good i at basic price to net government income.	(3.210)
$J^{(5)}_{(i1)}$	Ratio of total subsidy paid to exporters of good i to net government income.	(3.210)
J^H	Share of net government income accounted for by total tax on household income.	(3.210)
$G^{(3)c}_i$	Ratio of total household expenditure on effective good i including tax to net government income.	(3.210)
$J^{(3)c}_i$	Ratio of total sales tax paid by the household sector for consumption of effective good i to net government income.	(3.210)
$w^{(3)}_i$	Weight of effective good i in the cosumer price index.	(3.215)
$w^{(4)}_i$	Weight of effective good i in the government price index.	(3.216)
$w^{(2)}_j$	Weight of capital good j in the capital goods price index.	(3.217)

....*continued*

Table 4.2: (*continued*)

Coefficient or parameter	Description	Appearance in equations
σ_j	Elasticity of substitution between capital and labour in sector j.	(3.48), (3.49)
σ_i^c	Elasticity of substitution between domestic good i ($i = 1, 2, \ldots, 9$) and imported good i.	(3.141), (3.142)
ε_i	Household expenditure elasticity of demand for effective good i ($i = 0, 1, \ldots, 9$).	(3.122)
η_{ik}	Household elasticity of demand for effective good i ($i = 0, 1, \ldots, 9$) with respect to changes in the consumers' price for effective good k ($k = 0, 1, \ldots, 9$).	(3.122)
Q_j	Ratio of gross (before depreciation) to net (after depreciation) rate of return in sector j.	(3.176)
β_j	Elasticity of the expected marginal rate of return on capital in sector j with respect to increases in the planned stock of capital in sector j.	(3.177)
G_j	Ratio of industry j's gross investment to its capital stock of the following year.	(3.178)
J	Set of integers identifying those industries for which the models are allowed to determine investment according to relative rates of return.	(3.177)
γ_i	Reciprocal of the foreign elasticity of demand for domestic good i.	(3.144)
$\beta_{rs,j}$	Second-order parameters of the KLEM production submodel for current production of sector j.	(3.88), (3.90), (3.92), (3.94)
$\beta^E_{hr,j}$	Second-order parameters of the interfuel substitution submodel for current production of sector j.	(3.96)

....continued

Table 4.2: (*continued*)

Coefficient or parameter	Description	Appearance in equations
$\beta^M_{iq,j}$	Second-order parameters of the inter-material substitution submodel for current production of sector j.	(3.98)
$\alpha_{rs,j}$	Second-order parameters of the energy-material submodel for capital production of sector j.	(3.107), (3.109)
$\alpha^E_{hr,j}$	Second-order parameters of the interfuel submodel for capital production of sector j.	(3.111)
$\alpha^M_{iq,j}$	Second-order parameters of the inter-material submodel for capital production of sector j.	(3.113)
$h^{(2)}_j$	Indexing parameter. Fixes the relationship between movements in aggregate real private investment and investment in industry j where $j \notin J$.	(3.180)
h	Indexing parameter. Fixes the relationship between movements in the wage rate and the consumer price index.	(3.197)
$B^{(1)}_{Lj}$	Share of labour which is used by sector j for current production.	(3.196)
B_{Kj}	Share of the economy's total capital stock which is accounted for by the capital stock of sector j.	(3.219)
$T^H/(1-T^H)$	Taxes on household income as a fraction of net household income.	(3.207)

Shares of capital and labour in the total primary factor cost of sector j for current production are obtained from the two vectors $\tilde{U}$ and $\tilde{V}$ as follows:

$$S'^{(1)}_{Kj} = \tilde{v}_j/(\tilde{u}_j + \tilde{v}_j), \;\; j = 1, 2, \ldots, 9,$$

$$S'^{(1)}_{Lj} = \tilde{u}_j/(\tilde{u}_j + \tilde{v}_j), \;\; j = 1, 2, \ldots, 9,$$

where $S'^{(1)}_{Kj}$ and $S'^{(1)}_{Lj}$ are as described in Table 4.2.

Shares of aggregate factors or inputs, i.e., of capital, labour, energy and aggregate materials in a sector's total factor cost for current production are derived from matrices $\tilde{A}$, $\tilde{F}$, $\tilde{K}$, $\tilde{U}$ and $\tilde{V}$. In terms of the elements of these matrices, the total factor cost of sector j ($j = 1, 2, \ldots, 9$) for current production can be defined as

$$C_j = \sum_{i=1}^{9}(\tilde{a}_{ij} + \tilde{f}_{ij}) + \tilde{k}_j + \tilde{u}_j + \tilde{v}_j,$$

where C_j is the total factor cost of sector j for current production.The shares of capital, labour, energy and aggregate materials in the total factor cost of sector j for current production are derived by the following formulae:

$$\begin{aligned} S^{(1)}_{Kj} &= \tilde{v}_j/C_j, \\ S^{(1)}_{Lj} &= \tilde{u}_j/C_j, \\ S^{(1)}_{Mj} &= [\sum_{i=1}^{4}(\tilde{a}_{ij} + \tilde{f}_{ij}) + \tilde{k}_j]/C_j, \end{aligned}$$

and

$$S^{(1)}_{Ej} = [\sum_{i=5}^{9}(\tilde{a}_{ij} + \tilde{f}_{ij})]/C_j$$

respectively, where $S^{(1)}_{rj}$ ($r = K, L, E, M$) is defined as in Table 4.2.

Modified shares of capital, labour, energy and aggregate materials in the total factor cost of sector j for current production, i.e., $S^{*(1)}_{rs,j}$'s, are obtained by using equations (3.88), (3.90), (3.92) and (3.94) which define modified cost shares as functions of unmodified cost shares, $S_{rj}^{(1)}$'s, and the second-order parameters of the translog cost function (3.20), i.e., $\beta_{rs,j}$'s. The numerical values of the second-order parameters of the translog cost function are discussed in Section 4.3.

Shares of individual effective fuels in the total energy cost of sector j for current production, $S_{hj}^{(1)E}$'s, are derived from matrices $\tilde{A}$ and $\tilde{F}$. The share of effective fuel of type h ($h = 5, 6, \ldots, 9$; $h = 5$ is coal, $h = 6$ is crude oil, $h = 7$ is petroleum and coal products, $h = 8$ is electricity and $h = 9$ is gas utilities) in the total energy cost of sector j for current production is obtained by the following formula:

$$\begin{aligned} S_{hj}^{(1)E} &= (\tilde{a}_{hj} + \tilde{f}_{hj}) / \sum_{i=5}^{9} (\tilde{a}_{ij} + \tilde{f}_{ij}), \quad h = 5, 6, \ldots, 9; \\ & \quad j = 1, 2, \ldots, 9. \end{aligned}$$

Modified shares of individual effective fuels in the total energy cost of sector j for current production, i.e., $S_{hr,j}^{*(1)E}$'s, are calculated by using equations in (3.96) which define the modified energy cost shares as functions of unmodified energy cost shares, $S_{hj}^{(1)E}$'s, and the second-order parameters of the translog cost function (3.21), i.e., $\beta_{hr,j}^{E}$'s. For a discussion of the numerical values of $\beta_{hr,j}^{E}$'s see Section 4.3.

Shares of individual effective material inputs in the total material cost of sector j for current production, $S_{ij}^{(1)M}$'s, are derived from matrices $\tilde{A}$, $\tilde{F}$ and $\tilde{K}$. The share of non-competing imports in the total material cost of sector j for current production is obtained as follows:

$$S_{0j}^{(1)M} = \tilde{k}_j / [\sum_{i=1}^{4} (\tilde{a}_{ij} + \tilde{f}_{ij}) + \tilde{k}_j]$$

where $S_{0j}^{(1)M}$ is the share of non-competing imports in the total material cost of sector j for current production. Similarly, the share of effective material input of type i ($i = 1, 2, \ldots, 4$) in the total material cost of sector j for current production, $S_{ij}^{(1)M}$, is obtained as

$$S_{ij}^{(1)M} = (\tilde{a}_{ij} + \tilde{f}_{ij})/[\sum_{i=1}^{4}(\tilde{a}_{ij} + \tilde{f}_{ij}) + \tilde{k}_j], \quad i = 1, 2, \ldots, 4; \ j = 1, 2, \ldots, 9.$$

Modified shares of individual effective material inputs, i.e., $S_{iq,j}^{*(1)M}$'s, in the total material cost of sector j for current production are calculated by using equations in (3.98) which define these material cost shares as functions of unmodified material cost shares, $S_{ij}^{(1)M}$'s, and the second-order parameters of the translog cost function (3.22), i.e., β_{iq}^{M}'s. The numerical values of $\beta_{iq,j}^{M}$'s are discussed in Section 4.3.

The shares of energy and aggregate materials in the total factor cost of sector j for capital formation, $S_{rj}^{(2)}$ ($r = E, M$), have been derived from matrices $\tilde{B}$, $\tilde{G}$ and $\tilde{L}$. Notationally, the share of energy in the total factor cost of sector j for capital formation, $S_{Ej}^{(2)}$, is obtained as

$$S_{Ej}^{(2)} = \sum_{i=5}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij})/[\sum_{i=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij}) + \tilde{l}_j], \quad j = 1, 2, \ldots, 9.$$

Similarly, the share of aggregate materials in the total factor cost of sector j for capital formation, $S_{Mj}^{(2)}$, is calculated as

$$S_{Mj}^{(2)} = [\sum_{i=1}^{4}(\tilde{b}_{ij} + \tilde{g}_{ij}) + \tilde{l}_j]/[\sum_{i=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij}) + \tilde{l}_j], \quad j = 1, 2, \ldots, 9.$$

Modified shares of energy and aggregate materials in the total factor cost of sector j for capital formation, i.e., $S_{rs,j}^{*(2)}$'s, are obtained by using the equations (3.107) and (3.109) which define these cost shares as functions of unmodified cost shares, $S_{rj}^{(2)}$'s, and the second-order parameters of the translog cost function (3.99), i.e., $\alpha_{rs,j}$ ($r, s = E, M$). The numerical values of $\alpha_{rs,j}$'s are discussed in Section 4.3.

Shares of individual effective fuels in the total energy cost of sector j for capital formation, i.e. $S_{hj}^{(2)E}$'s, are obtained from matrices $\tilde{B}$ and $\tilde{G}$. Notationally, the share of effective fuel of type h ($h = 5, 6, \ldots, 9$) is obtained as

$$S_{hj}^{(2)E} = (\tilde{b}_{hj} + \tilde{g}_{hj}) / \sum_{t=5}^{9} (\tilde{b}_{tj} + \tilde{g}_{tj}),$$
$$h = 5, 6, \ldots, 9, \quad j = 1, 2, \ldots, 9.$$

Modified shares of individual effective fuels in the total energy cost of sector j for capital formation, i.e. $S_{hr,j}^{*(2)E}$'s, are calculated by using equations in (3.111) which define modified energy cost shares as functions of unmodified energy cost shares, $S_{hj}^{(2)E}$'s, and the second-order parameters of the translog cost function (3.100), i.e., $\alpha_{hr,j}^{E}$'s. The numerical values assigned to $\alpha_{hr,j}^{E}$'s are discussed in Section 4.3.

Shares of individual effective material inputs in the total material cost of sector j for capital formation, i.e. $S_{ij}^{(2)M}$'s, are derived from matrices $\tilde{B}$, $\tilde{G}$ and $\tilde{L}$. Notationally, the share of non-competing imports ($i = 0$) in the total material cost of sector j for capital formation, $S_{0j}^{(2)M}$, is calculated as

$$S_{0j}^{(2)M} = \tilde{l}_j / [\sum_{t=1}^{4} (\tilde{b}_{tj} + \tilde{g}_{tj}) + \tilde{l}_j], \quad j = 1, 2, \ldots, 9.$$

Similarly, the share of individual effective material input of type i ($i = 1, 2, \ldots, 4$) in the total material cost of sector j for capital formation, $S_{ij}^{(2)M}$, is obtained as

$$S_{ij}^{(2)M} = (\tilde{b}_{ij} + \tilde{g}_{ij}) / [\sum_{t=1}^{4} (\tilde{b}_{tj} + \tilde{g}_{tj}) + \tilde{l}_j],$$
$$i = 1, 2, \ldots, 4, \quad j = 1, 2, \ldots, 9.$$

Modified shares of individual effective material inputs in the total material cost of sector j for capital formation, i.e. $S_{iq,j}^{*(2)M}$'s, are calculated by using equations in (3.113) which define these shares as functions of unmodified material cost shares, $S_{ij}^{(2)M}$'s, and the second-order parameters of the translog cost function (3.101), i.e., $\alpha^M_{iq,j}$'s. The numerical values of $\alpha^M_{iq,j}$'s are discussed in Section 4.3.

Cost shares of domestic and foreign goods in the creation of effective goods, i.e. $S^c_{(it)}$'s, are derived from matrices $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, $\tilde{D}$, $\tilde{F}$, $\tilde{G}$, $\tilde{H}$ and $\tilde{J}$. The share of domestic good i in the total cost of creating effective good i, $S^c_{(i1)}$, is derived as

$$S^c_{(i1)} = \bar{T}^c_{(i1)}/(\bar{T}^c_{(i1)} + \bar{T}^c_{(i2)}), \quad i = 1, 2, \ldots, 9,$$

where $\bar{T}^c_{(i1)}$ is total expenditure on domestic good i by all domestic users defined as

$$\begin{aligned} \bar{T}^c_{(i1)} &= \sum_{j=1}^{9}(\tilde{a}_{ij} + \tilde{b}_{ij}) + \tilde{c}_i + \tilde{d}_i, \\ & \quad i = 1, 2, \ldots, 9, \end{aligned}$$

and $\bar{T}^c_{(i2)}$ is total expenditure on competing imports i by all domestic users defined as

$$\begin{aligned} \bar{T}^c_{(i2)} &= \sum_{j=1}^{9}(\tilde{f}_{ij} + \tilde{g}_{ij}) + \tilde{h}_i + \tilde{j}_i, \\ & \quad i = 1, 2, \ldots, 9. \end{aligned}$$

Similarly, the share of imported good i in the total cost of forming effective good i, $S^c_{(i2)}$, is derived as

$$S^c_{(i2)} = \bar{T}^c_{(i2)}/(\bar{T}^c_{(i1)} + \bar{T}^c_{(i2)}), \quad i = 1, 2, \ldots, 9.$$

Υ_j, the share of total investment which is accounted for by sector j, is calculated from matrices $\tilde{B}$, $\tilde{G}$, $\tilde{L}$ and $\tilde{R}$. The total investment expenditure made by all sectors, $C^{(2)}$, is calculated as

$$C^{(2)} = \sum_{i=1}^{9}\sum_{j=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij} + \tilde{r}_{ij}) + \sum_{j=1}^{9}\tilde{l}_j.$$

The share of total investment accounted for by sector j is then calculated as

$$\Upsilon_j = [\sum_{i=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij} + \tilde{r}_{ij}) + \tilde{l}_j]/C^{(2)}, \quad j = 1, 2, \ldots, 9.$$

$H_{ij}^{(1)c}$, $H_{ij}^{(2)c}$, $H_i^{(3)c}$ and $H_i^{(4)c}$, which are defined in Table 4.2, are derived from matrices $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, $\tilde{D}$, $\tilde{F}$, $\tilde{G}$, $\tilde{H}$ and $\tilde{J}$. The total sales of effective good i can be obtained as

$$\begin{aligned} \bar{T}_i^c &= \sum_{j=1}^{9}(\tilde{a}_{ij} + \tilde{f}_{ij} + \tilde{b}_{ij} + \tilde{g}_{ij}) + (\tilde{c}_i + \tilde{h}_i + \tilde{d}_i + \tilde{j}_i), \\ & \quad i = 1, 2, \ldots, 9. \end{aligned}$$

The share of total sales of effective good i which is absorbed by sector j as an input for current production is then calculated as

$$H_{ij}^{(1)c} = (\tilde{a}_{ij} + \tilde{f}_{ij})/\bar{T}_i^c, \quad i, j = 1, 2, \ldots, 9.$$

The share of total sales of effective good i which is absorbed by sector j as an input for capital formation is calculated as

$$H_{ij}^{(2)c} = (\tilde{b}_{ij} + \tilde{g}_{ij})/\bar{T}_i^c, \quad i, j = 1, 2, \ldots, 9.$$

The share of total sales of effective good i which is consumed by the household sector is derived as

$$H_i^{(3)c} = (\tilde{c}_i + \tilde{h}_i)/\bar{T}_i^c, \quad i = 1, 2, \ldots, 9.$$

The share of total sales of effective good i which is consumed by the government sector is calculated as

$$H_i^{(4)c} = (\tilde{d}_i + \tilde{j}_i)/\bar{T}_i^c, \quad i = 1, 2, \ldots, 9.$$

$B^c_{(i1)}$ and $B^{(5)}_{(i1)}$, which are defined in Table 4.2, are derived from matrices $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, $\tilde{D}$, and $\tilde{E}$. The total sales of domestic good i to both the domestic and foreign markets, $\bar{T}_{(i1)}$, is obtained as

$$\bar{T}_{(i1)} = \sum_{j=1}^{9}(\tilde{a}_{ij} + \tilde{b}_{ij}) + \tilde{c}_i + \tilde{d}_i + \tilde{e}_i, \quad i = 1, 2, \ldots, 9.$$

The share of total sales of domestic good i which is absorbed in the domestic market is then calculated as

$$B^c_{(i1)} = [\sum_{j=1}^{9}(\tilde{a}_{ij} + \tilde{b}_{ij}) + \tilde{c}_i + \tilde{d}_i]/\bar{T}_{(i1)}, \quad i = 1, 2, \ldots, 9.$$

The share of the total sales of domestic good i which is accounted for by exports is calculated as

$$B^{(5)}_{(i1)} = \tilde{e}_i/\bar{T}_{(i1)}, \quad i = 1, 2, \ldots, 9.$$

$H^{(1)c}_{0j}$, $H^{(2)c}_{0j}$, $H^{(3)c}_{0}$ and $H^{(4)c}_{0}$, which are described in Table 4.2, have been derived from matrices $\tilde{K}$, $\tilde{L}$, $\tilde{M}$ and $\tilde{N}$. The share of the total sales of non-competing imports which is absorbed by sector j as an input for current production is obtained as

$$H^{(1)c}_{0j} = \tilde{k}_j/[\sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n}], \quad j = 1, 2, \ldots, 9.$$

Similarly, $H^{(2)c}_{0j}$, $H^{(3)c}_{0}$ and $H^{(4)c}_{0}$ are obtained as follows:

$$\begin{aligned} H^{(2)c}_{0j} &= \tilde{l}_j/[\sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n}], \quad j = 1, 2, \ldots, 9, \\ H^{(3)c}_{0} &= \tilde{m}/[\sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n}], \end{aligned}$$

and

$$H_0^{(4)c} = \tilde{n}/[\sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n}].$$

$M_{(02)}$ and $M_{(i2)}$, defined in Table 4.2, have been calculated from matrices $\tilde{F}$, $\tilde{G}$, $\tilde{H}$, $\tilde{J}$, $\tilde{Z}$, $\tilde{K}$, $\tilde{L}$, $\tilde{M}$, $\tilde{N}$ and $\tilde{P}$. The foreign currency cost of competing import good i, $\bar{T}^w_{(i2)}$, can be calculated as

$$\bar{T}^w_{(i2)} = \sum_{j=1}^{9}(\tilde{f}_{ij} + \tilde{g}_{ij}) + \tilde{h}_i + \tilde{j}_i - \tilde{z}_i, \quad i = 1, 2, \ldots, 9.$$

The foreign currency cost of non-competing imports can be defined as

$$\bar{T}^w_{(02)} = \sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n} - \tilde{p}.$$

The total foreign currency cost of all imports, M, can be obtained as

$$M = \sum_{i=0}^{9} \bar{T}^w_{(i2)}.$$

The share of non-competing imports in the total foreign currency cost of imports is then calculated as

$$M_{(02)} = \bar{T}^w_{(02)}/M.$$

The share of competing import good i in the total foreign currency cost of imports is calculated as

$$M_{(i2)} = \bar{T}^w_{(i2)}/M, \quad i = 1, 2, \ldots, 9.$$

The share of export good i ($i = 1, 2, \ldots, 9$) in the total foreign currency value of all exports has been calculated from vectors $\tilde{E}$ and $\tilde{T}$. The total foreign currency value of all exports, E, can be calculated from these vectors as

$$E = \sum_{i=1}^{9} (\tilde{e}_i + \tilde{t}_i).$$

Then the share of export good i in E, $D^{(5)}_{(i1)}$, is obtained as

$$D^{(5)}_{(i1)} = (\tilde{e}_i + \tilde{t}_i)/E, \quad i = 1, 2, \ldots, 9.$$

G^L_j and G^K_j are derived from vectors $\tilde{U}$ and $\tilde{V}$. G^L_j, the share of gross (before tax) household income which is accounted for by wages received from sector j, has been calculated as

$$G^L_j = \tilde{u}_j / \sum_{j=1}^{9} (\tilde{u}_j + \tilde{v}_j), \quad j = 1, 2, \ldots, 9.$$

The share of gross household income which is accounted for by capital income from sector j, G^K_j, has been calculated as

$$G^K_j = \tilde{v}_j / \sum_{j=1}^{9} (\tilde{u}_j + \tilde{v}_j), \quad j = 1, 2, \ldots, 9.$$

Before calculating $R^{(1)}_{(j1)}$, $G^{(1)}_{(j1)}$, $R^{(2)}_j$, $G^{(2)}_j$, $G_{(i2)}$, $J_{(i2)}$, $G^{(5)}_{(i1)}$, $J^{(5)}_{(i1)}$, J^H, $G^{(3)c}_i$ and $J^{(3)c}_i$ (see Table 4.2 for the descriptions of these coefficients), one needs to calculate the total government income net of subsidy, $Y^{(4)}$. Assuming an average income tax of 21 percent (the basis of assuming this tax rate is discussed in Section 4.3), $Y^{(4)}$ has been calculated as

$$Y^{(4)} = 0.21 \sum_{j=1}^{9} (\tilde{u}_j + \tilde{v}_j) + \sum_{i=1}^{9} \sum_{j=1}^{9} (\tilde{q}_{ij} + \tilde{r}_{ij}) + \sum_{i=1}^{9} (\tilde{s}_i + \tilde{t}_i + \tilde{z}_i) + \tilde{p}.$$

The ratio of the total sales tax paid for current production by sector j to the net government income, $R^{(1)}_{(j1)}$, has then been calculated as

$$R^{(1)}_{(j1)} = \sum_{i=1}^{9} \tilde{q}_{ij}/Y^{(4)}, \quad j = 1, 2, \ldots, 9.$$

The ratio of the value of current output of sector j net of production taxes to the net government income, $G^{(1)}_{(j1)}$, is calculated as

$$\begin{aligned} G^{(1)}_{(j1)} &= [\sum_{i=1}^{9}(\tilde{a}_{ij} + \tilde{f}_{ij}) + \tilde{k}_j + \tilde{u}_j + \tilde{v}_j)]/Y_{(4)}, \\ & j = 1, 2, \ldots, 9. \end{aligned}$$

The ratio of total sales tax paid for capital formation by sector j to the net government income, $R^{(2)}_j$, is calculated as

$$R^{(2)}_j = \sum_{i=1}^{9} \tilde{r}_{ij}/Y^{(4)}, \quad j = 1, 2, \ldots, 9.$$

The ratio of the value of capital goods produced in sector j net of production taxes to the net government income is calculated as

$$G^{(2)}_j = [\sum_{i=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij}) + \tilde{l}_j]/Y^{(4)}, \quad j = 1, 2, \ldots, 9.$$

The ratio of the value of competing foreign good i including tariffs to the net government income, $G_{(i2)}$, is derived as

$$G_{(i2)} = [\sum_{j=1}^{9}(\tilde{f}_{ij} + \tilde{g}_{ij}) + \tilde{h}_i + \tilde{j}_i]/Y^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The ratio of the value of non-competing imports ($i = 0$) including tariffs to the net government income, $G_{(02)}$, is calculated as

$$G_{(02)} = [\sum_{j=1}^{9}(\tilde{k}_j + \tilde{l}_j) + \tilde{m} + \tilde{n}]/Y^{(4)}.$$

The ratio of the total tariffs imposed on competing import good i to the net government income, $J_{(i2)}$, is calculated as

$$J_{(i2)} = \tilde{z}_i / Y^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The ratio of tariffs imposed on non-competing imports ($i = 0$) to the net government income, $J_{(02)}$, is calculated as

$$J_{(02)} = \tilde{p} / Y^{(4)}.$$

The ratio of the value of exports of good i at basic price to the net government income, $G^{(5)}_{(i1)}$, is derived as

$$G^{(5)}_{(i1)} = \tilde{e}_i / Y^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The ratio of total subsidy paid to exporters of good i to the net government income, $J^{(5)}_{(i1)}$, is calculated as

$$J^{(5)}_{(i1)} = -\tilde{t}_i / Y^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The share of net government income accounted for by total tax on household income, J^H, is calculated as

$$J^H = 0.21[\sum_{j=1}^{9}(\tilde{u}_j + \tilde{v}_j)] / Y^{(4)}.$$

The ratio of the total household expenditure on effective good i including consumption tax to the net government income, $G^{(3)c}_i$, has been calculated as

$$G^{(3)c}_i = (\tilde{c}_i + \tilde{h}_i + \tilde{s}_i) / Y^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The ratio of total household expenditure on effective good $i = 0$, i.e. non-competing imports, including consumption tax to the net government income, $G_0^{(3)c}$, is calculated as

$$G_0^{(3)c} = \tilde{m}/Y^{(4)}.$$

Note that there was no tax associated with the consumption of non-competing imports in the household sector. The ratio of total tax paid by the household sector for the consumption of effective good i ($i = 0, 1, \ldots, 9$) to the net government income, $J_i^{(3)c}$, is calculated as

$$J_i^{(3)c} = \tilde{s}_i/Y^{(4)}, \quad i = 1, 2, \ldots, 9;$$

and

$$J_0^{(3)c} = 0.$$

Weight of effective good i ($i = 0, 1, \ldots, 9$) in the consumer price index, $w_i^{(3)}$, is obtained from vectors $\tilde{C}$, $\tilde{H}$, $\tilde{M}$ and $\tilde{S}$. The total expenditure of the household sector at consumer prices, $C^{(3)}$, is calculated as

$$C^{(3)} = \sum_{i=1}^{9}(\tilde{c}_i + \tilde{h}_i + \tilde{s}_i) + \tilde{m}.$$

The weight of effective good i ($i = 1, 2, \ldots, 9$) in the consumer price index is then calculated as

$$w_i^{(3)} = (\tilde{c}_i + \tilde{h}_i + \tilde{s}_i)/C^{(3)}, \quad i = 1, 2, \ldots, 9.$$

The weight of effective good $i = 0$, i.e. non-competing imports, in the consumer price index is calculated as

$$w_0^{(3)} = \tilde{m}/C^{(3)}.$$

Weight of effective good i ($i = 0, 1, \ldots, 9$) in the government price index, $w_i^{(4)}$, is calculated from vectors $\tilde{D}$, $\tilde{J}$ and $\tilde{N}$. The total expenditure of the government sector on effective goods, $C^{(4)}$, is calculated as

$$C^{(4)} = \sum_{i=1}^{9}(\tilde{d}_i + \tilde{j}_i) + \tilde{n}.$$

The weight of the effective good i ($i = 1, 2, \ldots, 9$) in the government price index is then calculated as

$$w_i^{(4)} = (\tilde{d}_i + \tilde{j}_i)/C^{(4)}, \quad i = 1, 2, \ldots, 9.$$

The weight of non-competing imports, i.e. effective good $i = 0$, in the government price index is calculated as

$$w_0^{(4)} = \tilde{n}/C^{(4)}.$$

Investment expenditure weights in the capital goods price index, $w_j^{(2)}$, are obtained from matrices $\tilde{B}$, $\tilde{G}$, $\tilde{L}$ and $\tilde{R}$. At first, total investment expenditure by all sectors, $C^{(2)}$, is calculated as

$$C^{(2)} = \sum_{i=1}^{9}\sum_{j=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij} + \tilde{r}_{ij}) + \sum_{j=1}^{9}\tilde{l}_j.$$

Weight of capital good j ($j = 1, 2, \ldots, 9$) in the capital goods price index is then calculated as

$$w_j^{(2)} = [\sum_{i=1}^{9}(\tilde{b}_{ij} + \tilde{g}_{ij} + \tilde{r}_{ij}) + \tilde{l}_j]/C^{(2)}, \quad j = 1, 2, \ldots, 9.$$

Note that there is no difference between the set of $w_j^{(2)}$'s and the set of Υ_j's in the present study.

4.3 Parameters of the Models

In the previous section, derivation procedures of the share coefficients from the base-period input-output data base have been discussed. In addition to the numerical values of the share coefficients discussed there, one must also determine the numerical values for the parameter set before attempting to solve the models. In other words, one must supply values for the following parameters and coefficients to the solution algorithms.

(a) The elasticities of substitution between capital and labour: σ_j, $j = 1, 2, \ldots, 9$.

(b) The elasticities of substitution between domestic and foreign goods: σ_i^c, $i = 1, 2, \ldots, 9$.

(c) The household expenditure and price elasticities of demand: ε_i, $i = 0, 1, \ldots, 9$ and η_{ik}, $i, k = 0, 1, \ldots, 9$.

(d) The investment parameters and coefficients: the elasticities of the expected rates of return, β_j, $j = 1, 2, \ldots, 9$; the ratios of gross to net rates of return, Q_j, $j = 1, 2, \ldots, 9$; the growth terms, G_j, $j = 1, 2, \ldots, 9$; and the set of industries, J, for which investment is explained by relative rates of return.

(e) The reciprocals of the export demand elasticities: γ_i, $i = 1, 2, \ldots, 9$.

(f) Second-order parameters of the translog cost functions for current production: second-order parameters of the translog cost function (3.20), $\beta_{rs,j}$, $r, s = K, L, E, M$ and $j = 1, 2, \ldots, 9$; second-order parameters of the translog cost function (3.21), $\beta_{hr,j}^E$, $h, r = 5, 6, \ldots, 9$ and $j = 1, 2, \ldots, 9$; and second-order parameters of the translog cost function (3.22), $\beta_{iq,j}^M$, $i, q = 0, 1, \ldots, 4$ and $j = 1, 2, \ldots, 9$.

(g) Second-order parameters of the translog cost functions for capital production: second-order parameters of the translog cost function (3.99), $\alpha_{rs,j}$, $r, s = E, M$ and $j = 1, 2, \ldots, 9$; second-order parameters of the translog cost function (3.100), $\alpha^{E}_{hr,j}$, $h, r = 5, 6, \ldots, 9$ and $j = 1, 2, \ldots, 9$; and second-order parameters of the translog cost function (3.101), $\alpha^{M}_{iq,j}$, $i, q = 0, 1, \ldots, 4$ and $j = 1, 2, \ldots, 9$.

(h) Indexing parameters: $h^{(2)}_j$, $j \notin J$ (exogenous investment); and h (wage indexation parameter).

(i) Base-period sectoral shares in aggregate employment calculated in persons: $B^{(1)}_{Lj}$, $j = 1, 2, \ldots, 9$.

(j) Base-period sectoral shares in the value of the economy-wide capital stock: B_{Kj}, $j = 1, 2, \ldots, 9$.

(k) Ratio of household income tax to the net household income: $T^H/(1 - T^H)$.

Elasticities of substitution between capital and labour: These parameters appear only in the CES-FC (CES-Fixed Coefficient) model. Since the production functions for current production in this model are intended to be similar to those of the ORANI model (see Dixon *et al.* 1982), it is assumed following Dixon *et al.* that the elasticity of substitution between capital and labour is 0.5 for all sectors, i.e., $\sigma_j = 0.5$, $j = 1, 2, \ldots, 9$.

Elasticities of substitution between domestic and foreign goods: In implementing the models it has been simply assumed that the elasticities of substitution between domestic and matching foreign goods (i.e., trade substitution elasticities) are unity, i.e., $\sigma^c_i = 1$, $i = 1, 2, \ldots, 9$. This simplifying assumption amounts to assuming that the production function for effective good i ($i = 1, 2, \ldots, 9$) is of Cobb-Douglas type, which is a special case of CES production functions. Although this assumption is theoretically restrictive, this has been made to keep the analysis simple. The main objective of the study is to examine the sensitivity of the model results to different production function specifications for current production and this assumption will not hinder achieving this. This is because all three CGE models will be equally affected by this restrictive assumption; any difference across the projections of the models can be ascribed to the difference in production structures employed in them.

Household expenditure and price elasticities of demand: Originally, it was intended to estimate the household expenditure and price elasticities of demand from time-series data by utilising the linear expenditure system of demand equations which has been described in the previous chapter. However, this was not possible due to time constraints. Instead, a simplifying assumption is made regarding household expenditure and price elasticities of demand. It is assumed that expenditure and own price elasticities of demand for effective good i are unity while cross price elasticities of demand are zero, that is, $\varepsilon_i = 1$, $i = 0, 1, \ldots, 9$, and $\eta_{ik} = -1$ if $i = k$ otherwise zero. This assumption implies that the aggregate household utility function is Cobb-Douglas in form. This assumption is theoretically as well as empirically restrictive. But this assumption can be defended on the same ground as is noted in the context of trade substitution elasticities.

Investment parameters and coefficients: As noted at the beginning of this section, one must choose the values of β_j's (the elasticities of the expected rates of return), Q_j's (the ratios of gross to net rates of return on fixed investment) and G_j's (the ratios of annual gross investment to future capital stocks). In addition, one needs to specify the set of industries, J, for which the rate-of-return theory of investment, described in Chapter 3, Section 3.7, is to apply. The set of investment parameters and coefficients, i.e., β_j's, Q_j's and G_j's are taken from the 1977–78 ORANI balanced data base reported in Blampied (1985). For the ORANI model, the β_j's were estimated from a time series data using the following formula:

$$\beta_j = \frac{\ln[Av\{R_j(0)\}] - \ln\{Av(\Omega)\}}{\ln[Av\{K_j(1)/K_j(0)\}]},$$

where $Av\{R_j(0)\}$ is the net rate of return on investment in sector j averaged over time; $Av\{K_j(1)/K_j(0)\}$ is average growth factor in sector j and $Av(\Omega)$ is the average safe rate of interest.[1] The G_j's and Q_j's were computed according to the following formulae:

$$G_j = 1 - [Av\{K_j(0)/K_j(1)\}](1 - d_j)$$

and

$$Q_j = [Av\{R_j(0)\} + d_j]/Av\{R_j(0)\},$$

where d_j is an estimate of the average rate of depreciation of fixed capital in sector j. For the present study, a set of these parameters/coefficients for a sector is constructed by simply taking the arithmetic average of ORANI estimates over the constituent industries. For example, the elasticity of the expected rate of return in the agriculture, mining and construction sector is specified as the average of elasticities of the expected rates of return in ORANI industries constituting this sector. The set of values decided for β_j's, G_j's and Q_j's for the present study are shown in Table 4.3.

Finally, as to the set of industries J, it is assumed that J contains all industries. That is, the rate of return theory of investment applies to all sectors in determining their levels of investment.

Reciprocals of the export demand elasticities: There is considerable lack of consensus among Australian economists as to the extent to which Australia can exert market power for its individual exports.[2] Sufficient econometric

[1] For a description of the estimation of these averages see Dixon, Parmenter, Ryland and Sutton (1977, pp.164–171), Vincent (1979) and Caddy (1977).

[2] See, for example, the exchange between Throsby and Rutledge (1979) and Scobie and Johnson (1979) and the paper by Cronin (1979).

Table 4.3: Values for γ, β, Q and G Used for the Models in this Study.

Sector	γ_j	β_j	Q_j	G_j
1. Agriculture, mining and construction	0.30	21.01	2.47	0.12
2. Manufacturing	0.21	54.29	1.95	0.11
3. Transportation	0.05	16.35	1.89	0.19
4. Communications, trade and services	0.05	12.34	1.47	0.18
5. Coal	0.05	13.80	1.50	0.20
6. Crude oil	0.05	17.90	1.68	0.16
7. Petroleum and coal products	0.05	30.40	2.02	0.11
8. Electricity	0.05	13.90	1.59	0.15
9. Gas utilities	0.05	13.50	1.96	0.15

evidence is not available to assist in resolving these differences. In setting the values of γ_i's, the reciprocals of the export demand elasticities, for the present study it was required to rely on ORANI data base once again.

For most agricultural and mining export commodities ORANI values of γ were obtained from Freebairn (1978) while for other export commodities they were set on the basis of Australia's share of world markets (see Dixon *et al.* (1982) for details). For the present study, the ORANI values of γ were averaged over commodities constituting a sector's output to determine the reciprocal of the elasticity of demand for exports from that sector. For example, the reciprocal of the elasticity of demand for exports from the agriculture, mining and construction sector is specified to be the average of the γ values of ORANI commodities produced by this sector. The set of γ's used in this study are shown in Table 4.3.

Second-order parameters of the translog cost functions for current production: To implement the translog versions of the current production submodels one must specify the values of three sets of parameters. These are:

(i) $\beta_{rs,j}$, $r,s = K,L,E,M$ and $j = 1,2,\ldots,9$, that is, the second-order parameters appearing in the translog version of capital (K), labour (L), energy (E) and aggregate materials (M) submodel (in brief, KLEM submodel) of current production of sector j;

(ii) $\beta^E_{hr,j}$, $h,r = 5,6,\ldots,9$ and $j = 1,2,\ldots,9$, that is, the second-order parameters appearing in the interfuel substitution submodel of sector j for current production; and

(iii) $\beta^M_{iq,j}$, $i,q = 0,1,\ldots,4$ and $j = 1,2,\ldots,9$, that is, the second-order parameters appearing in the inter-material submodel of sector j for current production. Note that $i = 0$ indicates non-competing imports.

One could estimate these parameters from time-series/cross-section data or obtain them from other studies. Although the former approach is preferable, the latter approach has been adopted for this study. Originally, it was hoped that the parameter sets, noted above, could be estimated from time-series data. But a preliminary survey of the publications of Australian Bureau of Statistics quickly suggested that it would be impossible for the present author to gather requisite data and to estimate the parameters of the translog submodels for sectoral current production in the time available. This judgement was substantiated by the experience of the Centre for Resource and Environmental Studies of the Australian National University in implementing the Hudson-Jorgenson (H-J) model (Hudson and Jorgenson 1974) for Australia. This centre's attempt to implement the H-J model was unsuccessful mainly because of lack of adequate data. In his final report on National Energy Research Dr. Donnelly wrote,

> "Implementing a comprehensive economic energy model proved to be impossible of achievement given existing quality of Australian data and the limited improvements in energy data collections likely to be made." (Donnelly 1984, p. iv).

The present author wrote to Dr. Donnelly enquiring about his experience in estimating the parameters of translog models for different Australian industries/sectors. In reply Dr. Donnelly wrote:

> "Australian translog modeling work is frustrated by the paucity of good, consistent data for various sectors of the economy. From the work on the iron and steel sector on which Turnovsky and I report in the Journal of Business and Economic Statistics (1984, 2: 54–63), we felt could not be extended to other sectors, such is done in the work of Hudson-Jorgenson." (Dr. Donnelly, Personal Communication, February 01, 1988).

The guideline for specifying the values of the parameter sets of the translog submodels for current production for the present study has been: (i) to use Australian estimates of these parameters if they are available, or (ii) to use estimates of foreign countries if Australian estimates are not available. A survey of Australian literature on energy substitution suggested that only a few studies were available in Australia concerning energy substitution and almost all of them were related to the manufacturing industry. These studies are Donnelly and Dragun (1984), Duncan and Binswanger (1974, 1976), Hawkins (1977, 1978), Rushdi (1984), Truong (1985), Turnovsky and Donnelly (1984), and Turnovsky, Folie and Ulph (1982).

Interfactor substitution elasticities for the manufacturing industry, the coal industry and the electricity industry are obtained from Australian studies. Turnovsky, Folie and Ulph (1982) have reported Allen elasticities of substitution (AES) between capital, labour, energy and aggregate materials for the manufacturing industry.[3] Their estimates of AES, which are reproduced in Table 4.4, have been used in this study to derive the second-order parameters of the KLEM submodel of manufacturing industry.

[3]For a definition of Allen partial elasticity of substitution see Allen (1938).

Table 4.4: Allen Partial Elasticities of Substitution between Capital, Labour, Energy and Aggregate Materials for Different Sectors.

Variable	1	2	3	4	Sector 5	6	7	8	9
σ_{KK}	-1.76	-4.79	-1.40	1.70	-4.09	-1.22	-10.69	-0.50	-1.07
σ_{KL}	0.36	2.00	0.18	1.09	3.43	8.10	1.40	0.09	0.00
σ_{KE}	-0.06	2.26	-0.86	1.21	9.94	-0.70	-1.30	0.40	0.00
σ_{KM}	0.61	0.74	0.57	0.07	-0.99	-0.60	1.10	-0.50	0.00
σ_{LL}	-2.50	-2.70	-1.09	-0.88	-3.15	-29.02	-33.89	-0.37	-2.61
σ_{LE}	1.41	-2.66	-0.06	2.31	-5.38	1.10	1.60	0.20	4.60
σ_{LM}	1.04	0.61	1.13	0.04	0.87	1.00	1.90	0.80	-1.20
σ_{EE}	-29.65	-8.73	-11.60	-49.36	-33.45	-14.19	-1.09	-0.58	-5.08
σ_{EM}	0.60	0.79	1.77	-1.82	-0.35	0.20	2.50	0.20	3.30
σ_{MM}	-0.83	-0.58	-1.73	-0.02	-0.04	-1.07	-18.64	-1.35	-4.66

Donnelly and Dragun (1984) have studied the substitution possibilities between capital, labour, energy and aggregate materials for the New South Wales (NSW) and Queensland (Qld.) coal industries. The AES between these factors for the NSW coal industry estimated by these two authors have been used in this study. These elasticities are reported in Table 4.4.

Substitution possibilities between capital, labour and energy in the electricity sector of South Australia have been studied by Rushdi (1984). The AES between these factors estimated by Rushdi for the South Australian electricity sector are used in the present study. Rushdi has not studied substitution possibilities between aggregate materials and capital or labour or energy for this industry. The estimates of AES between aggregate materials and other three factors used in this study are those of Hudson and Jorgenson (in Goulder 1982). The set of AES between capital, labour, energy and aggregate materials thus obtained for the electricity sector is reported in Table 4.4.

For other sectors Australian estimates of AES between capital, labour, energy and aggregate materials are not available. So Hudson and Jorgenson had to be relied on for these estimates. Estimates of AES between these factors have been reported in Hudson and Jorgenson (1978) for the four U.S. industrial sectors—agriculture, mining and construction sector, manufacturing sector, transportation sector and communications sector. All these estimates except those of the manufacturing sector have been used to derive the second-order parameters of the KLEM submodels of the corresponding industrial sectors of the present study. Hudson and Jorgenson's estimates of AES between the four factors—capital, labour, energy and aggregate materials—for the U.S. crude oil, petroleum and coal products, and the gas utilities sectors can be found in Goulder (1982). These estimates have been used to derive the second-order parameters of the KLEM submodels of the corresponding industrial sectors in the present study. These estimates are shown in Table 4.4.

Like the estimates of interfactor substitution elasticities, the estimates of AES between various fuels for different sectors have been obtained from various sources. These elasticity estimates then have been used to derive the second-order parameters of the interfuel submodels of different sectors.

Interfuel substitution possibilities in the Australian manufacturing industry have been examined by Turnovsky, Folie and Ulph (1982). Their estimates of interfuel substitution elasticities for the manufacturing industry have been used in this study. However, these authors have not examined the substitution possibilities between crude oil and other fuels. The elasticities of substitution between crude oil and other fuels used in this study are those of Goulder (1982). The set of AES between various fuels thus obtained for the manufacturing industry are reported in Table 4.5.

Estimates of AES between crude oil, gas and electricity for the petroleum and coal products sector are taken from Rushdi (1984) who has reported the estimates of these parameters for the South Australian chemical, petroleum and coal products industry. The Australian petroleum and coal products

Table 4.5: Allen Partial Elasticities of Substitution between Individual Fuels for Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
σ_{55}	122.70	-1.96	-6.64	-36.01	-2.33	UD	UD	7.21	-38.15
σ_{56}	-0.70	0.40	0.10	0.40	1.30	UD	UD	-14.2	1.00
σ_{57}	6.00	3.03	0.30	0.00	0.90	UD	UD	1.00	1.00
σ_{58}	8.50	0.81	-2.40	0.20	0.80	UD	UD	-1.10	1.00
σ_{59}	1.00	-1.55	1.00	0.80	1.00	UD	UD	-1.60	1.00
σ_{66}	-564.97	-50.38	-759.69	-301.20	-11.56	-1.51	-1.19	-38.85	-2.09
σ_{67}	1.20	0.80	0.90	0.80	1.50	-3.30	0.80	1.00	10.30
σ_{68}	1.30	0.80	0.70	0.90	3.20	0.00	2.23	0.20	1.00
σ_{69}	1.00	1.00	1.00	1.00	1.00	1.10	1.00	0.00	0.40
σ_{77}	-1.23	-6.56	-1.04	-4.02	-11.34	-19.86	-5.56	-11.83	-6.19
σ_{78}	22.40	-0.78	0.80	0.80	-11.60	-3.40	0.60	1.00	1.00
σ_{79}	1.00	4.50	1.00	1.00	1.00	2.50	13.45	1.00	1.00
σ_{88}	0.30	-0.72	-8.45	-1.66	-1.05	-0.41	-169.12	-1.50	-24.96
σ_{89}	1.00	3.18	1.00	1.00	1.00	0.20	-0.88	1.00	1.00
σ_{99}	-85.66	-40.30	-69.59	-15.72	-146.84	-80.25	-924.93	-418.80	-121.25

sector does not use coal as an input in its production. So the AES between coal and other fuels in this industry are undefined (UD).[4] The second-order parameters involving this input in the interfuel model for this industry are assumed to be zero.

Estimates of interfuel substitutions for other industrial sectors are not available from Australian sources. So these estimates are obtained from a foreign source, Goulder (1982). However, this was not sufficient to provide all the required estimates of AES between various fuels for some sectors. The AES between fuels which are not available from Goulder nor from any other source are set to unity thus making the production function Cobb-Douglas in respect of these inputs.

Most of the estimates of AES between individual material inputs including non-competing imports for different sectors are obtained from Goulder (1982) in the absence of any Australian estimates. As is the case with interfuel

[4]Similar is the case with the crude oil sector. The AES between coal and other fuels are also undefined in this sector (see Table 4.5).

Table 4.6: Allen Partial Elasticities of Substitution between Individual Materials for Different Sectors.

Variable	Sector 1	2	3	4	5	6	7	8	9
σ_{11}	-8.61	-4.25	-5.30	-23.70	-10.57	-2.05	-28.61	-51.63	-223.88
σ_{12}	0.30	1.80	0.20	1.90	0.90	2.70	2.30	2.70	4.80
σ_{13}	5.30	1.70	0.50	0.60	0.80	1.00	0.70	0.20	-4.3
σ_{14}	0.00	-1.80	-0.40	0.60	0.80	0.10	0.40	0.50	0.60
σ_{10}	4.20	4.50	0.40	24.10	1.00	1.00	1.00	1.00	1.00
σ_{22}	-1.00	-1.36	-1.11	-3.12	-2.08	-3.91	-6.73	-28.42	-4.98
σ_{23}	0.20	0.00	0.60	0.80	0.60	0.20	1.10	10.30	1.50
σ_{24}	0.20	0.40	-0.20	0.80	0.70	-0.10	-0.90	-1.40	0.20
σ_{20}	0.30	-0.20	0.50	-9.90	1.00	1.00	1.00	1.00	1.00
σ_{33}	-11.06	-2.88	-4.09	-12.05	-4.09	-12.52	-2.79	-8.23	-7.96
σ_{34}	-0.50	0.50	0.40	0.80	0.40	0.90	0.10	1.80	3.50
σ_{30}	-15.80	-1.60	0.70	1.40	1.00	1.00	1.00	1.00	1.00
σ_{44}	-1.33	-1.92	-0.82	-1.49	-2.19	-2.58	-9.28	-1.10	-1.58
σ_{40}	-0.30	1.80	0.10	0.60	1.00	1.00	1.00	1.00	1.00
σ_{00}	-131.94	-58.88	-224.14	-39.27	-1427.57	-1264.81	-28.94	-209.98	-96.94

substitutions, AES between materials not available from any source are set to unity. These estimates of AES for different sectors are shown in Table 4.6.

The AES between capital, labour, energy and aggregate materials for different sectors, which are shown in Table 4.4, were used in conjunction with the unmodified cost shares of these factors to derive a preliminary set of estimates for second-order parameters of KLEM production submodels. The definitions used to derive the $\beta_{rs,j}$'s are:

$$\beta_{rs,j} = S_{rj}^{(1)} S_{sj}^{(1)} (\sigma_{rs,j}^{(1)} - 1), \quad r \neq s, \quad r, s = K, L, E, M, \quad j = 1, 2, \ldots, 9;$$

and

$$\beta_{rr,j} = (S_{rj}^{(1)})^2 (\sigma_{rr,j}^{(1)} - 1) + S_{rj}^{(1)}, \quad r = K, L, E, M, \quad j = 1, 2, \ldots, 9;$$

where $\beta_{rs,j}$ $(r, s = K, L, E, M; \ j = 1, 2, \ldots, 9)$ is the second-order parameter of the KLEM submodel for current production of sector j; $S_{rj}^{(1)}$ and $S_{sj}^{(1)}$ are

Table 4.7: Second-Order Parameters of the KLEM Production Submodels of Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
β_{KK}	0.0877	0.0426	0.0565	0.3070	-0.4025	-0.3630	0.0209	0.1605	0.1162
β_{KL}	-0.0457	0.0232	-0.0234	0.0101	0.2591	0.3097	0.0006	-0.0580	-0.0863
β_{KE}	-0.0046	0.0029	-0.0095	0.0008	0.3632	-0.0610	-0.0671	-0.0643	-0.0669
β_{KM}	-0.0360	-0.0159	-0.0126	-0.0711	-0.1830	-0.2162	0.0004	-0.0389	-0.0520
β_{LL}	-0.0564	0.0254	0.0489	0.0816	-0.0315	-0.0573	-0.0229	0.1599	-0.0239
β_{LE}	0.0028	-0.0211	-0.0339	0.0084	-0.1761	0.0003	0.0210	-0.0753	0.2499
β_{LM}	0.0058	-0.0602	0.0239	-0.1218	-0.0081	0.0000	0.0047	-0.0046	-0.1187
β_{EE}	0.0076	0.0183	0.0037	0.0038	-0.2598	0.0108	-0.5369	0.1478	-0.0955
β_{EM}	-0.0035	-0.0032	0.0252	-0.0123	-0.0321	-0.0082	0.1441	-0.0307	0.0963
β_{MM}	0.0905	-0.0054	-0.0801	0.2059	0.1761	0.1165	-0.1634	0.0746	-0.0038

unmodified shares of factors r ($r = K, L, E, M$) and s ($s = K, L, E, M$) respectively in the total cost of sector j for current production; $\sigma^{(1)}_{rs,j}$ is the Allen cross partial elasticity of substitution between factor r and s; and $\sigma^{(1)}_{rr,j}$ is the Allen own elasticity of substitution of factor r. The preliminary set of $\beta_{rs,j}$, $r, s = K, L, E, M$, derived in this way are reported in Table 4.7

The preliminary set of estimates for $\beta^{E}_{hr,j}$'s ($h, r = 5, 6, \ldots, 9;\ j = 1, 2, \ldots, 9$), the second-order parameters of the interfuel submodels, were obtained from the AES between individual fuels (see Table 4.5), in conjunction with the unmodified energy cost shares of these fuels. The definitions used to derive this set of estimates are:

$$\beta^{E}_{hr,j} = S^{(1)E}_{hj} S^{(1)E}_{rj} (\sigma^{(1)E}_{hr,j} - 1), \quad h \neq r, \quad h, r = 5, 6, \ldots, 9, \quad j = 1, 2, \ldots, 9;$$

and

$$\beta^{E}_{hh,j} = (S^{(1)E}_{hj})^2 (\sigma^{(1)E}_{hh,j} - 1) + S^{(1)E}_{hj}, \quad h = 5, 6, \ldots, 9, \quad j = 1, 2, \ldots, 9;$$

where $\beta^{E}_{hr,j}$ ($h, r = 5, 6, \ldots, 9;\ j = 1, 2, \ldots, 9$) is the second-order parameter of the interfuel submodel for current production of sector j; $S^{(1)E}_{hj}$ and $S^{(1)E}_{rj}$

Table 4.8: Second-Order Parameters of the Interfuel Substitution Submodels of Different Sectors.

Variable	Sector 1	2	3	4	5	6	7	8	9
β_{55}	0.0020	0.0825	0.0097	0.0053	-0.1990	0.0000	0.0000	0.3689	0.0000
β_{56}	0.0000	-0.0020	0.0000	0.0000	0.0145	0.0000	0.0000	-0.2061	0.0000
β_{57}	0.0056	0.1218	-0.0066	-0.0020	-0.0037	0.0000	0.0000	0.0000	0.0000
β_{58}	0.0036	-0.0154	-0.0029	-0.0038	-0.0316	0.0000	0.0000	-0.2442	0.0000
β_{59}	0.0000	-0.0321	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0005	0.0000
β_{66}	0.0018	0.0019	0.0000	0.0000	-0.0432	-0.4888	-0.7044	-0.1591	-0.7464
β_{67}	0.0002	-0.0011	-0.0001	-0.0002	0.0046	-0.1036	-0.0263	0.0000	1.5613
β_{68}	0.0002	-0.0014	0.0000	-0.0002	0.0881	-0.1836	0.0028	-0.0406	0.0000
β_{69}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0000	-0.0002	-0.0033
β_{77}	-0.3696	-0.4096	-0.7316	-0.0980	-0.0028	0.0093	-0.0042	-0.0071	-0.1920
β_{78}	4.3655	-0.2277	-0.0146	-0.0354	-0.3817	-0.0417	-0.0002	0.0000	0.0000
β_{79}	0.0000	0.0698	0.0000	0.0000	0.0000	0.0007	0.0021	0.0000	0.0000
β_{88}	0.2347	0.1187	0.0187	-0.4790	0.0935	0.1669	0.0015	-0.4290	-0.0016
β_{89}	0.0000	0.0585	0.0000	0.0000	0.0000	-0.0027	0.0000	0.0000	0.0000
β_{99}	0.0000	-0.1081	-0.0002	-0.0070	0.0000	-0.0004	0.0000	0.0000	0.0002

are unmodified shares of fuels h ($h = 5, 6, \ldots, 9$) and r ($r = 5, 6, \ldots, 9$) respectively in the total energy cost of sector j for current production; $\sigma_{hr,j}^{(1)E}$ is the Allen cross partial elasticity of substitution between fuels h and r; $\sigma_{hh,j}^{(1)E}$ is the Allen own elasticity of substitution of fuel h. The preliminary set of estimates for $\beta_{hr,j}^{E}$'s, $h, r = 5, 6, \ldots, 9$, so derived is reported in Table 4.8.

The preliminary set of estimates for $\beta_{iq,j}^{M}$'s ($i, q = 0, 1, \ldots, 4;\ \ j = 1, 2, \ldots, 9$), the second-order parameters of the inter-material submodels, were derived from the AES between individual material inputs (see Table 4.6) in conjunction with the unmodified shares of these inputs in total material cost of sector j for current production. The definitions used to derive the set of estimates for $\beta_{iq,j}^{M}$'s are:

$$\begin{aligned}\beta_{iq,j}^{M} &= S_{ij}^{(1)M} S_{qj}^{(1)M} (\sigma_{iq,j}^{(1)M} - 1), \ \ i \neq q, \ \ i, q = 0, 1, \ldots, 4, \\ &\quad j = 1, 2, \ldots, 9;\end{aligned}$$

and

$$\beta_{ii,j}^{M} = (S_{ij}^{(1)M})^2 (\sigma_{ii,j}^{(1)M} - 1) + S_{ij}^{(1)M}, \ \ i = 0, 1, \ldots, 4, \ \ j = 1, 2, \ldots, 9;$$

Table 4.9: Second-Order Parameters of the Inter-Material Substitution Sub-models of Different Sectors.

Variable	Sector 1	2	3	4	5	6	7	8	9
β_{11}	-0.0017	0.0090	0.0346	-0.0079	0.0030	-0.3996	0.0002	-0.0058	-0.0034
β_{12}	-0.0442	0.0839	-0.0143	0.0120	-0.0034	0.1414	0.0064	0.0042	0.0050
β_{13}	0.0382	0.0079	-0.0043	-0.0012	-0.0022	0.0000	-0.0025	-0.0041	-0.0088
β_{14}	-0.0222	-0.0843	-0.0305	-0.0111	-0.0062	-0.1157	-0.0109	-0.0077	-0.0014
β_{10}	0.0010	0.0069	-0.0001	0.0167	0.0000	0.0000	0.0000	0.0000	0.0000
β_{22}	-0.1162	-0.2130	0.0911	-0.0461	-0.1142	0.0403	-0.0201	-0.2204	-0.0322
β_{23}	-0.0402	-0.0362	-0.0237	-0.0037	-0.0219	-0.0072	0.0036	0.2141	0.0242
β_{24}	-0.1004	-0.0578	-0.1799	-0.0333	-0.0460	-0.0373	-0.1516	-0.1635	-0.0841
β_{20}	-0.0012	-0.0076	-0.0004	-0.0470	0.0000	0.0000	0.0000	0.0000	0.0000
β_{33}	-0.0012	0.0473	0.0239	0.0095	0.0433	0.0109	0.0188	-0.2231	-0.3060
β_{34}	-0.0265	-0.0052	-0.0432	-0.0077	-0.0293	-0.0014	-0.1189	0.1134	0.3356
β_{30}	-0.0041	-0.0018	-0.0001	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000
β_{44}	0.1072	0.0855	0.0951	-0.2758	-0.0665	0.0413	-2.4838	-0.2331	-0.2113
β_{40}	-0.0008	0.0014	-0.0009	-0.0036	0.0000	0.0000	0.0000	0.0000	0.0000
β_{00}	0.0018	0.0038	0.0011	0.0059	0.0000	0.0000	0.0000	0.0000	0.0000

where $\beta^M_{iq,j}$ $(i, q = 0, 1, \ldots, 4;\ j = 1, 2, \ldots, 9)$ is the second-order parameter of the inter-material submodel for current production of sector j; $S^{(1)M}_{ij}$ and $S^{(1)M}_{qj}$ are unmodified shares of material inputs i $(i = 0, 1, \ldots, 4)$ and q $(q = 0, 1, \ldots, 4)$ respectively in the total material cost of sector j for current production; $\sigma^{(1)M}_{iq,j}$ is the Allen cross partial elasticity of substitution between material inputs i and q; and $\sigma^{(1)M}_{ii,j}$ is the Allen own partial elasticity of substitution of material input i. The set of estimates for $\beta^M_{iq,j}$'s thus obtained is reported in Table 4.9.

The preliminary sets of estimates for second-order parameters of the production submodels thus obtained satisfy the symmetry restrictions but do not satisfy the homogeneity restrictions since the sets of cost shares used to derive them are different from those which were used to derive the AES parameters in the various studies from which they are taken. Moreover, there is no guarantee that they will satisfy the concavity restrictions because they were not estimated by imposing these restrictions. At this stage, the preliminary sets of estimates for second-order parameters are modified in such a way so that they satisfy both homogeneity and concavity restrictions. At first, some of the preliminary estimates of second-order parameters were scaled up or down to the extent necessary for the imposition of the homogeneity restrictions. In the next step, the sectoral cost functions implied by these modified sets of parameter estimates were tested for concavity in the neighbourhood of the benchmark prices which are equal to one. In those cases where concavity conditions were not satisfied, the second-order parameters were further adjusted until concavity was assured. The adjustment procedure used to impose the concavity restrictions on the second-order parameters is discussed below.

It has been mentioned in Chapter 3 that an average cost function is concave if its Hessian matrix, H, is negative semi-definite. It has been further shown there that the Hessian matrix can be defined as

$$H = R(Z + B)R,$$

where matrices R, Z and B are as defined in Chapter 3, Section 3.1. For prices equal to one, the H matrix reduces to

$$H = Z + B.$$

Now, it can be shown that the matrix Z is always negative semi-definite since the elements of $\mathbf{w}$, which are cost shares of inputs, are non-negative and sum to unity. To prove this, consider the general case of an industry which uses n inputs for its production. $\mathbf{w}$ can then be defined as

$$\mathbf{w} = (w_1 \;\; w_2 \cdots w_n)'$$

such that $w_i \geq 0$ and $\mathbf{w}'\mathbf{e} = 1$ where

$$\mathbf{e} = (1 \;\; 1 \cdots 1)'.$$

Z is defined as

$$Z = \mathbf{w}\mathbf{w}' - diag.\mathbf{w}.$$

Now suppose that $\mathbf{u}$ is an eigenvector of Z and λ is the corresponding eigenvalue. Then

$$\mathbf{w}(\mathbf{w}'\mathbf{u}) = (diag.\mathbf{w} + \lambda I)\mathbf{u}$$

or

$$w_i(\mathbf{w}'\mathbf{u}) = (w_i + \lambda)u_i, \;\; i = 1, 2, \ldots, n. \tag{4.1}$$

Case 1: $\mathbf{w}'\mathbf{u} = 0$, then $\lambda = -w_i \leq 0$ for at least one i as $u_i \neq 0$ for all i.
Case 2: $\mathbf{w}'\mathbf{u} \neq 0$, then without loss of generality it can be assumed that $\mathbf{w}'\mathbf{u} = 1$. So one gets from (4.1)

$$w_i = (w_i + \lambda)u_i, \;\; i = 1, 2, \ldots, n. \tag{4.2}$$

One solution to this is: $\lambda = 0$, $u_i = 1$, $i = 1, 2, \ldots, n$. So $\mathbf{e}$ is an eigenvector of Z with eigenvalue 0.

Now, let $\lambda \neq 0$. Add the equations in (4.2) to get

$$\sum_{i=1}^{n} w_i = \sum_{i=1}^{n} w_i u_i + \lambda \sum_{i=1}^{n} u_i. \tag{4.3}$$

Since $\sum_{i=1}^{n} w_i = \sum_{i=1}^{n} w_i u_i = 1$ and $\lambda \neq 0$,

$$\sum_{i=1}^{n} u_i = 0. \tag{4.4}$$

Suppose $\lambda > 0$, then $w_i + \lambda > 0$, so $u_i = w_i/(w_i + \lambda) \geq 0$ (from (4.2)) and $\sum_{i=1}^{n} u_i > 0$ as not all $w_i = 0$. This is a contradiction to (4.4). Hence, any eigenvalue λ of Z not equal to zero must be less than zero. Therefore, $Z = \mathbf{ww}' - diag.\mathbf{w}$ is negative semi-definite.

Since the Z matrix is always negative semi-definite, H will also be negative semi-definite if B matrix is also negative semi-difinite. When B is not negative semi-definite, the negative semi-definiteness of H will depend on Z. If the elements of Z dominate over those of B, H will be negative semi-definite. Therefore, one consistent way to impose concavity restrictions on an average cost function is to scale down the B matrix to such an extent that the sum of Z and B becomes negative semi-definite. This is the procedure which has been used here to adjust the second-order parameters so that the average cost functions implied by them become concave.

For each sector, it was necessary to test all three translog average cost functions, i.e. functions (3.20)–(3.22) for concavity. For a given cost function, the elements of B matrix were adjusted only to the extent necessary for concavity. First, the characteristic roots of the H matrix formed from the original B matrix were computed. If the largest of them was found positive, all of the elements of B were multiplied by 0.99. The characteristics roots of H formed from the modified B were computed again and the check was repeated. If non-concavity persisted, the original elements were multiplied by 0.98, and so on. The sets of second-order parameters thus obtained are reported in Tables 4.10–4.12 and the AES implied by these parameters are reported in Tables 4.13–4.15. The percentage reductions in the values of second-order parameters of the submodels which were necessary to achieve concavity are shown in Table 4.16. The modified sets of second-order parameters reported in Tables 4.10–4.12 have been used to calculate the modified input cost shares for the translog version of the CGE model.

Table 4.10: Adjusted Second-Order Parameters of the KLEM Production Submodels of Different Sectors.

Variable	Sector 1	2	3	4	5	6	7	8	9
β_{KK}	0.0863	-0.0101	0.0453	0.0594	-0.3198	-0.0217	0.0297	0.1612	0.2052
β_{KL}	-0.0457	0.0230	-0.0233	0.0100	0.1886	0.2069	0.0154	-0.0580	-0.0863
β_{KE}	-0.0046	0.0029	-0.0095	0.0008	0.2644	-0.0407	-0.0604	-0.0643	-0.0669
β_{KM}	-0.0360	-0.0158	-0.0125	-0.0701	-0.1332	-0.1444	0.0153	-0.0389	-0.0520
β_{LL}	0.0371	0.0576	0.0332	0.1019	-0.0545	-0.2071	-0.0385	0.1379	-0.0449
β_{LE}	0.0028	-0.0209	-0.0337	0.0083	-0.1282	0.0002	0.0189	-0.0753	0.2499
β_{LM}	0.0058	-0.0597	0.0238	-0.1201	-0.0059	0.0000	0.0042	-0.0046	-0.1187
β_{EE}	0.0053	0.0212	0.0181	0.0031	-0.1128	0.0460	-0.0882	0.1703	-0.2793
β_{EM}	-0.0035	-0.0032	0.0251	-0.0121	-0.0234	-0.0055	0.1297	-0.0307	0.0963
β_{MM}	0.0337	0.0786	-0.0363	0.2023	0.1625	0.1499	-0.1492	0.0742	0.0744

Table 4.11: Adjusted Second-Order Parameters of the Interfuel Substitution Submodels of Different Sectors.

Variable	Sector 1	2	3	4	5	6	7	8	9
β_{55}	-0.0092	-0.0698	0.0091	0.0059	0.0036	0.0000	0.0000	0.0956	0.0000
β_{56}	0.0000	-0.0019	0.0000	0.0000	0.0025	0.0000	0.0000	-0.0437	0.0000
β_{57}	0.0056	0.1177	-0.0063	-0.0020	-0.0006	0.0000	0.0000	0.0000	0.0000
β_{58}	0.0036	-0.0149	-0.0028	-0.0038	-0.0055	0.0000	0.0000	-0.0518	0.0000
β_{59}	0.0000	-0.0310	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000
β_{66}	-0.0004	0.0043	0.0001	0.0004	-0.0187	0.0667	0.0235	0.0523	-1.5580
β_{67}	0.0002	-0.0011	-0.0001	-0.0002	0.0008	-0.0241	-0.0263	0.0000	1.5613
β_{68}	0.0002	-0.0014	0.0000	-0.0002	0.0153	-0.0428	0.0028	-0.0086	0.0000
β_{69}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	-0.0033
β_{77}	-4.3582	0.0359	0.0205	0.0376	0.0663	0.0337	0.0244	0.0000	-1.5613
β_{78}	4.3524	-0.2200	-0.0140	-0.0354	-0.0664	-0.0097	-0.0002	0.0000	0.0000
β_{79}	0.0000	0.0674	0.0000	0.0000	0.0000	0.0002	0.0021	0.0000	0.0000
β_{88}	-4.3562	0.1797	0.0168	0.0394	0.0566	0.0531	-0.0026	0.0604	0.0000
β_{89}	0.0000	0.0565	0.0000	0.0000	0.0000	-0.0006	0.0000	0.0000	0.0000
β_{99}	0.0000	-0.0929	0.0000	0.0001	0.0000	0.0003	-0.0021	0.0001	0.0033

Table 4.12: Adjusted Second-Order Parameters of the Inter-Material Substitution Submodels of Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
β_{11}	0.0149	-0.0125	0.0439	-0.0064	0.0118	-0.0256	0.0051	0.0076	0.0052
β_{12}	-0.0242	0.0727	-0.0128	0.0047	-0.0034	0.1411	0.0046	0.0042	0.0050
β_{13}	0.0209	0.0068	-0.0038	-0.0005	-0.0022	0.0000	-0.0018	-0.0041	-0.0088
β_{14}	-0.0122	-0.0731	-0.0272	-0.0043	-0.0062	-0.1155	-0.0079	-0.0077	-0.0014
β_{10}	0.0005	0.0060	-0.0001	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000
β_{22}	0.1019	0.0153	0.1947	0.0282	0.0712	-0.0967	0.1025	-0.0547	0.0549
β_{23}	-0.0220	-0.0314	-0.0211	-0.0014	-0.0219	-0.0072	0.0026	0.2139	0.0242
β_{24}	-0.0550	-0.0501	-0.1605	-0.0130	-0.0460	-0.0372	-0.1098	-0.1633	-0.0841
β_{20}	-0.0007	-0.0066	-0.0004	-0.0184	0.0000	0.0000	0.0000	0.0000	0.0000
β_{33}	0.0179	0.0306	0.0636	0.0048	0.0533	0.0086	0.0853	-0.3231	-0.3510
β_{34}	-0.0145	-0.0045	-0.0385	-0.0030	-0.0293	-0.0014	-0.0861	0.1133	0.3356
β_{30}	-0.0022	-0.0016	-0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
β_{44}	0.0821	0.1265	0.2270	0.0218	0.0814	0.1541	0.2037	0.0577	-0.2501
β_{40}	-0.0004	0.0012	-0.0008	-0.0014	0.0000	0.0000	0.0000	0.0000	0.0000
β_{00}	0.0028	0.0010	0.0013	0.0131	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4.13: Adjusted Allen Partial Elasticities of Substitution between Capital, Labour, Energy and Aggregate Materials for Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
σ_{KK}	-1.79	-10.51	-3.87	-1.97	-3.56	-0.50	-4.09	-0.49	0.00
σ_{KL}	0.36	1.99	0.18	1.09	2.77	5.74	10.66	0.09	0.00
σ_{KE}	-0.05	2.25	-0.86	1.21	7.51	-0.14	-1.07	0.40	0.00
σ_{KM}	0.61	0.74	0.57	0.08	-0.45	-0.07	4.49	-0.50	0.00
σ_{LL}	-1.66	-2.15	-1.18	-0.77	-3.47	-66.30	-42.09	-0.76	-2.85
σ_{LE}	1.41	-2.62	-0.06	2.30	-3.64	1.06	1.54	0.20	4.60
σ_{LM}	1.04	0.61	1.13	0.05	0.91	1.00	1.81	0.80	-1.20
σ_{EE}	-35.25	-3.65	-9.07	-52.60	-19.48	-1.25	-0.39	-0.44	-8.49
σ_{EM}	0.60	0.79	1.77	-1.78	0.02	0.47	2.35	0.20	3.30
σ_{MM}	-1.13	-0.37	-1.50	-0.06	-0.29	-0.21	-17.66	-1.39	-2.26

Table 4.14: Adjusted Allen Partial Elasticities of Substitution between Individual Fuels for Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
σ_{55}	-4064.64	-5.98	-11.68	-24.32	-1.27	UD	UD	-1.60	-38.15
σ_{56}	1.00	0.43	1.00	1.00	1.05	UD	UD	-2.22	1.00
σ_{57}	5.97	2.96	0.33	-0.02	0.98	UD	UD	1.00	1.00
σ_{58}	8.44	0.82	-2.24	0.19	0.97	UD	UD	0.55	1.00
σ_{59}	1.00	-1.46	1.00	0.79	1.00	UD	UD	0.74	1.00
σ_{66}	-691.33	-42.33	-716.50	-263.23	-9.55	-0.32	-0.16	-3.16	-3.85
σ_{67}	1.16	0.80	0.92	0.78	1.09	0.00	0.80	1.00	10.30
σ_{68}	1.38	0.81	1.00	0.91	1.38	0.77	2.23	0.83	1.00
σ_{69}	1.00	1.00	1.00	1.00	1.00	1.02	1.00	0.77	0.39
σ_{77}	-9.63	-1.87	-0.10	-2.18	-1.49	-0.25	-4.39	-10.83	-28.61
σ_{78}	22.34	-0.72	0.81	0.80	-1.19	-0.03	0.53	1.00	1.00
σ_{79}	1.00	4.38	1.00	1.00	1.00	1.36	13.42	1.00	1.00
σ_{88}	-52.07	-0.37	-8.72	-0.44	-1.33	-1.97	-718.07	-0.38	-23.96
σ_{89}	1.00	3.10	1.00	1.00	1.00	0.82	1.00	1.00	1.00
σ_{99}	-85.66	-36.66	-68.59	-14.09	-145.84	-76.09	-2725.34	-399.32	-72.44

Table 4.15: Adjusted Allen Partial Elasticities of Substitution between Individual Materials for Different Sectors.

	Sector								
Variable	1	2	3	4	5	6	7	8	9
σ_{11}	-7.13	-4.91	-1.71	-23.04	-9.31	-0.86	-24.30	-27.72	-32.42
σ_{12}	0.62	1.69	0.29	1.35	0.90	2.70	1.94	2.69	4.83
σ_{13}	3.35	1.61	0.55	0.85	0.80	1.00	0.78	0.21	-4.28
σ_{14}	0.45	-1.43	-0.25	0.84	0.80	0.10	0.57	0.50	0.61
σ_{10}	2.80	4.04	0.25	10.04	1.00	1.00	1.00	1.00	1.00
σ_{22}	-0.39	-0.68	-0.27	-2.19	-1.00	-10.15	-1.06	-13.45	-2.69
σ_{23}	0.56	0.13	0.64	0.92	0.60	0.20	1.07	10.29	1.50
σ_{24}	0.56	0.48	-0.07	0.92	0.70	-0.10	-0.38	-1.40	0.20
σ_{20}	0.62	-0.05	0.56	-3.26	1.00	1.00	1.00	1.00	1.00
σ_{33}	-8.36	-7.17	-2.69	-13.14	-3.51	-13.14	-1.67	-10.32	-8.69
σ_{34}	0.18	0.57	0.47	0.92	0.40	0.90	0.35	1.80	3.50
σ_{30}	-8.28	-1.30	0.77	1.16	1.00	1.00	1.00	1.00	1.00
σ_{44}	-1.90	-0.44	-0.10	-0.63	-1.11	-0.43	-0.15	-0.41	-1.71
σ_{40}	0.28	1.67	0.19	0.84	1.00	1.00	1.00	1.00	1.00
σ_{00}	-9.25	-82.92	-181.45	-8.34	-1407.45	-1264.82	-28.93	-209.53	-96.94

Table 4.16: Percentage Reductions in the Values of Second-Order Parameters of the Submodels.

Sector	Percentage reduction		
	KLEM submodel	Interfuel submodel	Inter-material submodel
1	0.0	0.3	45.2
2	1.0	3.4	13.3
3	0.5	3.8	10.8
4	1.4	0.0	61.0
5	27.2	82.6	0.1
6	33.2	76.7	0.2
7	10.0	0.0	27.6
8	0.0	79.0	0.1
9	0.0	0.0	0.0

Second-order parameters of the translog cost functions for capital production: In order to implement the translog cost functions for capital goods one needs to obtain estimates for the following parameters:

(i) $\alpha_{rs,j}$, $r, s = E, M$ and $j = 1, 2, \ldots, 9$, that is, the second-order parameters of the cost function involving prices of energy and aggregate materials.

(ii) $\alpha^{E}_{hr,j}$, $h, r = 5, 6, \ldots, 9$, and $j = 1, 2, \ldots, 9$, that is, the second-order parameters appearing in the interfuel substitution model of sector j for capital goods production.

(iii) $\alpha^{M}_{iq,j}$, $i, q = 0, 1, \ldots, 4$ and $j = 1, 2, \ldots, 9$, that is, the second-order parameters appearing in the inter-material substitution model of sector j for capital goods production.

In the absence of any suitable estimates of the above-mentioned parameters it has been simply assumed that these second-order parameters are all equal to zero. In this case, the production functions underlying the corresponding cost functions for capital goods reduce to Cobb-Douglas type of functions. Of course, this assumption is both theoretically and empirically restrictive. But since this assumption is to affect all three variants of the CGE model equally, achievement of the objective of the present study, which is to examine the sensitivity of the results of the CGE model to alternative production function specifications for current production, is not likely to be hampered. Moreover, this assumption greatly simplifies the present analysis. Note that in the case of Cobb-Douglas production function there is no difference between the modified and unmodified cost shares and the input-output data base is sufficient to specify these shares.

Indexing parameters: In the present study, it is assumed that the rate-of-return theory of investment applies to all sectors in the determination of their levels of investment. In other words, J^*, the number of elements in J, is 9. The result of this assumption is that equations in (3.180) no longer exist (see Table A.1 in Appendix A). Since $h_j^{(2)}$'s appear only in that equation set, one no longer requires to set the values of $h_j^{(2)}$'s. As to h, the wage indexation parameter, it has been set to unity implying full or 100 percent indexation to consumer prices.

Sectoral shares in the aggregate employment: The sectoral shares in aggregate employment, i.e., $B_{Lj}^{(1)}$'s, have been calculated from the 'persons' matrix reported in Blampied (1985, pp. 162–165). However, the persons matrix reported in Blampied is a 10×112 matrix showing employment in number of persons of 10 categories of labour in 112 industries. This matrix has been mapped into a 1×9 matrix which shows employment in persons of aggregate labour in each of the 9 sectors considered here. $B_{Lj}^{(1)}$ is then calculated as the share of the j^{th} element in the sum of all entries in the 1×9 persons matrix.

Sectoral shares in the economy-wide capital stock: The shares of the sectoral capital stocks in the economy-wide capital stock, i.e., B_{Kj}'s, have been calculated from the capital stocks matrix prepared for the ORANI model.[5] However, this is a 114×112 matrix. To suit the present purpose, this matrix was, at first, mapped into a 9×9 matrix by aggregating over relevant commodities and industries. Then, the share of the capital stock of sector j in the economy-wide capital stock, B_{Kj}, was calculated as the ratio of j^{th} column total of the 9×9 capital stocks matrix to the grand total of the matrix.

Ratio of the household income tax to the net household income: To determine this coefficient one just needs to know the average income tax rate, T^H. The average income tax rate is calculated to be 20.78 percent from the 1984/85 national and government accounts (see page 7 of Meagher and Parmenter (1987) for these accounts).

[5] See Blampied (1985, pp. 166–182) for the entries of the capital stock matrix.

Chapter 5

OIL PRICE SHOCK AND THE AUSTRALIAN ECONOMY

In the last two chapters, i.e., in Chaper 3 and Chapter 4, the theoretical foundations and the structural equations of alternative CGE models as well as the data base used to obtain the numerical values of the coefficients and parameters of these models have been fully discussed. In this chapter simulations of the effects on the Australian economy of a 10 percent increase in the world price of imported crude oil have been done with all three CGE models. These simulations are concerned with the implications of the hypothetical oil price shock for aggregate employment, balance of trade, sectoral outputs, sectoral output prices and sectoral employments of labour in alternative CGE models. Differences among the alternative models regarding the implications of the oil price shock for the above-mentioned variables are pointed out. An attempt is also made to single out the factors and mechanisms which have been responsible for giving rise to different implications of the oil price shock for the variables of interest in the alternative models.

5.1 Macroeconomic Environment

Each of the three CGE models, described in Chapter 3, contain 466 equations and 558 variables (see Tables A.1 and A.2 in Appendix A). Since the number of variables exceeds the number of equations by 92, this number of variables must be declared exogenous. The specification of these exogenous variables defines the macroeconomic environment for the present simulations. The following choices regarding exogenous variables have been made.

(a) *Nominal exchange rate* : The nominal exchange rate is assumed exogenous and fixed in the present simulations. Changes in the domestic price levels are therefore to be interpreted as changes in domestic prices relative to world prices.

(b) *Real domestic absorption* : Real investment, real household consumption and real government expenditures are assumed fixed. That is, in this macroeconomic environment simultaneous applications of fiscal and monetary instruments, which are external to the present CGE models, are assumed to prevent price rises in imported crude oil from having any net impact on aggregate demand.

(c) *Real wage* : Real wage is assumed to remain constant in the present simulations. This assumption implies slack labour market and full wage indexation to the consumer price index.

(d) *Sectoral capital stocks* : Plant and equipment in use in each industry is assumed to remain fixed. Thus the simulations presented in this chapter are short run in nature. In each industry, the rate of return to current capital adjusts to reflect any change in its scarcity value.

(e) *Exports* : All exports except those from agriculture and coal sectors are assumed fixed at their base year levels. Sectors whose exports are treated fixed are mainly domestic market oriented and export less than 15 percent of their total sales to foreign countries.

(f) *Other variables* : Other variables which are assumed exogenous in the present simulations are the number of households in the economy, foreign currency prices of all imports, current production taxes, taxes on capital goods production, consumption taxes, income tax, subsidies to exporting sectors, import duties, shift variables in the export demand equations, shift variables in the government demand equations and the shift variable in the labour demand equation. For more clarity see Table A.3 (in Appendix A) which provides a list of the exogenous variables with some descriptions.

5.2 Simulation Results

The effects of the 10 percent increase in the world price of imported crude oil on the macroeconomic variables, sectoral output levels, domestic prices of outputs and sectoral employments have been computed following Johansen's (1960) method under the macroeconomic environment described above. The macroeconomic results of the oil price shock are discussed in Subsection 5.2.1 while responses of sectoral outputs and output prices to the oil price shock are discussed in Subsections 5.2.2 and 5.2.3 respectively. The effects of the oil price shock on sectoral employment of labour are discussed in Subsection 5.2.4.

Before embarking upon the discussion of the effects of the oil price rise on the Australian economy it should be noted that no attempt has been made in the present simulations to allow the oil price rise to have effects on the rest of the world. This is not a realistic simulation of the oil price rise. A more realistic simulation would have been to allow foreign prices of imports and competitiveness of foreign producers *vis a vis* Australian producers to change in response to the rise in the world price of oil. Since the main objective of the present study is comparative model simulation, the emphasis here is on the examination and explanation of the sensitivities of the effects of the oil price shock to variation in model structure rather than on the plausibility of the simulation.

5.2.1 Macroeconomic effects

The macroeconomic effects of the 10 percent increase in the world price of imported crude oil are presented in Table 5.1. The results in the first column are projected by the CES-FC (CES-Fixed Coefficient) model, which allows substitution only between labour and capital. The results presented in the second column are projected by the CD (Cobb-Douglas) model which permits substitutions among all factors and inputs in current production. However, this model restricts the substitution parameter to unity for all pairs of inputs. The results presented in the third column are projected by the TL (Translog) model which defines the production possibility set for current production by a highly flexible translog production function. Interfactor as well as interfuel substitutions are allowed in the production of current goods in this model as in the CD model. But in contrast to the CD model, this model does not restrict the substitution parameter to any specific value; the substitution parameter is allowed to vary between different pairs of inputs.

The CES-FC model projects that aggregate employment will decline by 0.15 percent as a result of the 10 percent increase in the world price of imported crude oil. In Australia, about 56 percent of the total expenditure on crude oil is accounted for by imported crude oil. As the domestic price of imported crude oil increases, the costs of production of all domestic goods increase. Due to increased cost of production, competitiveness of Australian exporting sectors declines in the foreign markets and this leads to reduction in outputs of these exporting sectors. Moreover, outputs of other sectors which

Table 5.1: Macroeconomic Effects of a 10 Percent Increase in the World Price of Imported Crude Oil.

Variable	Percentage change		
	CES-FC model	CD model	TL model
Aggregate employment	-0.15	-0.11	-0.09
Aggregate exports	-0.35	-0.50	-0.53
Aggregate imports	0.85	0.55	0.53
Change in the balance of trade as percentage change in GDP	-0.18	-0.16	-0.16
Quantity index of imports	0.25	-0.04	-0.07
Quantity index of exports	-0.49	-0.66	-0.65
Gross domestic product	-0.11	-0.09	-0.09
Consumer price index	0.63	0.62	0.49

are closely related to these exporting sectors are also affected. In the domestic market the import competing sectors also face increased competition from imports as domestic prices rise while prices of imports, except crude oil, remain constant. This encourages domestic users to substitute imported goods for domestic goods. As a result employment is reduced. The CD model projects that aggregate employment will decline by 0.11 percent, while the TL model projects a reduction of about 0.09 percent.

It is noted above that the exporting and import competing sectors of Australia will be most affected due to an increase in the imported price of crude oil. Since this will increase domestic prices, prices of energy and energy-intensive products increasing most, exports will decline as exporting sectors will lose their competitiveness in the export markets and imports will increase as import competing sectors will face increasing competition in the domestic markets from imports. As a result, the economy will experience deterioration in its balance of trade. The CES-FC model projects that aggregate exports will decline by 0.35 percent while aggregate imports will increase by 0.85 percent resulting in a deterioration in the balance of trade of about $A174.10m which is about 0.18 percent of the GDP in the base year. The CD model projects that aggregate exports will decline by 0.50 percent, while aggregate imports will increase by 0.55 percent leading to a deterioration in the balance of trade of about \$A152.71m which is about 0.16 percent of the base year GDP. The TL model projects a decline in the aggregate exports of 0.53 percent while aggregate imports is projected to increase by 0.53 percent leading to a deterioration in the balance of trade of about \$A153.81m which is about 0.16 percent of the base year GDP.

A consistency check between the aggregate employment and the aggregate trade results can be done through the national income identity. In percentage change form it can be written that

$$gdp = S_A a + S_E q^E - S_M q^M \tag{5.1}$$

where gdp is the percentage change in gross domestic product (GDP); a is the percentage change in real domestic absorption; q^E is the percentage change in the quantity index of exports; q^M is the percentage change in the quantity index of imports; and S_A, S_E and S_M are shares of domestic absorption, exports and imports in the GDP. The percentage change in GDP can also be measured as a weighted average of percentage changes in the employment of primary factors, i.e.,

$$gdp = S_L l + S_K k \tag{5.2}$$

where l and k are percentage changes in the employment of labour and capital respectively; S_L and S_K are the shares of returns to labour and capital respectively in the GDP. For the present simulation it is assumed that

$$k = 0 \tag{5.3}$$

i.e., aggregate capital stock is fixed. The value for S_L, obtained from the IO data set used for the present study, is 0.64. Equations (5.2) and (5.3) together suggest a value for gdp of about -0.10 for the CES-FC model given the value of l in Table 5.1. On the other hand, equation (5.1) gives a value of gdp of about -0.11. In calculating gdp from equation (5.1) for the CES-FC model, the values used for S_E and S_M are 0.15281 and 0.15353 respectively (obtained from the IO data) while $a = 0$ since real domestic absorption is assumed fixed in the present simulations. The values for q^E and q^M were taken from Table 5.1.[1] For the CD model, equation (5.1) gives a value for gdp of about -0.09 while (5.2) and (5.3) give a value of about -0.07. For the TL model, equation (5.1) gives a value for gdp of about -0.09 while (5.2) and (5.3) give a value of about -0.06. Thus the checks are very close.

The last row of Table 5.1 shows the effect of a 10 percent increase in the world price of imported crude on the consumer price index (CPI). The CES-FC model projects an increase of 0.63 percent in the CPI, while the CD model projects an increase of 0.62 percent and the TL model projects an increase of 0.49 percent.

5.2.2 Sectoral output responses

Output responses of different sectors to the 10 percent increase in the world price of imported crude oil are presented in Table 5.2. It can be seen from this table that the sectoral output projections made by the three CGE models differ from one another quite significantly. These differences in model projections for sectoral output responses arise solely from differences in production submodels used in the CGE models to describe the behaviour of the producers involved in current production. In all three CGE models, the percentage change in the production of sector j is determined by the following equation:

$$x^{0}_{(j1)} = B^{c}_{(j1)} x^{c}_{(j1)} + B^{(5)}_{(j1)} x^{(5)}_{(j1)}, \quad j = 1, 2, \ldots, 9 \tag{5.4}$$

[1]Note that the values for q^E and q^M were calculated later from the results of the models.

where $x^0_{(j1)}$ is the percentage change in the production of sector j; $x^c_{(j1)}$ is the percentage change in the demand for domestic product j for the creation of effective good j; $x^{(5)}_{(j1)}$ is the percentage change in exports from sector j; $B^c_{(j1)}$ is the share of total production of sector j demanded by domestic users; and $B^{(5)}_{(j1)}$ is the share of exports in the total production of sector j. The equations determining $x^c_{(j1)}$ and $x^{(5)}_{(j1)}$ are also the same in all three models. The equation which determines $x^c_{(j1)}$ in the models is:

$$x^c_{(j1)} = x^c_j - \sigma^c_j(p_{(j1)} - \sum_{t=1}^{2} S^c_{(jt)} p_{(jt)}) \tag{5.5}$$

where x^c_j is the percentage change in the total demand for effective good j; $p_{(j1)}$ and $p_{(j2)}$ are the percentage changes in the prices of domestic good j and imported good j respectively; σ^c_j is the elasticity of substitution between domestic and imported good j; and $x^c_{(j1)}$ is as defined before. The equation which determines x^c_j is the same in all three models and can be written as

$$x^c_j = \sum_{i=1}^{9} H^{(1)c}_{ji} x^{(1)c}_{ji} + \sum_{i=1}^{9} H^{(2)c}_{ji} x^{(2)c}_{ji} + H^{(3)c}_j x^{(3)c}_j + H^{(4)c}_j x^{(4)c}_j \tag{5.6}$$

where $x^{(1)c}_{ji}$ is the percentage change in the demand for effective good j in sector i for the production of current goods; $x^{(2)c}_{ji}$ is the percentage change in the demand for effective good j in sector i for the production of capital goods; $x^{(3)c}_j$ is the percentage change in the demand for effective good j in the household sector; $x^{(4)c}_j$ is the percentage change in the demand for effective good j in the government sector; $H^{(1)c}_{ji}$, $H^{(2)c}_{ji}$, $H^{(3)c}_j$ and $H^{(4)c}_j$ are shares of respective users in the total supply of effective good j.

Although all three CGE models use the same equations to determine $x^{(2)c}_{ji}$, $x^{(3)c}_j$ and $x^{(4)c}_j$, they specify different equations to determine $x^{(1)c}_{ji}$. In the CES-FC model, the equation determining $x^{(1)c}_{ji}$ is specified as

$$x^{(1)c}_{ji} = x^0_{(i1)}, \;\; j = 1, 2, \ldots, 9, \;\; i = 1, 2, \ldots, 9. \tag{5.7}$$

Table 5.2: Effects of a 10 Percent Increase in the World Price of Imported Crude Oil on Domestic Production.

Sector	Percentage change in production		
	CES-FC model	CD model	TL model
Agriculture,mining & construction	-0.25	-0.30	-0.18
Manufacturing	-0.12	-0.04	-0.07
Transport	-0.19	-0.21	-0.10
Communications	-0.02	-0.02	-0.03
Coal	-0.35	-0.98	-2.33
Crude oil	0.30	-0.09	0.79
Petroleum and coal products	-2.23	-3.65	-2.48
Electricity	-0.15	-0.37	0.06
Gas utilities	-0.50	-1.06	0.00

In the CD model the equations determining $x_{ji}^{(1)c}$'s are specified as

$$x_{ji}^{(1)c} = m_i^{(1)} - (p_j^c - \sum_{t=0}^{4} S_{ti}^{(1)M} p_t^c), \quad j = 1, 2, \ldots, 4 \tag{5.8}$$

and

$$x_{ji}^{(1)c} = e_i^{(1)} - (p_j^c - \sum_{k=5}^{9} S_{ki}^{(1)E} p_k^c), \quad j = 5, 6, \ldots, 9 \tag{5.9}$$

where $m_i^{(1)}$ and $e_i^{(1)}$ are the percentage changes in the demands for aggregate materials and energy for current production in sector i; $S_{ti}^{(1)M}$ is the share of material input t ($t = 0, 1, \ldots, 4$) in the total material cost of sector i for current production; and $S_{ki}^{(1)E}$ is the share of fuel k ($k = 5, 6, \ldots, 9$) in the total energy cost of sector i for current production. In the TL model, the equations determining $x_{ji}^{(1)c}$'s are specified as

$$x_{ji}^{(1)c} = m_i^{(1)} - (p_j^c - \sum_{t=0}^{4} S_{jt,i}^{*(1)M} p_t^c), \quad j = 1, 2, \ldots, 4 \tag{5.10}$$

and

$$x_{ji}^{(1)c} = e_i^{(1)} - (p_j^c - \sum_{k=5}^{9} S_{jk,i}^{*(1)E} p_k^c), \quad j = 5, 6, \ldots, 9 \tag{5.11}$$

where $S_{jt,i}^{*(1)M}$ is the modified share of material t ($t = 0, 1, \ldots, 4$) in the total material cost of sector i for current production (note that modified cost share of an input, unlike in the CD model, vary across input demand equations which is a result of using translog production functions); and $S_{jk,i}^{*(1)E}$ is the modified share of fuel k ($k = 5, 6, \ldots, 9$) in the total energy cost of sector i for current production (these shares also vary across input demand equations). It is due to this difference in the specifications of equations for $x_{ji}^{(1)c}$ (which is a direct result of using different production functions for current production) that the different projections for x_j^c arise in the different models. This difference in the projections for x_j^c leads to different projections for $x_{(j1)}^c$ through equation (5.5) which ultimately leads to different projections for $x_{(j1)}^0$, the percentage change in the production of sector j ($j = 1, 2, \ldots, 9$), in different models through equation (5.4).

In fact, the change in the demand for a sector's output is influenced by five forces: (i) change in the activity levels of the sectors using the product concerned for producing current and capital goods; (ii) substitution of the product concerned for other products and primary factors in the production of current goods; (iii) substitution of the product concerned for other products by other users such as the household and government sectors and the capital goods producing sectors; (iv) substitution of matching imported product for the domestically produced product by all users, i.e., by the producers of current and capital goods, household sector and the government sector; and (v) change in the foreigners' demand for the domestic product concerned. While both the CD and TL models incorporate all these five forces affecting demand for a sector's output, the CES-FC model fails to incorporate the second force affecting the demand. If it is assumed that all forces except the second one lead to the same percentage change in the demand for a sector's output in all models, then it is expected that the output projection of the CES-FC model will be smaller (or larger) than those projected by the CD and TL models provided that the substitution effect is positive (or negative) for the product concerned in the production of current goods.

The argument developed above can be further clarified with the help of an example. Assume that the 10 percent increase in the price of imported crude also leads to a 10 percent increase in the price of domestic crude (note that in the present simulations this assumption of import parity pricing is not made). Since the percentage change in the price of effective crude oil is a weighted average of the percentage changes in the domestic and import prices of crude, the weights reflecting the expenditures on domestic crude and imported crude, this will lead to a 10 percent increase in the price of the effective crude. Now, consider the first-round effects of this increase in the price of the effective crude oil on the domestic production of the 6^{th} sector, i.e., the production of the crude oil sector, $x^0_{(61)}$. In the CES-FC model, the first-round effect of the 10 percent increase in the price of effective crude oil on its demand in sector i for current production will be predicted to be zero, i.e., $x^{(1)c}_{6i} = 0$ (see equation (5.7)) if it is assumed that the activity level of sector i is not yet affected by changes in other variables. As a result, $\sum_{i=1}^{9} H^{(1)c}_{6i} x^{(1)c}_{6i} = 0$ and the change in the domestic production of crude oil due to changes in its demand as intermediate inputs in current production is zero.

In the CD model, producers of current goods are allowed to substitute between different fuels. Since the price of effective crude oil has increased by 10 percent, producers of current goods will substitute other relatively cheaper fuels for crude oil. The result is a reduction in the demand for effective crude oil for current production. Equation (5.9) suggests that the first-round effect of the price increase on the demand for effective crude oil in sector i for current production will be a reduction of $10(1 - S^{(1)E}_{6i})$ percent. The first-round effect on the total demand for effective crude oil will be a reduction of $10\sum_{i=1}^{9} H_{6i}^{(1)c}(1-S_{6i}^{(1)E})$ percent which will lead to a reduction in the domestic production of crude oil by $10B_{(61)}^{c}\sum_{i=1}^{9} H_{6i}^{(1)c}(1-S_{6i}^{(1)E})$ percent.

In the TL model, producers of current goods are also allowed to substitute between different fuels. Equation (5.11) suggests that the first-round effect of the price increase on the demand for effective crude oil in sector i for current production will be a reduction of $10(1-S_{66,i}^{*(1)E})$ percent. The first-round effect on the total demand for effective crude oil will be a reduction of $10\sum_{i=1}^{9} H_{6i}^{(1)c}(1-S_{66,i}^{*(1)E})$ percent which will lead to a reduction in the domestic production of crude oil by $10B_{(61)}^{c}\sum_{i=1}^{9} H_{6i}^{(1)c}(1-S_{66,i}^{*(1)E})$ percent. Using the relationship

$$S_{66,i}^{*(1)E} = S_{6i}^{(1)E} + \frac{\beta_{66,i}^{E}}{S_{6i}^{(1)E}},$$

where $\beta_{66,i}^{E}$ is a parameter of the translog energy cost function of sector i, it can be said in other words that output of crude oil will decline by $10B_{(61)}^{c}\sum_{i=1}^{9} H_{6i}^{(1)c}\{1-S_{6i}^{(1)E}-(\beta_{66,i}^{E}/S_{6i}^{(1)E})\}$ percent.

Since the first-round projections for $x_{(61)}^{(5)}$, $x_{6i}^{(2)c}$, $x_{6}^{(3)c}$ and $x_{6}^{(4)c}$ will be negative but the same in value in all three models, the results obtained so far suggest that the CD model will predict larger reduction and so will the TL model in the domestic production of crude oil than the CES-FC model. The suggested reduction in the domestic production of crude oil by the TL model will be larger (smaller) than that suggested by the CD model if $\beta_{66,i}^{E}$ is negative (positive). A corollary of this illustration is that the projections for all sectoral output responses to a 10 percent increase in the price of the imported crude oil will be different in the three models in the first round. Because the first-round effects on the output of crude oil differ across the models, there will also be differences in the first-round effects on the output of other sectors induced by input-output linkages.

So far, it has been demonstrated why the three CGE models will lead to different projections for output responses of different sectors to a 10 percent increase in the price of imported crude oil. The following discussion explains why different sectors will reorganise their output decisions differently in response to the increase in the price of imported crude oil.

As can be seen from Table 5.2, the output of the agriculture, mining and construction sector (hereafter the agriculture sector) is projected to decline in all three models. The increase in the price of imported crude oil increases the cost of production of this sector. The oil price shock affects the cost of production of this sector rather indirectly since this sector spends a negligible percentage of its total cost on crude oil. The oil price shock increases the CPI, which in turn increases the wage rate which is fully indexed to the CPI. About 33 percent of this sector's total cost is on labour. So the cost of production increases as the wage rate increases. The prices of material inputs to this sector also increase due to the oil price shock and lead to further increase in the cost of production in this sector. This sector depends on both the domestic and foreign markets for the sale of its products. The increase in the cost of production makes it less competitive in both markets. In the foreign market, this sector becomes subjected to a cost-price squeeze. Since it faces an elastic demand curve for its exports in the foreign market (the elasticity of foreign demand is 3.33) it can pass on only a very small percentage of the increase in its cost to the foreign buyers. As a result, value of exports from this sector decline. In the domestic market, users of the products of this sector substitute relatively cheaper imports for the products of this sector. The sale of the products of this sector to the domestic market also declines due to shrinkage in the activity levels of other sectors. Table 5.2 shows that all sectors except the crude oil experience decline in their activity levels. Reductions in both exports and sale to the domestic market are, thus, responsible for the decline in the activity level of the agriculture sector. According to the CES-FC model, exports from this sector will decline by 1.52 percent and domestic demand will decline by 0.01 percent due to increase in the cost of production of this sector. Since this sector sells about 84 percent of its products in the domestic market and the rest in the export market, the total decline in its output is 0.25 ($-0.01 \times 0.84 - 1.52 \times 0.16$) percent.

According to the CD model, exports from this sector will decline by 1.79 percent. The reduction in exports in this model is larger than in the CES-FC model because the price of this sector's output rises more in this model than in the latter. The price of output of the agriculture sector rises by 0.46 percent in the CES-FC model while it rises by 0.54 percent in the CD model.[2] Given the fact that foreigners' demand for the products of this sector is modelled in an identical way in both models, a larger price increase has led to a larger reduction in exports in the CD model than in the CES-FC model. The CD model also projects that domestic users will reduce their demand for the products of this sector by 0.02 percent. Reductions in both exports and domestic demand has led to a 0.30 ($-0.02 \times 0.84 - 1.79 \times 0.16$) percent reduction in this sector's output in the CD model. This model projects a larger reduction in the activity level of the agriculture sector than the CES-FC model mainly because exports decline more in the former than in the latter model. About 86 percent of the difference in the output projections made by these two models is explained by the difference in their projections for export change.

The TL model projects that exports from this sector will decline by 1.22 percent and domestic demand for this sector's output will increase by 0.02 percent which will lead to a reduction in the output of this sector by 0.18 ($0.02 \times 0.84 - 1.22 \times 0.16$) percent. As explained in Subsection 5.2.3, the increase in the price of this sector's output is less in the TL model than those in the other two models. Consequently, exports from this sector decline

[2]For an explanation of differences in sectoral price projections made by alternative CGE models see Subsection 5.2.3.

less in the TL model than in the other two models. Moreover, domestic demand for this sector's output increases in this model while it decreases in the other two models.[3] Due to these two factors output of the agriculture sector declines less in this model than in the other two. About 69 percent of the difference in output projections between the CES-FC model and the TL model is explained by their difference in export projections. On the other hand, about 76 percent of the difference between the TL model and the CD model in projecting output change is explained by their difference in projecting change in exports from this sector.

The increase in the price of imported crude oil also leads to an increase in the cost of production of the manufacturing sector. This sector, like the agriculture sector, spends a negligible percentage of its total cost on crude oil. The oil price shock increases the cost of production of this sector rather indirectly by increasing the wage rate and prices of other intermediate inputs. Exports from this sector are maintained at the base-year level through increased subsidies to the exporters. So output response of this sector depends solely on the reactions of the domestic users to the increase in cost in this sector. Since domestically produced manufactured products are now relatively dearer than imported ones, domestic users substitute imported manufactured goods for domestic ones. Besides this, sales to other sectors suffer because activity levels of other sectors decline. The major buyers of this sector's output are agriculture, manufacturing itself and communications. The CES-FC model projects that domestic users will reduce their demand for domestically produced manufactured goods by 0.14 percent. Since domestic demand accounts for 89 percent of the output of this sector, this leads to a decrease in its output by 0.12 (-0.14×0.89) percent. The output of this sector is affected less than that of the agriculture sector because exports from this sector remain unchanged while exports from the agriculture sector decline.

[3]This is because activity levels of main users of this sector's output decline less and substitution effect in favour of agricultural inputs in current production is stronger in the TL model than in the other two models.

The CD model projects that domestic users reduce their demand by 0.04 percent leading to an output reduction in the manufacturing sector of about 0.04 (-0.04×0.89) percent. Output of the manufacturing sector declines less in the CD model than in the CES-FC model because its sale to the domestic users suffers less in the former model than in the latter. The domestic demand for the output of the manufacturing sector declines less in the CD model than in the CES-FC model because current goods producing sectors, being allowed to substitute between inputs in the material nest, substitute relatively cheaper manufactured goods for relatively dearer inputs from the transport and communications sectors (see Table 5.3 for price results).

The TL model projects that the domestic demand for domestically produced manufactured goods will decline by 0.08 percent as a result of the oil price shock which will lead to a reduction in the output of this sector by 0.07 (-0.08×0.89) percent. Output of the manufacturing sector declines less in the TL model than in the CES-FC model because the sale of the manufactured products to the domestic users suffers less in the former than in the latter model. Several factors have led to lower reduction in domestic use of manufactured products in the TL model than in the CES-FC model. Firstly, the activity levels of the main users of this sector's output decline relatively less in this model than in the CES-FC model. Secondly, the price of the output of the manufacturing sector increases less in the TL model than in the CES-FC model (see Table 5.3). As a result, the trade substitution effect against the domestically produced manufactured goods is weaker in the former model than in the latter. Thirdly, the CES-FC model does not allow substitution between inputs in the material nest in current production while the TL model does. It can be seen from Table 5.3 (TL model) that the inputs from the manufacturing sector are relatively cheaper than other inputs, except those from the agriculture sector, in the material nest. The users of this sector's output find it profitable to substitute manufactured products for relatively dearer products from other sectors. The domestic demand for the output of the manufacturing sector declines more in the TL model than in the CD model because the price of manufactured products relative to that of agricultural products increases more in the former model than in the latter (see Table 5.3). This factor and the fact that the ease of substitution between agricultural and manufactured products is greater in the TL model (see Table 4.15 in Chapter 4) than in the CD model have resulted in a much smaller substitution effect in favour of manufactured products in the former model than in the latter. As a result, there has been a larger reduction in domestic demand for manufactured products and, consequently, a larger reduction in the output of the manufacturing sector in the TL model than in the CD model.

The cost of production of the transport sector also increases since the wage rate and costs of intermediate inputs to this sector increase due to the oil price shock. Exports from this sector are held constant in the present simulations. So its output is affected by the reactions of the domestic buyers to the increase in its output price. Changes in the activity levels of other sectors which use its products in their production also affect the output of this sector. The major buyers of transport services are agriculture, manufacturing, communications and households. Since the output levels of agriculture, manufacturing and communications decline, demands from these sectors for transport services also decline. Moreover, demand for this sector's output declines due to trade substitution effect. Since the price of the products produced by this sector rises relative to that of similar imported products domestic users substitute imported transport services for domestic ones. The result is a reduction in the demand for domestic transport services. The CES-FC model projects that domestic users will reduce their demand for domestically produced transport services by 0.25 percent. Since domestic users purchase only 77 percent of the total production of the transport sector a 0.25 percent reduction in their demand leads to a 0.19 (-0.25×0.77) percent decline in the output of this sector in this model.

The CD model projects that domestic users will reduce their demand for domestically produced transport services by 0.27 percent which leads to an output reduction of 0.21 (-0.27×0.77) percent in this model. Output of the transport sector is affected more in the CD model than in the CES-FC model because domestic demand decreases more in the former model than in the latter. The demand for transport services declines more in the CD model than in the CES-FC model because current goods producers, in addition to other users, are substituting relatively cheaper material inputs from other sectors for relatively dearer transport services in the CD model while they are barred from doing so in the CES-FC model (see Table 5.3 for the price results).

The TL model projects that the domestic demand for domestic transport services will decline by 0.13 percent which leads to an output decline of 0.10 (-0.13×0.77) percent. Output of the transport sector declines less in the TL model than in the other two models because the domestic demand for its output declines less in this model. The domestic demand for transport services declines less in the TL model than in the CES-FC model mainly because the activity levels of their main users decrease less in the former than in the latter model. The domestic demand for transport services declines less in the TL model than in the CD model because the cost of these services increase less in the former model than in the latter which results in a weaker trade substitution effect against these services in the former model than in the latter. (See Table 5.3 for the relative prices of outputs). Secondly, the fact that the ease of substitution between transport services and materials from other sectors in the production of outputs of the main users of transport services is relatively less in the TL model (see Table 4.15 in Chapter 4) than in the CD model has also resulted in a weaker substitution effect against transport services in the former model than in the latter. Mainly, these two factors have led to a smaller output reduction for the transport sector in the TL model than in the CD model.

The output of the communications sector has been found relatively insensitive to the oil price shock. All three models have projected only a slight decline in its output. Several factors may be held responsible for this. Firstly, this sector can be classified as a nontrading sector because it sells about 98 percent of its output in the domestic market where it confronts an insignificant level of import penetration. As a result, the selling price of its products can adjust approximately in line with the costs of the purchased inputs necessary for its production without serious loss in sales. Secondly, exports from this sector are held constant in the present simulations. On the other hand, this sector is not heavily dependent on any exporting sector for the sale of its output. This characteristic keeps this sector free from the effects of cost-price squeeze imposed on exporting sectors. Finally, this sector sells about 67 percent of its total domestic sales to the household and government sectors. Since the aggregate level of real consumption and the aggregate level of real government expenditures are held constant in the present simulations there is little scope for variation in the output of this sector. However, the output of this sector has slightly declined due to substitution among commodities in the household and government consumption.

Like other sectors, the coal sector also experiences an increase in its cost of production due to increase in the price of imported crude oil. The cost of production of this sector is, however, affected indirectly by the oil price shock. Of its total cost of production, only 1 percent is incurred for crude oil. However, this sector incurs about 27 percent of its total cost for labour. With the increase in CPI the labour costs of this sector increase. Moreover, it incurs higher costs than before, like other sectors, for material inputs since their prices also increase due to increase in the costs of producing them. In the domestic market, the demand for domestic coal suffers firstly because the activity levels of its main users, the manufacturing and electricity sectors, decline; and secondly because domestic users substitute relatively cheaper imported coal for local coal. It should be noted that the trade substitution effect against local coal is very small because Australia imports only a negligible amount of coal from overseas. In addition to the domestic market, the coal sector heavily depends on the foreign market for the sale of its products. It exports about 69 percent of its total production. In the foreign market this sector faces an almost perfectly elastic demand curve for its exports (the elasticity of demand for coal exports is 20.0), and is able to pass on little of the increase in its cost of production to the foreign buyers. In this way, the coal sector is similar to the first sector, agriculture, mining and construction.[4] As a result, exports from this sector are greatly reduced by the increase in its cost of production.

From the previous discussion it emerges that the output of the coal sector suffers because its sales to the domestic market as well as to the foreign market suffer. The CES-FC model projects a 0.16 percent fall in the domestic demand and a 0.44 percent fall in the foreign demand for this sector's output. Since this sector sells 31 percent of its total production to the domestic users and 69 percent to the foreign market, its production declines by 0.35 ($-0.16 \times 0.31 - 0.44 \times 0.69$) percent. The CD model projects that domestic users will increase the demand for domestic coal, in contrast to the CES-FC model, by 0.25 percent and its exports will decline by 1.53 percent leading to a reduction in the domestic production of coal by 0.98 ($0.25 \times 0.31 - 1.53 \times 0.69$) percent. These differences in the projections made by the CES-FC model and the CD model for domestic demand for domestic coal need some explanation. The major users of coal in the domestic market are manufacturing, coal sector itself and the electricity sector. These three sectors use about 96 percent of the domestic supply of coal for current goods production. The CES-FC model projects that activity levels in these three sectors declines due to the oil price shock. Since in this model it is assumed that demand for intermediate inputs

[4]In fact, the agriculture sector has slight edge over coal sector in passing the increase in cost to the foreign buyers since this sector faces less elastic foreign demand curve than the coal sector. As a result, the output of the agriculture sector is less affected in all three models than that of the coal sector.

will vary proportionately with activity level, this model projects that demand for coal in these sectors and in the domestic market as well will decline. In the CD model, decreases in the activity levels of these sectors decrease the demand for coal as well. But the CD model, in contrast to the CES-FC model, allows substitution between intermediate inputs in current production. Since coal is still the cheapest fuel in the energy nest (see Table 5.3), producers in manufacturing, coal and electricity sectors find it profitable to substitute coal for other expensive fuels. This substitution effect for coal is stronger than the negative output effect. As a result, demand for coal in the domestic market increases in the CD model.

The CD model projects a larger decline in the output of coal due to the oil price shock than the CES-FC model because exports of coal decline more in the former model than in the latter. A relatively larger increase in the price of coal in the former model than in the latter has led to a larger reduction in foreign demand for coal in the former model than in the latter. (Why coal price rises more in the CD model than in the CES-FC model is explained in Subsection 5.2.3.)

The TL model projects that use of domestic coal in the domestic market will decrease by 0.10 percent and exports from this sector will decrease by 3.33 percent leading to a reduction in the output of the coal sector by 2.33 ($-0.10 \times 0.31 - 3.33 \times 0.69$) percent. The output of the coal sector declines more in this model than in the CES-FC model because exports of coal suffer more due to larger increase in coal price in this model than in the latter. The output of coal declines more in the TL model than in the CD model, firstly, because domestic demand for coal declines in the former model but it increases in the latter; and, secondly, because exports of coal declines more in the former model than in the latter. One possible explanation for the decline of domestic demand for coal in the TL model, unlike in the CD model, is that coal and crude oil are good complements in the production of electricity (the elasticity of substitution between these two inputs is -2.22) in the TL model while they are substitutes in the CD model. Since the domestic price of crude oil increases substantially in the TL model the electricity sector, which uses about 41 percent of coal output in its production, reduces the use of both coal and crude oil. But in the CD model the substitution effect increases the demand for coal and decreases the demand for crude oil in the electricity sector since the price of crude rises relatively more than that of coal (see Table 5.3).

Contrasting projections have been made by the three CGE models for output response of the crude oil sector to the increase in the price of the imported crude oil. While both the CES-FC and TL models predict that output of this sector will increase as a result of the oil price shock, the CD model projects that output of this sector will decline. Since exports from this sector are maintained at their base-year levels in the present simulations, differences in output projections made by the models can be explained by their differences in projecting changes in domestic demands for crude oil. About 86 percent of the total domestic supply of crude oil is used by the petroleum and coal products sector for producing refined petroleum and coal products. As can be seen from Table 5.2, the output of this sector is affected the most by the increase in the price of imported crude. It is likely that this sector will reduce its demand for crude oil. The CES-FC model projects that the domestic demand for effective crude oil will decline by 1.98 percent. However, domestic users will achieve the reduced usage of effective crude oil by increasing their demand for domestic crude by 0.35 percent and decreasing demand for imported crude by 3.84 percent. This result suggests that domestic users will substitute relatively cheaper domestic crude for imported crude, and this substitution effect is stronger than the negative output effect in the creation of effective crude oil. Since domestic users account for about 86 percent of the domestic production of crude, an increase of 0.35 percent in the domestic demand for domestic crude leads to increase in output in the crude oil sector by 0.30 (0.86×0.35) percent in the CES-FC model.

The CD model projects that the domestic demand for effective crude oil will decline by 5.09 percent. This result is much higher than its counterpart in the CES-FC model. This happens, firstly, because in the CD model the activity level of the petroleum and coal products sector, the main user of crude oil, declines more than in the CES-FC model and, secondly, because the overall substitution effect against crude oil is larger in the former model than in the latter. Since coal is now the cheapest among all fuels (see Table 5.3), the petroleum and coal products sector, being allowed to substitute crude oil for other fuels, substitute coal for crude oil in its current production of refined petroleum and coal products. In other words, the CD model suggests that the petroleum and coal products sector changes its output composition in favour of coal products; a suggestion which is hard to accept considering the short-run nature of the simulations. However, the reduction in demand for effective crude oil of 5.09 percent in the CD model leads to reduction in demands for domestic crude by 0.10 percent and for imported crude by 9.08 percent. Domestic users still substitute relatively cheaper domestic crude for imported crude but the adverse output effect dominates the favourable substitution effect on domestic crude in the creation of effective crude oil. The 0.10 percent reduction in the domestic consumption of domestic crude in the CD model leads to reduction in the output of the crude oil sector by 0.09 (-0.10×0.86) percent.

The TL model projects that domestic users will reduce their demand for effective crude oil by 3.40 percent. Predicted reduction in domestic demand for effective crude oil in this model is larger than that in the CES-FC model because the petroleum and coal products sector along with other sectors is allowed to substitute relatively cheaper other fuels for relatively dearer crude oil. Domestic users achieve their reduced demand for effective crude oil by increasing demand for domestic crude by 0.92 percent and reducing demand for imported crude by 6.86 percent. In this case, substitution effect in favour of domestic crude is stronger than the negative output effect in the creation of effective crude oil. The increase of 0.92 percent in domestic demand for domestic crude in the TL model leads to output increase in the crude oil sector by 0.79 (0.86×0.92) percent.

As has already been mentioned, the production of the petroleum and coal products sector suffers most due to the increase in the price of imported crude. This sector is highly energy intensive and particularly crude oil intensive. Of its total cost of production about 80 percent is accounted for by energy inputs and about 84 percent of its total energy cost is on crude oil. So the increase in the price of crude oil exerts a strong upward pressure on the cost of production of this sector. Since export from this sector is held constant in the present simulation, output suffers because domestic users reduce their demand for this sector's output. The main users of petroleum and coal products are the four non-energy, current goods producing sectors and the household sector. They together use about 86 percent of the total domestic supply of petroleum and coal products. The CES-FC model projects that the domestic demand for effective petroleum and coal products will decrease by 1.41 percent mainly because activity levels of the non-energy sectors have declined due to the oil price shock and the household sector substitutes other relatively cheaper fuels for petroleum and coal products. The CES-FC model also indicates that domestic users will reduce their demand for domestic petroleum and coal products by 2.48 percent and increase their demand for imported petroleum and coal products by 3.41 percent to satisfy their reduced demand for effective petroleum and coal products. This result implies that domestic users will substitute imported petroleum and coal products, the price of which has not changed, for domestic petroleum and coal products the price of which has increased substantially. Since the petroleum and coal products sector sells about 90 percent of its products to domestic users, a reduction of 2.48 percent in their demand for these products leads to output reduction in this sector by 2.23 (-2.48×0.90) percent in this model.

Since current goods producing sectors are allowed to substitute relatively cheaper fuels for relatively dearer ones in the CD model and since the price of petroleum and coal products rises the most of all fuels, all current goods producing sectors substitute against petroleum and coal products in favour of other relatively cheaper fuels. As a result, the domestic demand for effective petroleum and coal products declines more in the CD model than in the CES-FC model. In the CD model, the domestic demand for effective petroleum and coal products declines by 3.23 percent. The CD model also suggests that this reduced demand for effective petroleum and coal products will be achieved by reducing demand for domestic petroleum and coal products by 4.08 percent and increasing demand for imported petroleum and coal products by 0.57 percent. The reduction of 4.08 percent in the demand for domestic petroleum and coal products leads to output reduction in the petroleum and coal products sector by 3.65 (-4.08×0.90) percent in this model.

The TL model projects that the domestic demand for effective petroleum and coal products will decline by 2.21 percent. This reduced demand for effective petroleum and coal products is achieved by reducing demand for domestic petroleum and coal products by 2.76 percent and increasing demand for imported petroleum and coal products by 0.30 percent. The reduction of 2.76 percent in the demand for domestic petroleum and coal products leads to output reduction in the petroleum and coal products sector by 2.48 (-2.76×0.90) percent in this model.

The electricity sector is obviously a highly energy intensive sector. About 40 percent of its total cost is on energy. Of this, 18 percent is on coal, 8 percent on crude oil, 8 percent on petroleum and coal products and 66 percent on electricity. Since prices of all fuels increase due to the increase in the imported price of crude, the cost of production of electricity increases. Moreover, increase in the wage rate due to increase in the CPI raises the cost of electricity further since this sector spends about 24 percent of its total cost on labour. The main users of electricity are manufacturing, communications, electricity sector itself and households. Since activity levels in these sectors are reduced due to the oil price shock, the demand for electricity as intermediate inputs in current production also decreases. The demand for electricity in the household sector also declines since households substitute other relatively cheaper fuels, such as coal, for electricity. The CES-FC model projects that domestic users reduce their demand for electricity by 0.15 percent. Since the electricity sector sells about 100 percent of its output to the domestic market, this decline in domestic users' demand for electricity leads to a reduction in electricity production by 0.15 (-0.15×1.0) percent.

The CD model projects that domestic users reduce their demand for electricity by 0.37 percent which leads to an output reduction of 0.37 (-0.37×1.0) percent in the electricity sector. Output of the electricity sector declines more in the CD model than in the CES-FC model because, unlike in the CES-FC model, the producers engaged in current production are allowed to substitute between different fuels in the CD model. Thus while the substitution effect on the demand for electricity in current production is zero in the CES-FC model, it is negative in the CD model since producers of current goods substitute relatively cheaper coal for electricity. From Table 5.3 it can be seen that the price of coal rises by 0.08 percent only but the price of electricity increases by 0.90 percent in this model. The negative substitution effect in current production on the demand for electricity in the CD model contributes to the larger reduction in the output of electricity in this model than in the CES-FC model.

The TL model projects that the demand for electricity will increase by 0.06 percent in the domestic market. Since domestic users account for 100 percent of the production of the electricity sector, output of this sector is increased by the same percentage points. Output of the electricity sector increases slightly in the TL model while it declines in the CES-FC and CD models. This is because the activity levels of the non-energy producing sectors which use about 43 percent of the output of the electricity sector decline relatively less in the TL model than in the other two models thus giving rise to less adverse effects on the output of the electricity sector. This adverse effect is so small that it is easily outweighed by the favourable substitution effect on electricity demand thus giving rise to a slight increase in the output of this sector in the TL model.

About 23 percent of the total cost of the gas utilities sector is spent on energy and about 68 percent of its total energy expenditure is incurred by inputs from the crude oil sector.[5] So its cost of production increases directly with the increase in the price of imported crude oil. Moreover, increase in the wage rate which is induced by higher CPI, also increases the cost of this sector since this sector spends about 30 percent of its total cost on labour. The single major user of this sector's output is the household sector which uses about 52 percent of its output. Other major users are manufacturing and transport which together use about 41 percent of the total output of gas utilities. Since outputs of these two sectors decline, they reduce their demand for gas utilities. The household sector also demands less gas as it substitutes cheaper fuels for gas. The CES-FC model projects that domestic users will reduce their demand for gas by 0.50 percent. Since gas utilities sector sells 100 percent of its output to the domestic market, its output will decline by 0.50 (-0.50×1.0) percent according to this model.

The CD model projects that the demand for gas utilities will be reduced by 1.06 percent leading to a reduction of 1.06 (-1.06×1.0) percent in the output of the gas utilities sector. The output of gas utilities declines more in the CD model than in the CES-FC model because manufacturing and transport, which are major users of gas utilities, substitute relatively cheaper coal, crude oil and electricity for relatively dearer gas in their production in this model unlike in the CES-FC model where they were not allowed to do so. This unfavourable substitution effect joins forces with the adverse effect on

[5]Note that natural gas and crude oil have been aggregated together in the present study. Thus the price of natural gas moves directly with the price of crude oil.

the output of gas utilities sector caused by reductions in the activity levels of its main buyers in the CD model. As a result, output of gas utilities declines more in the CD model than in the CES-FC model.

As can be seen from Table 5.2, output of the gas utilities sector is not affected by the oil price shock in the TL model. This is because the adverse effect on the output of this sector caused by reductions in the activity levels of its major buyers is balanced by the favourable substitution effect for this sector's output. In this model, the price of gas has increased less relative to the prices of all other fuels except that of coal (see Table 5.3). As a result, current goods producing sectors as well as the household sector substitute this fuel for other fuels. Moreover, the fact that coal and gas are complements ($\sigma_{59} = -1.47$) in manufacturing, one of the major users of gas, has also contributed to this favourable substitution effect.

5.2.3 Sectoral output price responses

As can be seen from Table 5.3, the responses of the domestic prices of domestically produced goods to a 10 percent increase in the world price of imported crude oil vary significantly from model to model. For example, while the CES-FC model projects an increase in the price of domestically produced crude oil of 5.81 percent, the CD model projects an increase of only 1.03 percent; the TL model projects an increase of 2.23 percent. For the electricity sector, the CES-FC model projects an increase in price of 0.84 percent, the CD model projects an increase of 0.90 percent while the TL model projects an increase of 1.52 percent. It can also be seen from Table 5.3 that the forecasts of price increases by the TL model are consistently lower, except those of coal and electricity, than those made by the CES-FC model. These forecasts of prices of the TL model are also lower than those of the CD model with exception of prices of coal, crude oil and electricity.

Table 5.3: Effects of a 10 Percent Increase in the World Price of Imported Crude Oil on the Domestic Prices of Domestic Goods.

Sector	Percentage change in domestic prices		
	CES-FC model	CD model	TL model
Agriculture,mining & construction	0.46	0.54	0.37
Manufacturing	0.53	0.56	0.44
Transport	0.85	0.81	0.55
Communications	0.61	0.61	0.49
Coal	0.02	0.08	0.17
Crude oil	5.81	1.03	2.23
Petroleum and coal products	5.89	4.65	3.07
Electricity	0.84	0.90	1.52
Gas utilities	1.49	1.64	1.22

The differences in projections of the three models regarding price responses can be explained by the differences in their production submodels employed to capture the behaviour of producers in current production. To recapitulate, these three CGE models differ from one another in specifying the production submodels for current production in two respects. Firstly, the CES-FC model allows substitution only between two factors—labour and capital. But both the CD and TL models allow substitution among more factors or inputs. In addition to substitution between labour and capital, they allow substitution between these factors and energy, between these factors and aggregate materials as well as among individual fuels and among individual materials. Secondly, in the CES-FC model the elasticity of substitution between labour and capital is assumed to be 0.5. However, the value of the elasticity of substitution between inputs is unity in the CD model. Unlike the CD model, the TL model allows the value of the substitution parameter to vary across different pairs of inputs. Moreover, any two inputs are allowed to be either substitutes or complementary to each other. It can be shown that the extent of substitution allowed in the production models and values of substitution parameters permitted by these models do have significant influence, both directly and indirectly, on the average costs of production or prices of outputs.

The equation determining the price of output of sector j in the models can be written in percentage change form as

$$p_{(j1)} = S_{Kj}^{(1)} p_{Kj}^{(1)} + S_{Lj}^{(1)} p_{L}^{(1)} + S_{Ej}^{(1)} p_{Ej}^{(1)} + S_{Mj}^{(1)} p_{Mj}^{(1)}, \quad j = 1, 2, \ldots, 9. \tag{5.12}$$

where $p_{(j1)}$ is the percentage change in the domestic price of output of sector j; $p_{Kj}^{(1)}$, $p_L^{(1)}$, $p_{Ej}^{(1)}$ and $p_{Mj}^{(1)}$ are percentage changes in the rental rate of capital services, wage rate, price of energy and price of aggregate materials respectively in sector j; and $S_{Kj}^{(1)}$, $S_{Lj}^{(1)}$, $S_{Ej}^{(1)}$ and $S_{Mj}^{(1)}$ are shares of capital, labour, energy, and aggregate materials in the total cost of production of sector j. Since equations in (5.12) do not include any substitution parameter, one may argue that the substitution elasticities do not have any influence in determining the prices of domestic goods. However, this is not so in the short run.

In the CES-FC model, the percentage change in the demand for capital in sector j due to an external shock is determined by the equation

$$k_j^{(1)} = x_{(j1)}^0 - \sigma_j (p_{Kj}^{(1)} - S_{Lj}^{\prime(1)} p_L^{(1)} - S_{Kj}^{\prime(1)} p_{Kj}^{(1)}) \tag{5.13}$$

where $k_j^{(1)}$ is the percentage change in the demand for capital in sector j; $x_{(j1)}^0$, $p_L^{(1)}$ and $p_{Kj}^{(1)}$ are as defined before; $S_{Lj}^{\prime(1)}$ and $S_{Kj}^{\prime(1)}$ are shares of labour and capital in the total primary factor cost of sector j respectively; and σ_j is the elasticity of substitution between labour and capital assumed to be 0.5 for all sectors. Since the present analysis is intended to be short run in nature, it is assumed in the simulations that

$$k_j^{(1)} = 0, \quad j = 1, 2, \ldots, 9. \tag{5.14}$$

Substituting (5.14) into (5.13) and solving for $p_{Kj}^{(1)}$ give

$$p_{Kj}^{(1)} = \frac{1}{\sigma_j(1 - S_{Kj}^{\prime(1)})} x_{(j1)}^0 + \frac{S_{Lj}^{\prime(1)}}{(1 - S_{Kj}^{\prime(1)})} p_L^{(1)}. \tag{5.15}$$

By definition,

$$S_{Lj}^{\prime(1)} + S_{Kj}^{\prime(1)} = 1 \tag{5.16}$$

and

$$S_{Kj}^{\prime(1)} = S_{Kj}^{(1)} / S_{Fj}^{(1)} \tag{5.17}$$

where $S_{Kj}^{(1)}$ is the share of capital in the total cost of sector j; $S_{Fj}^{(1)}$ is the share of primary factors in the total cost of sector j; and other variables are as defined before. Substituting (5.16) and (5.17) into (5.15) gives

$$p_{Kj}^{(1)} = \frac{1}{\sigma_j(1 - (S_{Kj}^{(1)} / S_{Fj}^{(1)}))} x_{(j1)}^0 + p_L^{(1)} \tag{5.18}$$

Now, substituting (5.18) into (5.12) and rearranging give

$$\begin{aligned} p_{(j1)} \quad = \quad & \frac{S_{Kj}^{(1)}}{\sigma_j(1 - (S_{Kj}^{(1)} / S_{Fj}^{(1)}))} x_{(j1)}^0 + (S_{Lj}^{(1)} + S_{Kj}^{(1)}) p_L^{(1)} + S_{Ej}^{(1)} p_{Ej}^{(1)} + \\ & S_{Mj}^{(1)} p_{Mj}^{(1)}), \quad j = 1, 2, \ldots, 9. \end{aligned} \tag{5.19}$$

Equation (5.19) is the short-run average cost function of sector j in percentage change form implied by the production function used in the CES-FC model to describe the technology of current production of sector j. Satisfaction of equation (5.12) guarantees that there is no pure profit in the production of current goods in sector j and so does equation (5.19). While the price of a sector's output is independent of the output level in the long run under the assumption of constant returns to scale, it depends on the output level in the short run due to the operation of the law of variable proportions in current production. The short-run average cost function (5.19) verifies this.

If it is assumed that $p_L^{(1)} = p_{Ej}^{(1)} = p_{Mj}^{(1)} = 0$, then equations in (5.19) simplify into equations (5.20)

$$p_{(j1)} = \frac{S_{Kj}^{(1)}}{\sigma_j(1 - (S_{Kj}^{(1)}/S_{Fj}^{(1)}))} x_{(j1)}^0, \quad j = 1, 2, \ldots, 9. \tag{5.20}$$

Equation (5.20) represents the short-run supply curve of sector j in percentage change form. Since the coefficient of $x_{(j1)}^0$ is positive, the supply curve of sector j will be sloping upward which implies that an increase in output can only be achieved at an increasing cost and a lower level of output can be obtained at a lower cost. This property of the supply curve is a direct result of the working of the law of variable proportions in the short run when the capital stock remains constant. Any increase (decrease) in the wage rate or the price of energy or the price of aggregate materials will shift the short-run supply curve upward (downward) and the extent of the shift will depend on the coefficients of $p_L^{(1)}$, $p_{Ej}^{(1)}$ and $p_{Mj}^{(1)}$.

The implicit short-run average cost function of sector j in the CD model (in percentage change form) can be obtained in the same way. In the CD model, the equation which determines the percentage change in capital demand in sector j is specified as

$$k_j^{(1)} = x_{(j1)}^0 - (p_{Kj}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}), \quad r = K, L, E, M; \tag{5.21}$$

where the variables and coefficients are as defined before. Substituting (5.14) into (5.21) and solving for $p_{Kj}^{(1)}$ gives

$$p_{Kj}^{(1)} = \frac{1}{(1 - S_{Kj}^{(1)})}(x_{(j1)}^0 + S_{Lj}^{(1)} p_L^{(1)} + S_{Ej}^{(1)} p_{Ej}^{(1)} + S_{Mj}^{(1)} p_{Mj}^{(1)}). \tag{5.22}$$

Finally, substituting (5.22) into (5.12) and rearranging give

$$p_{(j1)} = \frac{1}{(1-S_{Kj}^{(1)})}(S_{Kj}^{(1)}x_{(j1)}^{0} + S_{Lj}^{(1)}p_{L}^{(1)} + S_{Ej}^{(1)}p_{Ej}^{(1)} + S_{Mj}^{(1)}p_{Mj}^{(1)}),$$
$$j = 1, 2, \ldots, 9. \qquad (5.23)$$

Equation (5.23) defines the short-run average cost function of sector j for current production in the CD model. A comparison between the short-run average cost functions implied by the production submodels for current production in the CES-FC model and the CD model suggests that these cost functions are structurally different from each other in the sense that they have different coefficients for the variables included in the functions.

The equation representing the short-run supply curve of sector j in the CD model can be obtained as

$$p_{(j1)} = \frac{S_{Kj}^{(1)}}{(1-S_{Kj}^{(1)})}x_{(j1)}^{0}, \quad j = 1, 2, \ldots, 9, \qquad (5.24)$$

assuming that $p_{L}^{(1)} = p_{Ej}^{(1)} = p_{Mj}^{(1)} = 0$. A comparison between the short-run supply curves implied by the CES-FC and CD models suggests that the sectoral supply curves implied by the former model are usually steeper in slope than those implied by the latter. This certainly will be true if σ_j in the CES-FC model is less than or equal to 1. Hence, the sectoral supply curves generated in the CES-FC model are relatively less elastic to price than those generated in the CD model. The numerical values of the short-run sectoral price elasticities of supply implied by the CES-FC and CD models are shown in Table 5.4. The sectoral supply curves are steeper in the CES-FC model than in the CD model, as can be seen from Table 5.4, because $\{1 - (S_{Kj}^{(1)}/S_{Fj}^{(1)}\} < (1 - S_{Kj}^{(1)})$ and σ_j is assumed to be 0.5 in the CES-FC model. Since the short-run supply curves in the CES-FC model are relatively less elastic than those in the CD model, a given percentage change in the activity level of a sector will result in a larger percentage change in price in the former than in the latter model. Moreover, the higher the capital

Table 5.4: Short-Run Sectoral Price Elasticities of Supply Implied by Alternative Production Functions.

Sector	Short-run elasticities of supply		
	CES-FC model	CD model	TL model
Agriculture,mining & construction	1.43	3.68	1.79
Manufacturing	3.73	9.41	10.51
Transport	6.40	13.83	3.87
Communications	1.20	2.85	1.97
Coal	0.51	1.52	3.56
Crude oil	0.06	0.45	0.49
Petroleum and coal products	7.47	26.41	4.09
Electricity	0.87	2.71	0.49
Gas utilities	0.88	2.47	0.00

intensity of a sector the larger will be the difference between the projected prices of the models. However, this conclusion depends on the *ceteris paribus* condition. The ultimate differences in the projections of sectoral prices by the CES-FC model and the CD model will depend on the differences in short-run average cost functions implied by the production functions incorporated in them. As has been noted above, the implicit average cost functions in the CES-FC model and the CD model differ from each other regarding the value of the coefficients of the relevant variables. As can be deduced from equations (5.19) and (5.23), a given percentage change in the price of energy or material will lead to a larger shift in the short-run supply curve in the CD model than in the CES-FC model since the coefficients of these variables are larger in the former than in the latter model. A conclusive comment is difficult to make about the coefficient of $p_L^{(1)}$ since it is not analytically clear which model has the larger coefficient for this variable. However, the final results on price projections will also depend on the projections of percentage changes in the variables relevant to the average cost functions. It was already seen in Subsection 5.2.2 that the CGE models differ in projecting changes in the sectoral output levels. It is likely that they will differ from one another in projecting changes in the prices of energy and aggregate materials as well as in the nominal wage rate.

Equations (5.19) and (5.23) can be tested to see whether they correctly predict domestic prices in the CES-FC and CD models. For this purpose the crude oil sector is chosen because these two models differ sharply in projecting the change in the price of this sector's output (see Table 5.3). The shares of labour, capital, energy and aggregate materials in the total cost of this sector are:

$S_{L6}^{(1)} = 0.063397$, $S_{K6}^{(1)} = 0.688082$, $S_{E6}^{(1)} = 0.052150$, and $S_{M6}^{(1)} = 0.196371$.

Percentage changes in output, wage rate and prices of energy and aggregate materials as projected by the CES-FC and CD models for the crude oil sector are shown below:

Variable	CES-FC model	CD model
$x_{(j1)}^{0}$	0.301693	-0.089834
$p_{L}^{(1)}$	0.632515	0.623793
$p_{E6}^{(1)}$	5.974019	4.504571
$p_{M6}^{(1)}$	0.498826	0.546852

When these values are substituted in equations (5.19) and (5.23) they give values for $p_{(61)}$, the percentage change in the price of the domestic crude oil, as 5.80616 and 1.02602 respectively which are exactly what are reported in Table 5.3.

The price projections for different sectors made by the TL model differ from those made by the CES-FC and CD models because the equations which define the short-run average cost functions in this model are structurally different from those in the other two. The difference in short-run average cost functions occurs because the TL model specifies demand equations for capital which are structurally different from those in the other two models. For sector j, the equation determining the percentage change in the demand for capital is specified in the TL model as:

$$k_j^{(1)} = x_{(j1)}^0 - (p_{Kj}^{(1)} - \sum_r S_{Kr,j}^{*(1)} p_{rj}^{(1)}), \quad r = K, L, E, M; \tag{5.25}$$

where

$$S_{Kr,j}^{*(1)} = S_{rj}^{(1)} + (\beta_{Kr,j} / S_{Kj}^{(1)}).$$

$S_{Kr,j}^{*(1)}$ can be interpreted as the modified share of factor r ($r = K, L, E, M$) in the total cost of production of sector j appearing in the capital demand equation. The difference between equation (5.25) and equation (5.21) is that the latter includes unmodified cost shares of capital, labour, energy and aggregate materials while the former includes cost shares of these inputs but modified by the parameters of the translog cost function. Price equations like (5.19) and (5.23) can be derived for the TL model in the same way; but these will be different in specifications from (5.19) and (5.23). It is this difference, which is the result of using translog production functions for current production, which will lead to different price projections in the TL model from those in the CES-FC and CD models. The price determining equations for the TL model are somewhat cumbersome, so they are not reported here. However, the short-run supply curve of sector j, generated by the translog production function in the TL model, is represented by the following equation

$$p_{(j1)} = \frac{S_{Kj}^{(1)}}{[(1 - S_{Kj}^{(1)}) - (\beta_{KK,j} / S_{Kj}^{(1)})]} x_{(j1)}^0, \quad j = 1, 2, \ldots, 9. \tag{5.26}$$

If $\beta_{KK,j} = 0$, equation (5.26) converges to equation (5.24), the supply curve in the Cobb-Douglas case. Assuming $S_{Kj}^{(1)} \neq 0$, the supply curve in the TL model will be steeper in slope than that in the CD model if $\beta_{KK,j} > 0$. If $\beta_{KK,j} < 0$, then the supply curve in the CD model will be steeper than that in the TL model. The estimates of β's used in the present study, however, imply that all sectoral supply curves, except those of the manufacturing, coal and crude oil sectors, are steeper in slope in the TL model than in the CD model (see Table 5.4). It can be suggested from Table 5.4 that for four sectors—transport, petroleum and coal products, electricity and gas utilities—the implied short-run supply curves are steeper and for the rest of the sectors they are flatter in the TL model than in the CES-FC model. An inspection of Table 5.4 also suggests that the short-run supply elasticity of the petroleum and coal products sector implied by the CD model is too large to be acceptable in the light of supply elasticities for this sector suggested by the other two models. This result casts some doubt on the appropriateness of using Cobb-Douglas production function to describe the technology of this sector.

So far, it has been demonstrated that the three CGE models variously project sectoral price responses. Differences in the flexibility of the production functions regarding substitution between inputs in current production generate structurally different short-run average cost functions in the CGE models which directly and indirectly (general equilibrium effects) lead to different price projections.

The short-run average cost functions generated by the alternative CGE models can be used to explain the sectoral price changes projected by these models. The short-run average cost functions show that the percentage change in the price of a sector's output depends on two factors:

(i) percentage changes in the prices of variable inputs; and

(ii) the percentage change in the activity level of the sector concerned.

The percentage change in the unit cost of production due to changes in the prices of variable inputs to the sector will be called the cost effect. The cost effect is different from model to model because the models differ in their coefficients of the prices of variable inputs in the average cost equations and in their projections of changes in the prices of variable inputs. The cost effect on price can be measured by the last three terms on the right-hand side of the equations (5.19) and (5.23), the short-run average cost functions in the CES-FC model and the CD model respectively.[6] These terms are associated with the percentage changes in the prices of variable inputs. The first term on the right-hand side of equations (5.19) and (5.23) measures, in the CES-FC and CD models respectively, the percentage change in the price due to a change in output. A change in a sector's output leads to a change in the demand for capital services in that sector. Since the sectoral capital stock remains constant in the short run, this change in demand for capital services leads to a change in the market clearing rental price of capital and consequently to a change in the average cost of production. The percentage change in the price of a sector's output caused by a change in output is called the quantity effect.[7] For a given percentage change in output the quantity effect on price will be larger, the larger is the coefficient of the output change. The coefficient of the output change is interpreted before as the slope of the supply curve of a sector. So the steeper the slope of the supply curve (less flexible production technology) of a sector, the larger is the effect on price of a given percentage change in output. The quantity effect on price will be different from model to model because the CGE models differ in the slopes of the supply curves generated by them as well as in the projections of sectoral output changes.

Thus the percentage change in the price of a sector's output is the result of two effects: (a) quantity effect and (b) cost effect. These quantity and cost effects on price can be used to explain the differences among the CGE models in projecting the sectoral price changes.

The CES-FC model projects that the price of the output of the agriculture sector will increase by 0.46 percent. The unit cost of production in this sector increases by 0.64 percent due to increase in the costs of variable inputs to

[6]The cost effects on prices in the TL model can be measured by using the corresponding terms of the average cost functions implied by this model.

[7]The quantity effect on price is measured in the TL model by equation (5.26).

this sector (cost effect). Output of this sector has decreased by 0.25 percent (see Table 5.2) in this model which has led to a fall of 0.18 percent in the average cost of production of this sector by squeezing the rental price of capital (quantity effect). The net result of these two effects is the 0.46 percent increase in the price of this sector's output.

In the CD model, increases in the costs of variable inputs to this sector have led to an increase in the price of this sector's output by 0.62 percent (cost effect). Output of this sector has decreased by 0.30 percent in this model which has induced the unit cost of production to fall by 0.08 percent by depressing the rental price of capital (quantity effect). The net result of the quantity and cost effects on price is the 0.54 percent increase in the equilibrium price of the output of the agriculture sector (see Table 5.3). The price of this sector's output has increased more in the CD model than in the CES-FC model because the supply curve of this sector is more elastic in the former model (see Table 5.6). As a result, a decline of 0.25 percent in the output of the agriculture sector has led to a larger negative quantity effect on price in the CES-FC model than a 0.30 percent decline in output has done in the CD model. This result also suggests that the rental price of capital has been more squeezed in the former model than in the latter.

The TL model projects that the price of the output of the agriculture sector will increase by 0.37 percent. Increases in the costs of variable inputs to this sector have led to an increase of 0.47 percent in its average cost of production (cost effect). Output has declined by 0.18 percent in this model which has led to a fall of 0.10 percent in the price of output by squeezing the rental price of capital (quantity effect). As a result, the price of this sector's output finally settles at a level which is 0.37 percent higher than that in the base year. The price increase projected by the TL model is less than those projected by the CES-FC and CD models because the cost effect on price is smaller in this model than in the other two models. The costs of labour and aggregate materials to the agriculture sector have increased relatively less in the TL model than in the other two (see Table 5.5). Since this sector spends about 77 percent of its total cost on these inputs the cost effect on the price of this sector's output has been less adverse in the TL model than in the other two.

The price of the products of the manufacturing sector is projected by the CES-FC model to increase by 0.53 percent. Increases in the costs of variable inputs to this sector lead to an increase in the average cost of production by 0.56 percent (cost effect). Output declines by 0.12 percent which leads to a fall of 0.03 percent in the price by squeezing the rental price of capital (quantity effect). As a result, the price of manufactures settles in this model at a level which is 0.53 percent higher than that in the base year.

The CD model projects that the price of the output of the manufacturing sector will increase by 0.56 percent. The per unit cost of production increases by 0.56 percent due to increases in the costs of variable inputs to this sector (cost effect). Output of this sector declines by 0.04 percent. The quantity effect on price in this model is quite insignificant because the supply curve of this sector generated by this model is highly elastic (see Table 5.4) and the output has decreased by only a very small percentage. As a result, the price of this sector's output settles at a level which is 0.56 percent higher than that in the base year. The price increase in the manufacturing sector projected by the CES-FC model is less than that projected by the CD model because the quantity effect on price is negative in the CES-FC model while it is zero in the CD model. Two factors are responsible for a stronger quantity effect on price in the CES-FC model than in the CD model. Firstly, output of the manufacturing sector declines more in the former model than in the latter (see Table 5.2). Secondly, the supply curve of the manufacturing sector is of steeper slope in the former than in the latter model. These two factors together lead to a larger squeeze on the rental price of capital and, consequently, to a larger reduction in price due to an output reduction in the CES-FC model than in the CD model.

Table 5.5: Percentage Changes in the Costs of Inputs to Different Sectors in Alternative CGE Models.

Sector	Percentage change in the cost of		
	labour	energy	material
	CES-FC model		
Agriculture,mining and construction	0.63	3.60	0.49
Manufacturing	0.63	2.07	0.47
Transport	0.63	4.40	0.56
Communications	0.63	1.98	0.55
Coal	0.63	1.63	0.54
Crude oil	0.63	5.97	0.50
Petroleum and coal products	0.63	7.59	0.59
Electricity	0.63	1.59	0.61
Gas utilities	0.63	6.76	0.60
	CD model		
Agriculture,mining and construction	0.62	2.92	0.51
Manufacturing	0.62	1.77	0.50
Transport	0.62	3.50	0.56
Communications	0.62	1.75	0.56
Coal	0.62	1.35	0.55
Crude oil	0.62	4.50	0.55
Petroleum and coal products	0.62	5.65	0.59
Electricity	0.62	1.40	0.61
Gas utilities	0.62	5.07	0.60
	TL model		
Agriculture,mining and construction	0.49	2.20	0.39
Manufacturing	0.49	1.63	0.38
Transport	0.49	2.39	0.43
Communications	0.49	1.77	0.43
Coal	0.49	1.56	0.42
Crude oil	0.49	4.98	0.39
Petroleum and coal products	0.49	5.89	0.45
Electricity	0.49	1.75	0.47
Gas utilities	0.49	5.14	0.45

The TL model projects that the price of the output of the manufacturing sector will increase by 0.44 percent. The average cost of production increases by 0.45 percent in this sector due to increases in the costs of variable inputs (cost effect). A decline of 0.07 percent in the output of this sector squeezes the rental price of capital and, consequently, leads to a fall of 0.01 percent in the price of output (quantity effect). The net result of both the quantity and cost effects is the 0.44 percent increase in the price of the output of the manufacturing sector in this model. The price of the output of this sector increases less in this model than in the CES-FC and CD models mainly because the cost effect on price is smaller in this model than in the other two models. The cost effect on the price of this sector is smaller in the TL model than in the other two models mainly because the costs of labour and aggregate materials, which constitute about 88 percent of this sector's total cost, have increased less in the TL model than in the other two models (see Table 5.5).

The CES-FC model projects that the price of the output of the transport sector will increase by 0.85 percent due to the increase in the price of imported crude oil. Increases in the costs of variable inputs lead to an increase of 0.88 percent in the price of this sector's output. Output of this sector declines by 0.19 percent in this model (see Table 5.2). This reduction in output leads to a 0.03 percent reduction in the price by squeezing the rental price of capital in this sector (quantity effect). The net result of both the quantity and cost effects on price is the 0.85 percent increase in the price of transport products.

The CD model projects that the price of this sector's output will increase by 0.81 percent. The per unit cost of production increases by 0.83 percent due to increases in the costs of variable inputs to this sector (cost effect). Output of this sector decreases by 0.21 percent which leads to a decrease in the unit cost of production by 0.02 percent by depressing the rental rate of capital (quantity effect). The net result of these two forces is the 0.81 percent increase in the price of output. The price increase projected by the CD model is smaller in magnitude than that projected by the CES-FC model because the cost effect on price is smaller in the former model. The main factor which has led to a smaller cost effect on price in the CD model than in the CES-FC model is the cost of energy to this sector which rises relatively less in the former model.

The TL model projects that the price of the output of the transport sector will increase by 0.55 percent. Increases in the costs of variable inputs to this sector are responsible for a 0.58 percent increase in price (cost effect). Output of this sector declines by 0.10 percent which leads to a fall of 0.03 percent in the price by forcing the rental rate of capital to decline in this sector (quantity effect). The equilibrium price ultimately settles at a level which is 0.55 percent higher than that in the base year. The price increase projected by the TL model for the transport goods is lower than those projected by the other two models. This is because the cost effect on price is smaller in the TL model than in the other two. The costs of all variable inputs—labour, energy and aggregate materials—to this sector have increased relatively less in this model than in the other two models (see Table 5.5). This factor has given rise to much less cost effect on the price of transport goods in this model than in the other two.

The price of the output of the communications sector is projected by the CES-FC model to increase by 0.61 percent. Increases in the costs of variable inputs to this sector are responsible for an increase of 0.63 percent in the price of this sector's output (cost effect). Output of this sector declines by 0.02 percent which leads to a 0.02 percent decrease in price by depressing the rental price of capital in this sector (quantity effect). The net result of these two effects is the 0.61 percent increase in the price of this sector's output.

The CD model also projects that the price of this sector's output will increase by 0.61 percent. Increases in the costs of variable inputs to this sector lead to an increase in price by 0.62 percent. Output of this sector declines by 0.02 percent which leads to a fall of 0.01 percent in price by squeezing the rental rate of capital (quantity effect). The net result of these two effects is the 0.61 percent increase in the price of this sector's output. The CES-FC model and the CD model have projected the same percentage increase in the price of communication products because the quantity and cost effects are almost the same in both models.

The TL model projects that the equilibrium price of this sector's output will increase by 0.49 percent. Increases in the costs of variable inputs to this sector cause the price to increase by 0.51 percent in this sector (cost effect). Output of this sector declines by 0.03 percent which forces the price to fall by 0.02 percent by depressing the rental price of capital (quantity effect). The net result of these two forces is the 0.49 percent increase in the price of this sector's output. The price of the output of the communications sector is projected to increase less in the TL model than in the other two models because the cost effect is smaller in this model than in the other two. The communications sector spends about 73 percent of its total cost on labour and aggregate materials. Since the costs of these inputs to this sector have increased relatively less in the TL model than in the other two models, the cost effect on price has been relatively less in the TL model than in the other two.

The price of the output of the coal sector is projected to increase by only 0.02 percent by the CES-FC model. Increases in the costs of variable inputs lead to an increase in the price of coal by 0.71 percent (cost effect). Output of this sector declines by 0.35 percent which forces the price to fall by 0.69 percent by depressing the rental price of capital (quantity effect). The net result of these two forces is the 0.02 percent increase in the price as projected by the CES-FC model.

The CD model projects that the price of the output of the coal sector will increase by 0.08 percent. Increases in the costs of variable inputs are responsible for a 0.72 percent increase in the price of coal (cost effect). Output of this sector declines by 0.98 percent which causes price to fall by 0.64 percent by depressing the rental price of capital (quantity effect). The increase in price due to cost effect is thus partially offset by the negative quantity effect. As a result, the price of coal increases by 0.08 percent only. The price of coal increases more in the CD model than in the CES-FC model mainly because the supply curve of coal generated in the former model is more elastic than that generated in the latter model. Because of this, a smaller reduction in output has led to a larger negative quantity effect on price in the CES-FC model.

The TL model projects that the price of coal will increase by 0.17 percent. Increases in the costs of variable inputs lead to an increase in the price of coal by 0.82 percent (cost effect). Output of coal declines by 2.33 percent in the TL model which leads to a fall of 0.65 percent in the price by forcing the rental price of capital to decline (quantity effect). The net result of these two effects is the 0.17 percent increase in the equilibrium price of coal. The price of coal increases more in the TL model than in the CES-FC model because the supply curve of coal generated in the TL model is more elastic than that generated in the CES-FC model. As a result, a 2.33 percent reduction in the output of coal has produced a smaller (negative) quantity effect on price in the TL model than a 0.35 percent reduction in output has produced in the CES-FC model. Secondly, the cost effect on the price of coal is larger in the former model than in the latter. Although the costs of all variable inputs to this sector have increased less in the TL model than in the CES-FC model, it is the coefficient of the energy price variable in average cost function which has led to a larger cost effect on price in the former model than in the latter. This coefficient is found to be more than three times larger in the TL model than that in the CES-FC model thus giving rise to a larger cost effect in the former model than in the latter. The price of coal increases more in the TL model than in the CD model, firstly, because energy cost to the coal sector increases more in the former model than in the latter. Secondly, in the TL model, the coefficient of the energy price variable in the average cost function is twice as large as that in the CD model. These two factors jointly have led to a larger cost effect on price in the TL model than in the CD model.

As can be seen from Table 5.3, the price of coal products has increased the least of all in all three models. This sector heavily depends on the export market for the sale of its output where it faces an almost perfectly elastic demand curve. Consequently, it is able to pass on little of the increase in its cost to foreign buyers. Any increase in cost squeezes output and the rental price of capital. Although agriculture also depends on foreign markets its dependence is not as severe as that of coal. It exports only 16 percent of its output in contrast to coal which exports about 69 percent of its output. Moreover, agriculture faces a much less elastic foreign demand curve. Therefore, it is in a somewhat better position to pass increases in its cost of production on foreign buyers. That is why the output of the agriculture sector has been less affected and the price of its output has increased more in comparison to coal.

The price of the output of the crude oil sector is projected by the CES-FC model to increase by 5.81 percent. Increases in the costs of variable inputs to this sector have led to an increase in the unit cost of production of this sector by 0.81 percent (cost effect). As has been seen in Subsection 5.2.2, the demand for domestic crude increases by 0.30 percent in this model. This increase in the output of domestic crude forces the price to increase by 5 percent by increasing the rental price of capital (quantity effect). The net result of these two forces—quantity and cost effects—is the 5.81 percent increase in the price of domestic crude oil. The increase in the price of domestic crude has been the largest of all sectors in the CES-FC model except that of petroleum and coal products. This has happened for two reasons: first, the supply curve of domestic crude is the least elastic to price; and second, while demands for the outputs of all other sectors have decreased, demand for the output of crude oil has increased. These two factors jointly have led to a large, positive quantity effect on the price of crude oil in contrast to negative quantity effects on the prices of other products. The price of the output of the petroleum and coal products sector has increased more than that of the crude oil sector because the effect of the increased input prices in raising the price of the petroleum and coal products is stronger than the effect of the increased output in raising the price of crude oil. While an increase of 0.30 percent in the output of domestic crude has increased its price by 5 percent, increases in the costs of variable inputs to the petroleum and coal products sector have increased the price of petroleum and coal products by 6.19 percent.

The CD model projects that the price of domestic crude oil will increase by 1.03 percent. Increases in the costs of variable inputs to the crude oil sector give rise to an increase in the price of crude by 1.23 percent. But the output of domestic crude is projected to decline, in contrast to both the CES-FC and TL models, by 0.09 percent. This decrease in the output of crude oil forces the price of crude to fall by 0.20 percent by depressing the rental price of capital. The net result of these two forces is the increase of 1.03 percent in the price of crude. The price of domestic crude has been projected to increase less in the CD model than in the CES-FC model because the output of crude has been projected to decline in the former model while it has been projected to increase in the latter. In other words, the price of crude increases more in the CES-FC model than in the CD model because both quantity and cost effects increase the price of crude in the former model while in the latter the quantity effect offsets the price increase caused by the cost effect.

The TL model projects that the price of domestic crude will increase by 2.23 percent. Increases in the costs of variable inputs lead to an increase in the average cost of production of 0.62 percent (cost effect). In the TL model, the output of domestic crude is projected to increase by 0.79 percent which forces the price of domestic crude to increase by 1.61 percent (quantity effect). The net result of these two forces is the 2.23 percent increase in the price of crude as projected by the TL model. The price of domestic crude is projected to increase less in the TL model than in the CES-FC model. Two factors are responsible. First, the supply curve of domestic crude generated in the TL model is less inelastic to price than that generated in the CES-FC model. As a result, a 0.79 percent increase in the output of crude has been achieved with a lower price increase in the TL model than a 0.30 percent increase in output has been achieved in the CES-FC model. Second, the costs of variable inputs to this sector have increased relatively less in the TL model than in the CES-FC model thus giving rise to smaller cost effect on price in the former model. The projected price increase for domestic crude is higher in the TL model than in the CD model mainly because the projected increase in output in the TL model has caused price to rise while the projected decrease in output in the CD model has caused price to decrease.

The CES-FC model projects that the price of the output of the petroleum and coal products sector will increase by 5.89 percent. Increases in the costs of variable inputs to this sector lead to an increase of 6.19 percent in the per unit cost of production of this sector (cost effect). Output of this sector declines by 2.23 percent which forces the price to fall by 0.30 percent by squeezing the rental price of capital in this sector (quantity effect). The net result of both the quantity and cost effects on price is the 5.89 percent increase in the price of petroleum and coal products. The price of the petroleum and coal products has increased more than the price of other sectors. This is because increases in the prices of variable inputs to this sector have led to the largest price increase in this sector than in other sectors. The petroleum and coal products sector incurs about 67 percent of its total cost on effective crude oil. Since the price of effective crude oil increases the most in the present simulations, the average cost of production of this sector increases more than those of other sectors in which crude oil constitutes only a smaller part of the total cost.

The CD model projects that the price of the petroleum and coal products will increase by 4.65 percent. Increases in the costs of variable inputs to the petroleum and coal products sector are responsible for a 4.79 percent increase in price (cost effect). Output of this sector declines by 3.65 percent which causes price to fall by 0.14 percent by depressing the rental price of capital (quantity effect). The net result of these two forces is the 4.65 percent increase in the price of the domestic petroleum and coal products. As in the CES-FC model, the price of this sector's output increases by more than other sector's prices because this sector is highly crude oil intensive and the price of crude oil increases the most in the present simulations. The price of the petroleum and coal products is projected to increase less in the CD model than in the CES-FC model because increases in the costs of variable inputs to this sector have led to a smaller cost effect on price in this model than in the latter. The petroleum and coal products sector is highly energy intensive in its production; about 80 percent of its total cost is incurred for energy. Since the cost of energy to this sector increases relatively less in the CD model than in the CES-FC model (see Table 5.5), the cost effect on the price of petroleum and coal products is smaller in the former model than in the latter.

The TL model projects that the price of the petroleum and coal products will increase by 3.07 percent. Increases in the costs of variable inputs to this sector have increased the price of petroleum and coal products by 3.68 percent (cost effect). Output of this sector declines by 2.48 percent which leads to a decrease in the price of petroleum and coal products by 0.61 percent by squeezing the rental price of capital in this sector (quantity effect). The net result of these two forces is the 3.07 percent increase in the price of the domestic petroleum and coal products. As is seen in other two models, the price of the domestic petroleum and coal products increases more than other prices in the TL model as well. However, the price of the output of this sector increases less in the TL model than in the other two models. Two factors are mainly responsible. First, the supply curve of petroleum and coal products is less elastic in the TL model than in the other two. This factor has been responsible for a larger decrease in price through the quantity effect in this model. Second, increases in the costs of variable inputs to this sector have given rise to smaller increase in price in this model.

The price of electricity is projected to increase by 0.84 percent in the CES-FC model. Increases in the costs of variable inputs to the electricity sector are responsible for an increase of 1.01 percent in the price (cost effect). Output of electricity declines by 0.15 percent in this model which causes the price to fall by 0.17 percent by depressing the rental price of capital in this sector (quantity effect). The net result of these two forces is the 0.84 percent increase in the price of electricity.

The CD model projects that the price of electricity will increase by 0.90 percent. Increases in the costs of variable inputs lead to an increase of 1.04 percent in the price of electricity in this model (cost effect). Output of electricity declines by 0.37 percent which causes the price to fall by 0.14 percent by squeezing the rental price of capital (quantity effect). The net result of these two forces is the 0.90 percent increase in the price of electricity. The price of electricity increases more in the CD model than in the CES-FC model for two reasons. First, the cost effect raises the price of electricity sector more in the CD model than in the CES-FC model. Second, a flatter supply curve of electricity in the CD model than in the CES-FC model has led to a smaller, negative quantity effect on price in the former model even though output of electricity has decreased more in the former model.

The TL model projects that the price of electricity will increase by 1.52 percent. Increases in the costs of variable inputs to the electricity sector cause the price to rise by 1.40 percent (cost effect). Output of electricity increases by 0.06 percent in this model which leads to an increase of 0.12 percent in the price of electricity by increasing the rental price of capital (quantity effect). The net result of these two forces is the 1.52 percent increase in the price of electricity in this model. The price of electricity increases more in the TL model than in the other two models. The following two factors are responsible for this. First, increases in the costs of variable inputs have led to a larger increase in the price of electricity in the TL model. The electricity sector is energy intensive in its production. Energy cost to this sector rises more in the TL model than in the other two (see Table 5.5). This fact and the fact that the energy price has a larger coefficient in the average cost function of this sector in the TL model than in other two models have led to a larger cost effect on price in the TL model than in the other two models. Second, the output of electricity increases in the TL model but decreases in the other two models. As a result, the quantity effect has increased the price of electricity in the TL model while it has decreased the price in the other two models. These two factors jointly have given rise to a larger price increase for electricity in the TL model than in the other two models.

The CES-FC model projects that the price of gas utilities will increase by 1.49 percent due to the oil price shock. Increases in the costs of variable inputs to this sector cause the per unit cost of gas to rise by 2.06 percent (cost effect). Output of gas utilities declines by 0.50 percent which leads to a fall of 0.57 percent in the price of gas by squeezing the rental price of capital (quantity effect). The net result of these two forces is the 1.49 percent increase in the price of gas utilities.

The CD model projects that the price of gas utilities will increase by 1.64 percent. Increases in the costs of variable inputs to the gas utilities sector lead to an increase of 2.07 percent in price (cost effect). Output of gas utilities declines by 1.06 percent which causes the price to fall by 0.43 percent (quantity effect). The net result of these two forces is the 1.64 percent increase in price. Price increases more in the CD model than in the CES-FC model mainly because the supply curve of the gas utilities sector generated by the former model is more elastic to price than that generated by the latter (see Table 5.4). As a result, a 1.06 percent reduction in output leads to a smaller (negative) quantity effect on price in the CD model than a 0.50 percent reduction in output does in the CES-FC model.

The TL model projects that the price of gas utilities will increase by 1.22

percent. Increases in the costs of variable inputs cause the the price of gas utilities to rise by 1.22 percent (cost effect). The quantity effect on the price of gas utilities is zero in this model since output of this sector is not affected by the oil price shock. The price of gas utilities increases less in the TL model than in the other two models because increases in the costs of variable inputs lead to a smaller price increase in the TL model than in the other two models.

5.2.4 Effects on sectoral employments

The effects of a 10 percent increase in the world price of imported crude oil on sectoral employments are shown in Table 5.6. The results presented in this table suggest that sectoral employments, like sectoral outputs and output prices, are quite sensitive to variations in the flexibility of the production functions. This result was expected. The three CGE models differ from one another regarding the number of inputs among which substitutions are allowed and also regarding the degree of substitution among them. This fact has given rise to different specifications for the demand function for labour, as well as for other inputs used in current production, in different models. An examination of the labour demand equations in the three CGE models will explain why these models provide different projections for changes in employment in different sectors in response to the oil price shock. The demand equation for labour, in percentage change form, for sector j is specified as

$$l_j^{(1)} = x_{(j1)}^0 - \sigma_j(p_L^{(1)} - S_{Lj}'^{(1)} p_L^{(1)} - S_{Kj}'^{(1)} p_{Kj}^{(1)}), \quad j = 1, 2, \ldots, 9, \qquad (5.27)$$

in the CES-FC model, where $l_j^{(1)}$ is the percentage change in the employment of labour in sector j and other variables and coefficients are as defined before. Substituting equations (5.16) and (5.17) into (5.27) and reorganising one can re-write equation (5.27) as

$$l_j^{(1)} = x_{(j1)}^0 + (\sigma_j S_{Kj}^{(1)} / S_{Fj}^{(1)})(p_{Kj}^{(1)} - p_L^{(1)}), \quad j = 1, 2, \ldots, 9. \qquad (5.28)$$

Table 5.6: Effects of a 10 Percent Increase in the World Price of Imported Crude Oil on Sectoral Employments.

Sector	Percentage change in employment		
	CES-FC model	CD model	TL model
Agriculture,mining & construction	-0.41	-0.39	-0.22
Manufacturing	-0.17	-0.10	-0.20
Transport	-0.22	-0.02	-0.15
Communications	-0.04	-0.03	0.00
Coal	-0.87	-1.53	-3.90
Crude oil	3.58	0.31	9.75
Petroleum and coal products	-4.08	0.37	-14.38
Electricity	-0.32	-0.09	0.21
Gas utilities	-0.98	-0.04	4.97

The first-term on the right-hand side of this equation measures the output effect on employment, that is, the change in employment induced by output change if other variables are held constant. The second-term on the right-hand side of this equation measures the substitution effect on employment. Note that this substitution effect on employment depends on the relative percentage changes in the rental price of capital and the wage rate, the degree of substitution between labour and capital, which is assumed to be 0.5 for all sectors in this model, and the share of capital in the total primary factor cost of sector j.

An equation like (5.28) but different in structure can also be obtained for the CD and TL models. The counterpart of equation (5.28) in the CD model can be written as

$$\begin{aligned} l_j^{(1)} &= x_{(j1)}^0 + S_{Kj}^{(1)}(p_{Kj}^{(1)} - p_L^{(1)}) + S_{Ej}^{(1)}(p_{Ej}^{(1)} - p_L^{(1)}) + S_{Mj}^{(1)}(p_{Mj}^{(1)} - p_L^{(1)}), \\ & \quad j = 1, 2, \ldots, 9, \qquad (5.29) \end{aligned}$$

where the variables and coefficients are as defined before. The first term on the right-hand side of equation (5.29) measures, as in (5.28), the output effect on employment; the second term measures the effect on employment due to substitution between labour and capital; the third term measures the effect on employment due to substitution between energy and labour; and the last term measures the effect on employment due to substitution between labour and aggregate materials. The overall substitution effect on labour employment is measured by the last three terms on the right-hand side of equation (5.29). Note that the degree of substitution between inputs is unity in the CD model. So this parameter is implicit in equation (5.29).

The counterpart of equation (5.28) in the TL model can be written as

$$\begin{aligned} l_j^{(1)} &= x_{(j1)}^0 + S_{LK,j}^{*(1)}(p_{Kj}^{(1)} - p_L^{(1)}) + S_{LE,j}^{*(1)}(p_{Ej}^{(1)} - p_L^{(1)}) + \\ & \quad S_{LM,j}^{*(1)}(p_{Mj}^{(1)} - p_L^{(1)}), \;\; j = 1,2,\ldots,9, \end{aligned} \tag{5.30}$$

where

$$S_{Lr,j}^{*(1)} = S_{rj}^{(1)} + (\beta_{Lr,j}/S_{Lj}^{(1)}), \;\; r = K, E, M.$$

The variables and coefficients appearing in (5.30) have been defined before. Equation (5.30) has the same interpretation as equation (5.29). Note that the degrees of substitution in input pairs in this model are reflected by the $\beta_{Lr,j}$ parameters. Connections between these parameters and Allen partial elasticities are shown in Chapter 4, Section 4.3.

Equations (5.28), (5.29) and (5.30) embody the assumptions made regarding substitutability among inputs in current production in the three alternative CGE models and so provide an explanation why the alternative models will make different projections for sectoral employment changes. A comparison of these equations suggests that a given percentage change in a sector's output, *ceteris paribus*, will result in the same percentage change in employment in all three models. But given the fact that these models differ regarding projections for output changes, it is expected that they will project different output effects on employment. These equations also suggest that these three models will also differ regarding the overall substitution effects on employment due to the following. Firstly, the CES-FC model considers only the effect of substitution between labour and capital in measuring the overall substitution effect on employment. But the other two models also take account of effects on employment of substitutions between labour and energy, and between labour and aggregate materials in addition to the effect of substitution between labour and capital. Secondly, these models differ from one another regarding the ease of substitution among inputs which is seen to affect the labour demand. Thirdly, the models will differ regarding changes in the prices of inputs since they differ regarding changes in sectoral outputs and output prices. It can be shown that changes in sectoral outputs and output prices affect the prices of inputs. Finally, different coefficients associated with the substitution terms in equations (5.28)–(5.30) will also lead to different substitution effects on employment in different CGE models.

The discussion above conclusively suggests that the alternative CGE models will lead to different projections for sectoral employment changes due to the oil price shock. Their differences in projecting employment changes arise because of their differences in measuring the output and substitution effects on employment. Therefore, the differences among the models in projecting sectoral employment changes can be explained in terms of their differences in measuring output and substitution effects on employment in different sectors.

It should be noted here that the sectoral employment changes reported in Table 5.6 are the results of both output and substitution effects on employments. Since a given percentage change in output leads to the same percentage change in employment in the present simulations, a result of the assumption of constant returns to scale, the figures reported in Table 5.2 can be considered as employment effects of output changes. The substitution effects on employment can be calculated by simply subtracting the figures in Table 5.2 from the corresponding figures in Table 5.6. The substitution effects on employment are reported in Table 5.7.

A comparison between the figures of sectoral employment changes and output changes in the CES-FC model (see Tables 5.6 and 5.2) suggests that employment changes have the same signs as the output changes and are larger in magnitudes than output changes. This is because both output and substitution effects work in the same direction in influencing the demand for labour in this model (see Tables 5.2 and Table 5.7). This feature of the model is a result of the assumption that only labour and capital are substitutable in current production and the assumption that capital stock in a sector remains constant in the short run. Given these assumptions, an increase (decrease) in the output of a sector can only be achieved by increasing (decreasing) the level of employment of labour. Consider the crude oil sector the output of which increases by 0.30 percent in the CES-FC model. This increase in output increases the demands for both capital and labour by 0.30 percent (output effect) in this sector. Since capital stock is constant, the 0.30 percent increase in the demand for capital must be met by using more labour, i.e., by substituting labour for capital (substitution effect). The fact that both output and substitution effects work in the same direction to influence labour demand in the CES-FC model is implicit in equations (5.28) and (5.18). A given percentage decrease in the output of a sector leads to the same percentage decrease in employment due to the output effect. This effect is captured by the first term on the right-hand side of equation (5.28). But this decrease in output also makes capital relatively cheaper than labour (see equation (5.18)). As a result, capital is substituted for labour thus giving rise to negative substitution effect on employment of labour. This effect is measured by the second term on the right-hand side of equation (5.28). Since both output and substitution effects are negative the overall effect on employment will be more negative than the negative output change. Similarly, it could be shown using equations (5.28) and (5.18) that a positive percentage change in the output of a sector would lead to a larger positive percentage change in employment in the CES-FC model.

Table 5.7: Substitution Effect on Employment in Different Sectors as Projected by the Alternative CGE Models.

Sector	Percentage change in employment due to substitution		
	CES-FC model	CD model	TL model
Agriculture, mining and construction	-0.16	-0.09	-0.04
Manufacturing	-0.05	-0.06	-0.13
Transport	-0.03	0.19	-0.05
Communications	-0.02	-0.01	0.03
Coal	-0.52	-0.55	-1.57
Crude oil	3.28	0.40	8.96
Petroleum and coal products	-1.85	4.02	-11.90
Electricity	-0.17	0.28	0.15
Gas utilities	-0.48	1.02	4.97

Equation (5.28) in association with equation (5.18) also suggests that the larger the capital intensity of a sector the larger will be the substitution effect on employment initiated by a given change in output. For example, consider the electricity and transport sectors. The output of the electricity sector declines less than that of the transport sector in the CES-FC model (see Table 5.2) but employment in the former sector declines more than in the latter (see Table 5.6). This is because the production technology of the electricity sector is more capital intensive than that of the transport sector. The electricity sector spends about 27 percent of its total cost on capital while the transport sector spends only about 7 percent of its total cost on capital. As a result, a 0.15 percent decrease in output in electricity sector leads to a larger decrease in employment in this sector *via* substitution effect than a 0.19 percent decrease in output does in the transport sector (see Table 5.7).

While the substitution effects on employment always have the same signs as the output effects in the CES-FC model, it is not expected that this will be the case in the CD or the TL models. In the latter models, the overall substitution effect on employment depends on the directions and strengths of substitutions between labour and capital, between labour and energy, and between labour and aggregate materials unlike in the CES-FC model where substitution effect on employment depends solely on the substitution between labour and capital. So it is not as simple in these models as in the CES-FC model to relate the direction of the substitution effect on employment to the direction of the output effect. It is possible for output and substitution effects in these models to work in opposite directions in influencing the demand for labour in a sector. However, if output and substitution effects on employment are both positive or negative, the percentage change in employment will be larger than the percentage change in output in absolute value. If the output and substitution effects have opposite signs, then the direction and magnitude of employment change will depend on their relative strengths.

It can be seen from Tables 5.2 and 5.7 that the output and substitution effects on employment are both negative in agriculture, manufacturing, communications and coal in the CD model. As a result, the percentage decrease in employment is larger than the percentage decrease in output in these sectors. In transport, electricity and gas utilities the substitution effects on employment are positive while the output effects are negative and stronger than the substitution effects. As a result, employment in these sectors, in the CD model, decreases but by a smaller percentage points than output. In the other sectors, crude oil, and petroleum and coal products, the substitution effects on employment are positive and stronger than the negative output effects on employment. As a result, employment in these sectors increases even if output declines.

The sectoral employment changes projected by the TL model can also be explained in terms of the output and substitution effects on employment. Employment of labour decreases in agriculture, manufacturing, transport, coal, and petroleum and coal products by a larger percentage than output because both the output and substitution effects on employment are negative in these sectors. In the communications sector, the substitution effect on employment is positive and just balances the negative output effect on employment. As a result, employment in this sector does not change. Employment of labour increases in crude oil, electricity and gas utilities by a larger percentage than output because both the output and substitution effects are positive.

The output and substitution effects on employment, reported in Tables 5.2 and 5.7 respectively, can also be used to explain the differences between the models in projecting changes in employment in different sectors. The CES-FC model projects a larger percentage decrease in employment in the agriculture sector than the CD model (see Table 5.6) simply because the substitution effect is more adverse to employment in the CES-FC model than in the CD model (see Table 5.7). The projected decrease in employment in this sector is smaller in the TL model than in the other two models because both the output and substitution effects on employment are of smaller magnitudes in this model than in the other two (see Tables 5.2 and 5.7).

Employment of labour is projected to decrease in the manufacturing sector by all three models. However, the TL model projects the largest percentage decrease in employment in this sector. The percentage decrease in employment is larger in the TL model than in the CD model because both the output and substitution effects on employment are more adverse in this model than in the latter (see Tables 5.2 and 5.7). Employment in this sector declines more in the TL model than in the CES-FC model because the substitution effect has led to a larger reduction in employment in the former model than in the latter. The CD model projects a smaller decline in employment in the manufacturing sector than the CES-FC model simply because the output effect reduces employment less in this model than in the latter.

The transport sector presents an interesting case in the sense that although output of this sector declines the most in the CD model (see Table 5.2) employment in this sector declines the least in this model (see Table 5.6).

This is because the substitution effect on employment is positive in this model for the transport sector while it is negative in the other two models—CES-FC and TL (see Table 5.7). Thus the substitution effect is reinforcing the adverse output effect in the CES-FC and TL models in decreasing employment in this sector but counteracting the adverse output effect on employment in the CD model. The substitution effect has been positive in the CD model because labour has been substituted for energy in this sector and this substitution effect in favour of labour has been stronger than unfavourable effects on employment due to substitutions between labour and aggregate materials and between labour and capital.

Employment in the communications sector is not affected by the oil price shock in the TL model (see Table 5.6) although output of this sector decreases slightly in this model. This is because the substitution effect is favourable to employment in this sector in the TL model and is as strong as the adverse output effect on employment (see Tables 5.2 and 5.7) thus resulting in no change in employment. The CES-FC model and the CD model project almost the same percentage decrease in employment as they project roughly the same percentage decrease in the output of the communications sector.

All three models are in consensus regarding the signs of the output and substitution effects on employment in the coal sector although they differ regarding their magnitudes (see Tables 5.2 and 5.7). The TL model projects the largest percentage decrease in employment in the coal sector because both the output and substitution effects on employment are the most negative of all in this model. The CD model projects a larger decline in employment in this sector than the CES-FC model mainly because output declines more in this model.

The CD model provides another interesting result regarding output and substitution effects on employment. In the CD model, output of the crude oil sector is projected to decline by 0.09 percent but employment is projected to increase by 0.31 percent. This result suggests not only a positive substitution effect on employment in this sector but also a stronger substitution effect than the adverse output effect on employment. Theoretically, this result is quite plausible since the output and substitution effects can work in opposite directions in influencing the demand for labour and the substitution effect can be stronger than the output effect. In the CES-FC model and the TL model, the substitution effects on employment in the crude oil sector have also turned out to be positive. These substitution effects join force with the positive output effects in these models to augment employment in the crude oil sector. Employment in the crude oil sector increases more in the CES-FC and TL models than in the CD model because both the output and substitution effects are positive in these models but they are of opposite signs in the CD model. The TL model projects a larger increase in employment in the crude oil sector than the CES-FC model because both output and substitution effects on employment are stronger in this model than in the latter. Further analysis of the substitution effects on employment in this sector in the TL and CES-FC models suggests that the greater ease of substitution between labour and capital in the former model than in the latter is responsible for a larger substitution effect in favour of labour in the former model than in the latter. The elasticity of substitution between labour and capital is 5.74 in the TL model while it is 0.5 in the CES-FC model.

Output of the petroleum and coal products sector declines and, as a result, there is an unfavourable output effect on employment in all three models. But substitution effects on this sector's employment are not of the same sign and magnitudes in all three models. While substitution effect on employment is negative in both the CES-FC and TL models it turns out to be positive in the CD model even though output of the sector declines the most in this model (see Tables 5.2 and 5.7). Considering the signs and magnitudes of output changes of the petroleum and coal products sector in all three models and the signs of substitution effects on employment in the CES-FC and CD models, the positive substitution effect suggested for employment by the CD model is quite unacceptable. Moreover, this result of the CD model has the implication that the petroleum and coal products sector is producing petroleum and coal products out of labour which is again hardly acceptable. What this result indicates is that the Cobb-Douglas production function is not suitable to describe the production technology of the petroleum and coal products sector. It should be noted here that a discussion in Subsection 5.2.3 of the short-run supply elasticities of petroleum and coal products implied by the alternative CGE models also led to the same conclusion for the CD model.

Employment of labour in the petroleum and coal products sector declines more in the TL model than in the CES-FC model because, firstly, output of this sector declines more and thus leads to a larger decline in employment (output effect) in the former model than in the latter. Secondly, a larger output decline in association with a less elastic supply curve for the petroleum and coal products squeezes the rental rate of capital more in the TL model than in the CES-FC model. This fact and the fact that the degree of substitution between labour and capital in this sector is higher in the TL model than in the CES-FC model[8] have led to a larger substitution effect against labour in the former model than in the latter. These two factors—output and substitution effects on employment—have thus been responsible for a larger reduction in employment in the petroleum and coal products sector in the TL model than in the CES-FC model.

Employment in the electricity sector is projected to increase by the TL model while both the CES-FC and CD models project that employment will decrease. In the TL model, both output and substitution effects have led to increases in employment in this sector. Although substitution effect on employment of labour in the electricity sector is positive in the CD model it

[8]The elasticity of substitution between labour and capital in the petroleum and coal products sector is 10.66 in the TL model but it is only 0.5 in the CES-FC model.

has been outweighed by the adverse output effect on employment. As a result, employment in this sector declines in this model. In the CES-FC model, both output and substitution effects on employment are negative and thus result in a larger percentage decrease in employment in this model than in the CD model for the electricity sector.

Although both the CES-FC and CD models project a decrease in the employment of labour in the gas utilities sector, the TL model projects an increase in employment in this sector (see Table 5.6). Output of the gas utilities sector does not change in the TL model. So only substitution effect is responsible for the 4.97 percent increase in the employment of labour in this sector in the TL model. Further analysis of this substitution effect reveals that a high degree of substitution between labour and energy ($\sigma_{LE} = 4.60$) and a fair degree of complementarity between labour and aggregate materials ($\sigma_{LM} = -1.20$) in this sector are responsible for this substitution effect in favour of labour in the TL model. Substitution effect on employment in this sector is also positive in the CD model. But the output effect on employment is negative and stronger than the positive substitution effect in this model. As a result, employment slightly declines in this model. In the CES-FC model, both output and substitution effects work in the direction of decreasing employment in the gas utilities sector. As a result, employment in the gas utilities sector declines more in this model than in the CD model.

5.3 Conclusions

From the discussion above it becomes evident that the overall performance of the Australian economy will be affected moderately by an oil price shock equivalent to a 10 percent increase in the price of imported crude oil. Aggregate employment and GDP decline and the balance of trade of the economy becomes unfavourable. The 10 percent increase in the price of imported crude leads to an increase, both directly and indirectly, in the costs of production of all domestic goods. As a result, exporting sectors become subjected to a price-cost squeeze in the export markets and the import-competing sectors face increased competition from imports in the domestic markets. Activity levels of these sectors decline and so do those of other sectors which are closely related to these sectors.

A comparison of the effects of the oil price shock under alternative CGE models suggests that these effects are sensitive to variations in the flexibility of production technology. These models are in consensus regarding the direction of change in macroeconomic variables but they differ in magnitudes. However, as to disaggregated variables such as sectoral outputs, sectoral employments, etc., these models differ from one another not only in magnitude of change but also in direction of change. Variation in the specification of production functions for current production leads to different implications of the oil price shock for the endogenous variables in alternative CGE models by affecting demand and supply sides of all factor and product markets. A conclusion which can be drawn from the present simulations of oil price shock is that different CGE models incorporating production functions of different flexibility for current production will lead to different results for any type of simulation. So in constructing CGE models for energy analysis or economic analyses in general one must be careful in specifying production submodels to describe production technologies in different sectors. Model builders should be guided by both economic theory and empirical experience. The present author is, however, of the opinion that a highly flexible and general production function like translog function should be used which allows interfactor as well as interfuel substitution in production. Energy studies on substitution (e.g., Berndt and Wood 1975, Hudson and Jorgenson 1978, Truong 1985, etc.) have suggested that energy and capital are complements; and labour and energy are substitutes in the production processes of the manufacturing sector. Complementarity between capital and energy is reported also for agriculture and transport sectors by Hudson and Jorgenson (1978). These findings should be accommodated in CGE energy models, otherwise the predictions made by a model will not truely reflect effects of a policy change on an economy.

Another finding of the present study is that Cobb-Douglas type of production function is not suitable to describe current production technologies in all sectors of an economy. This type of production functions suffers from restrictive assumptions regarding substitution between inputs which lead to implausible projections for substitution effect on input demands in some sectors.

Chapter 6

SUMMARY AND CONCLUSIONS

This chapter is organised into two sections. In Section 6.1, the present work is summarised and major conclusions are drawn. In Section 6.2, limitations of the present models regarding their structures and data base are pointed out. Further research should be directed towards removing these limitations.

6.1 Summary and Conclusions of the Study

The present study was motivated by a desire to investigate the suitability of the ORANI model of the Australian economy in simulating the effects of energy crises such as sudden change in the world price of oil, embargo on oil exports by the oil producing countries, etc. or energy policy changes such as introduction of import parity pricing on the economy. The hypothesis of the present study was that this model would be biased in simulating the effects of such energy crises or policy changes since it only allows substitution between labour and capital in current production. While it has been the feature of most large-scale energy models to allow interfuel substitution, the ORANI model lacks such feature. It was conjectured that the ORANI model should be modified to incorporate this feature if it is to be applied to examine the effects on the economy of energy related issues. To determine how important it is to incorporate this feature in the ORANI model, three alternative models have been constructed and applied to simulate the effects on the Australian economy of a 10 percent increase in the world price of imported crude oil.

The three models developed in the present study are all general equilibrium models and thus capture energy-economy interactions in the simulations. However, these models differ from one another regarding flexibilities of production technologies assumed for current production of different sectors of the economy. In other aspects such as modelling production technologies of capital goods, allowing substitution between domestic and foreign goods, modelling consumers and government preferences, etc. there is no difference between the models. The first model called the CES-FC (CES-Fixed Coefficient) model is similar to the ORANI model in that it assumes substitutability only between labour and capital and fixes input-output relationships for intermediate inputs including fuels. Moreover, as in the ORANI model, this model assumes the degree of substitution between labour and capital to be 0.5 for all sectors of the economy. The second model called the CD (Cobb-Douglas) model allows substitution, in contrast to the first model, between labour, capital, energy and aggregate materials, also between individual fuels and between individual material inputs. The degree of substitution between factors or inputs is unity in this model which is a result of using Cobb-Douglas type of functions to represent the production technologies of different sectors involved in producing current goods. The third model called the TL (Translog) model is similar to the CD model in allowing substitution between factors and inputs. But this model assumes greater flexibility of the production technologies than the CD model. Unlike in the latter model, a pair of inputs are allowed to be either substitutes or complements to each other. Moreover, the degree of substitution or complementarity between factors or inputs can vary across input pairs in this model.

Although these models can be used for a wide range of simulations, in the present study one in particular has been demonstrated; a simulation of the effect on the Australian economy of a 10 percent increase in the world price of imported crude oil. All three models suggest that the overall performance of the economy will be adversely affected by the oil price shock. Aggregate employment, balance of trade and GDP of the economy were found to suffer due to the oil price shock in all three models. However, these macroeconomic effects were modest comparing to the more substantial effects of the oil price shock on sectoral output, output prices and employment. Moreover, it was observed that not all sectors were affected uniformly by the oil price shock. Output and employment were found to be affected more in some sectors than in others while some sectors were found to gain from this particular price shock. In general, output and employment in the exporting sectors and the crude oil intensive sectors suffered the most. The increase in the price of imported oil increased the consumer price index and money wages and thus imposed a cost-price squeeze on exports, agriculture and coal, and sectors facing significant import competition. Such a sector is petroleum and coal products. This sector was also shown to be adversely affected by being highly crude oil intensive in its production. The only sector which was found to gain from the oil price shock is the crude oil sector. This sector gained mainly because domestic users substituted relatively cheaper domestic crude for the dearer imported crude.

A comparison of the effects of the oil price shock implied by the alternative CGE models suggests that these effects are sensitive to variations in the flexibility of production functions. Although macroeconomic effects were found to be only moderately sensitive to these variations, the sensitivity of sectoral effects was found to be substantial. The models were found to differ from one another not only regarding the magnitudes of the sectoral effects of the oil price shock but also regarding the signs of these effects. Variation in the flexibility of production functions regarding substitution and ease of substitution between factors or inputs were found to affect the performances of the sectors in many ways. In general, variations in the specifications of production functions affect both demand and supply sides of all factor and product markets and thus give rise to different implications of the oil price shock for the endogenous variables in alternative models. This finding of sensitivity of both macroeconomic and sectoral effects to variation in the flexibility of production functions supports the hypothesis of the present study that the ORANI model should be modified to incorporate interfuel substitution as well as substitutions among factors and material inputs in order to apply this model to energy analyses. If the actual production technologies of different sectors for current production are as flexible as are assumed in the TL model, then the use of the CES-FC model or the ORANI model to simulate the effects of a 10 percent increase in the world price of imported crude oil on the economy will provide biased projections for these effects. This conclusion is quite general.

Another conclusion which may be drawn from the present study is that one should be very careful in specifying production functions in general equilibrium models if one expects that relative prices of inputs, both intermediate and primary, will undergo significant changes in the simulations planned to be conducted with the models. In such cases, instead of choosing arbitrarily a particular type of production function one should base choice on both economic theory and facts. Energy modellers should take note of the findings of energy studies. For example, some energy studies on substitution (e.g., Truong 1985, Berndt and Wood 1975, Hudson and Jorgenson 1974, etc.) have suggested that energy and capital are complements; and labour and energy are substitutes in the production processes of the manufacturing sector. Complementarity between capital and energy has been reported also for agriculture and transport sectors by Hudson and Jorgenson (1974). These findings should be accommodated in CGE energy models.

Another finding of the present study is that Cobb-Douglas type of production functions are not suitable to describe production technologies of all sectors of an economy. These production functions entail restrictive assumptions regarding substitution between inputs. These assumptions in turn lead to implausible implications for the substitution effects on input demands in some sectors.

6.2 Directions for Further Research

Although the present analysis has been useful in demonstrating the importance of allowing substitution among factors and intermediate inputs including fuels in CGE models, the simulation results provided by the models should be cautiously used for policy purposes. The models developed in this study suffer from many limitations which must be taken into account before one draws policy conclusions from the projected results. Moreover, in order to make these models useful for studying policy related issues in other areas such as public finance, international trade, etc. further research should be undertaken to refine them. The possible areas of the models in which further research can be undertaken are discussed below.

One of the limitations of the present models is that they provide only a partial equilibrium treatment of the rest of the world and thus fail to take account of some important mechanisms at work in the markets. Since the present models do not attempt to measure the supply responses of foreign producers to the oil price shock, the prices of other foreign products remained unchanged in the present simulations. But a more plausible picture of the oil price shock would be that prices of foreign products, particularly petroleum and coal products, would increase due to the increase in the oil price and this, in turn, would offset (strengthen) the adverse (favourable) effects on the outputs and employments of the Australian sectors. Thus to provide a complete picture of the effects on the Australian economy of the oil price shock the present models should be extended into multi-country general equilibrium models in line with the works of Deardorff and Stern (1986), Whalley (1985), Harrison (1984) and Stoeckel (1985).

The present work has been simplified by implementing Cobb-Douglas type of production functions for capital goods and effective goods and by representing consumers' and government preferences for goods and services by the same type of functions. This type of function restricts the elasticity of substitution in describing production technology and consumers' preferences for goods and services in ways which are both theoretically and empirically untenable. For example, for capital goods production the use of Cobb-Douglas type of production functions imposes the restriction that the elasticity of substitution between any two inputs is unity. Similarly, in the case of effective goods the use of Cobb-Douglas production functions imposes the restriction that the trade substitution elasticity between goods of domestic and foreign sources is unity. In representing government and household preferences these functions imply that expenditure and own-price elasticities of demand are unity while cross-price elasticities of demand are zero. Although for the present purpose (i.e., analysis of the sensitivity of model to alternative formulations of production functions) simplifications in the consumption, capital creation and trade specifications can be justified, to obtain more useful results these specifications should be replaced by more general specifications which are both theoretically and empirically plausible. However, one also should take into consideration the fact that employing more general specifications will increase greatly the number of parameters of the models which must be estimated by econometric techniques from time-series data. Thus using more general specifications will require the use of larger data bases to estimate the parameters.

The assumptions of perfectly competitive market and constant returns to scale in production may sound restrictive for some sectors in some policy simulations. In a recent study, Harris (1984) has shown that the quantitative and qualitative significance of incorporating the features of scale economies and imperfect competition in a general equilibrium trade model of a small open economy are considerable. Thus it is important to allow for scale economies and imperfect competition for some sectors when the present models are used to examine trade related issues such as protection.

Some improvements can also be made regarding the data base used for the present study. The most important sources of data for the present models are input-output tables. As has been noted in Chapter 4, the ORANI input-output data base for the year 1977–78 has been used for the present study. However, ORANI data base has been updated recently by using the input-output tables for 1978–79. This new set of data could be used to implement the present models.

The most serious limitations in data have been experienced in implementing the translog cost functions of the TL model. Due to lack of adequate data, the parameters of these functions could not be estimated. As an alternative, a set of estimates was obtained from various studies for use as proxies for the parameters of these functions. Thus the usefulness of the TL model has been greatly affected. The present study clearly indicates that simulation results are sensitive to variation in the specification of production functions. In order to facilitate use of highly flexible production functions like the ones represented by translog cost functions in CGE models, agencies responsible for data collection must direct effort towards collecting relevant time-series data (including input-output tables with supporting price data) required for the implementation of translog cost functions or production functions with similar generality and flexibilty.

The issues of validation of the models and investigation of dynamic adjustment mechanisms of the endogenous variables have been neglected in this study. The obvious reasons are the lack of time-series data and the time constraint imposed on the completion of the present research project. Even an attempt at partial validation of the present models of the type conducted for the SNAPSHOT model (Dixon and Vincent 1980) by Dixon, Harrower and Vincent (1978) requires more research resource and time than are available to the present author. Given sufficient resources, these models could be validated in line with the works of the above-mentioned authors or of Cook (1981) who has gone further than these authors in validating a 14-sector, Johansen style model. With regard to the investigation of adjustment mechanisms of the variables, one could follow the suggestion of FitzGerald (1979) or an alternative suggestion of Powell (1977, 1980) given in the context of the ORANI model.

Appendix A

EQUATIONS AND VARIABLES OF THE MODELS

Table A.1: Equations of the CGE Models in Percentage Change Forms.

Identifier	Equation	Subscript range	Number	Description
Equations appearing in the CES-FC model				
(3.48)	$k_j^{(1)} = x_{(j1)}^0 - \sigma_j(p_{Kj}^{(1)} - \sum_{t=K,L} S_{tj}^{\prime(1)} p_{tj}^{(1)})$	$j = 1,2,\ldots,9$	9	Demand for capital in sector j for current production.
(3.49)	$l_j^{(1)} = x_{(j1)}^0 - \sigma_j(p_L^{(1)} - \sum_{t=K,L} S_{tj}^{\prime(1)} p_{tj}^{(1)})$	$j = 1,2,\ldots,9$	9	Demand for labour in sector j for current production.
(3.50)	$e_j^{(1)} = x_{(j1)}^0$	$j = 1,2,\ldots,9$	9	Demand for energy in sector j for current production.
(3.51)	$m_j^{(1)} = x_{(j1)}^0$	$j = 1,2,\ldots,9$	9	Demand for aggregate materials in sector j for current production.
(3.52)	$x_{sj}^{(1)c} = x_{(j1)}^0$	$s = 5,6,\ldots,9$ $j = 1,2,\ldots,9$	45	Demand for fuel s in sector j for current production.
(3.53)	$x_{tj}^{(1)c} = x_{(j1)}^0$	$t = 0,1,\ldots,4$ $j = 1,2,\ldots,9$	45	Demand for material t in sector j for current production.
Equations appearing in the CD model				
(3.65)	$k_j^{(1)} = x_{(j1)}^0 - (p_{Kj}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}),$ $r = K,L,E,M$	$j = 1,2,\ldots,9$	9	Demand for capital in sector j for current production.
(3.66)	$l_j^{(1)} = x_{(j1)}^0 - (p_L^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}),$ $r = K,L,E,M$	$j = 1,2,\ldots,9$	9	Demand for labour in sector j for current production.
(3.67)	$e_j^{(1)} = x_{(j1)}^0 - (p_{Ej}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}),$ $r = K,L,E,M$	$j = 1,2,\ldots,9$	9	Demand for energy in sector j for current production.
(3.68)	$m_j^{(1)} = x_{(j1)}^0 - (p_{Mj}^{(1)} - \sum_r S_{rj}^{(1)} p_{rj}^{(1)}),$ $r = K,L,E,M$	$j = 1,2,\ldots,9$	9	Demand for aggregate materials in sector j for current production.
(3.69)	$x_{sj}^{(1)c} = e_j^{(1)} - (p_s^c - \sum_{k=5}^{9} S_{kj}^{(1)E} p_k^c)$	$s = 5,6,\ldots,9$ $j = 1,2,\ldots,9$	45	Demand for fuel s in sector j for current production.
(3.70)	$x_{tj}^{(1)c} = m_j^{(1)} - (p_t^c - \sum_{q=0}^{4} S_{qj}^{(1)M} p_q^c)$	$t = 0,1,\ldots,4$ $j = 1,2,\ldots,9$	45	Demand for material t in sector j for current production.

continued.....

Table A.1: (*continued*)

Identifier	Equation	Subscript range	Number	Description
Equations appearing in the TL model				
(3.87)	$k_j^{(1)} = x^0_{(j1)} - (p^{(1)}_{Kj} - \sum_r S^{*(1)}_{Kr,j} p^{(1)}_{rj})$, $r = K, L, E, M$	$j = 1, 2, \ldots, 9$	9	Demand for capital in sector j for current production.
(3.89)	$l_j^{(1)} = x^0_{(j1)} - (p^{(1)}_{L} - \sum_r S^{*(1)}_{Lr,j} p^{(1)}_{rj})$, $r = K, L, E, M$	$j = 1, 2, \ldots, 9$	9	Demand for labour in sector j for current production.
(3.91)	$e_j^{(1)} = x^0_{(j1)} - (p^{(1)}_{Ej} - \sum_r S^{*(1)}_{Er,j} p^{(1)}_{rj})$, $r = K, L, E, M$	$j = 1, 2, \ldots, 9$	9	Demand for energy in sector j for current production.
(3.93)	$m_j^{(1)} = x^0_{(j1)} - (p^{(1)}_{Mj} - \sum_r S^{*(1)}_{Mr,j} p^{(1)}_{rj})$, $r = K, L, E, M$	$j = 1, 2, \ldots, 9$	9	Demand for aggregate materials in sector j for current production.
(3.95)	$x^{(1)c}_{hj} = e^{(1)}_j - (p^c_h - \sum_{s=5}^{9} S^{*(1)E}_{hs,j} p^c_s)$	$h = 5, 6, \ldots, 9$ $j = 1, 2, \ldots, 9$	45	Demand for fuel h in sector j for current production.
(3.97)	$x^{(1)c}_{ij} = m^{(1)}_j - (p^c_i - \sum_{q=0}^{4} S^{*(1)M}_{iq,j} p^c_q)$	$i = 0, 1, \ldots, 4$ $j = 1, 2, \ldots, 9$	45	Demand for material i in sector j for current production.
Equations appearing in all three models (CES-FC, CD and TL)				
(3.106)	$e^{(2)}_j = i_j - (p^{(2)}_{Ej} - \sum_{r=E,M} S^{*(2)}_{Er,j} p^{(2)}_{rj})$	$j = 1, 2, \ldots, 9$	9	Demand for energy in sector j for capital production.
(3.108)	$m^{(2)}_j = i_j - (p^{(2)}_{Mj} - \sum_{r=E,M} S^{*(2)}_{Mr,j} p^{(2)}_{rj})$	$j = 1, 2, \ldots, 9$	9	Demand for aggregate materials in sector j for capital production.
(3.110)	$x^{(2)c}_{hj} = e^{(2)}_j - (p^c_h - \sum_{t=5}^{9} S^{*(2)E}_{ht,j} p^c_t)$	$h = 5, 6, \ldots, 9$ $j = 1, 2, \ldots, 9$	45	Demand for fuel h in sector j for capital production.
(3.112)	$x^{(2)c}_{ij} = m^{(2)}_j - (p^c_i - \sum_{q=0}^{4} S^{*(2)M}_{iq,j} p^c_q)$	$i = 0, 1, \ldots, 4$ $j = 1, 2, \ldots, 9$	45	Demand for material i in sector j for capital production.
(3.122)	$x^{(3)c}_i = q + \varepsilon_i(c^{(3)} - q) + \sum_{k=0}^{9} \eta_{ik} p^{(3)c}_k$	$i = 0, 1, \ldots, 9$	10	Household demand equations.
(3.136)	$x^{(4)c}_i = c^{(4)} - p^c_i + f^{(4)c}_i$	$i = 0, 1, \ldots, 9$	10	Government demand equations.
(3.141)	$x^c_{(i1)} = x^c_i - \sigma^c_i(p_{(i1)} - \sum_{t=1}^{2} S^c_{(it)} p_{(it)})$	$i = 1, 2, \ldots, 9$	9	Demand for domestic good i for the creation of effective good i.

continued....

Table A.1: (*continued*)

Identifier	Equation	Subscript range	Number	Description
(3.142)	$x^c_{(i2)} = x^c_i - \sigma^c_i(p_{(i2)} - \sum_{t=1}^{2} S^c_{(it)}p_{(it)})$	$i = 1,2,\ldots,9$	9	Demand for imported good i for the creation of effective good i.
(3.144)	$p^w_{(i1)} = -\gamma_i x^{(5)}_{(i1)} + f^w_{(i1)}$	$i = 1,2,\ldots,9$	9	Foreign demands for Australian exports.
(3.151)	$p_{(j1)} = \sum_r S^{(1)}_{rj} p^{(1)}_{rj} - t^{(1)}_j$, $r = K, L, E, M$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in current production.
(3.152)	$p^{(1)}_{Ej} = \sum_{h=5}^{9} S^{(1)E}_{hj} p^c_h$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in creating energy input for current production.
(3.153)	$p^{(1)}_{Mj} = \sum_{i=0}^{4} S^{(1)M}_{ij} p^c_i$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in creating aggregate materials for current production.
(3.157)	$p_{Ij} = \sum_{r=E,M} S^{(2)}_{rj} p^{(2)}_{rj} - t^{(2)}_j$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in capital goods production.
(3.158)	$p^{(2)}_{Ej} = \sum_{h=5}^{9} S^{(2)E}_{hj} p^c_h$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in creating energy input for capital production.
(3.159)	$p^{(2)}_{Mj} = \sum_{i=0}^{4} S^{(2)M}_{ij} p^c_i$	$j = 1,2,\ldots,9$	9	Zero-pure-profit conditions in creating aggregate materials for capital production.
(3.162)	$p^c_i = S^c_{(i1)} p_{(i1)} + S^c_{(i2)} p_{(i2)}$	$i = 1,2,\ldots,9$	9	Zero-pure-profit conditions in creating effective goods.
(3.164)	$p_{(i2)} = p^w_{(i2)} + \phi + t_{(i2)}$	$i = 1,2,\ldots,9$	9	Zero-pure-profit conditions in importing competing imports.
(3.165)	$p^c_0 = p^w_{(02)} + \phi + t_{(02)}$		1	Zero-pure-profit condition in importing non-competing imports.
(3.167)	$p_{(i1)} = p^w_{(i1)} + \phi + t^{(5)}_{(i1)}$	$i = 1,2,\ldots,9$	9	Zero-pure-profit conditions in exporting domestic goods.

continued.....

Table A.1: (*continued*)

Identifier	Equation	Subscript range	Number	Description
(3.169)	$p_i^{(3)c} = t_i^{(3)c} + p_i^c$	$i = 0, 1, \ldots, 9$	10	Consumer prices.
(3.176)	$r_j(0) = Q_j(p_{Kj}^{(1)} - p_{Ij})$	$j = 1, 2, \ldots, 9$	9	Rates of return on capital in each industry.
(3.177)	$-\beta_j\{k_j(1) - k_j(0)\} + r_j(0) = \omega$	$j \in J$	J^*	Equality of rates of return across industries.
(3.178)	$k_j(1) = k_j(0)(1 - G_j) + i_j G_j$	$j = 1, 2, \ldots, 9$	9	Capital accumulation.
(3.179)	$\sum_{j\in J}(p_{Ij} + i_j)\Upsilon_j = (\sum_{j\in J}\Upsilon_j)c^{(2)}$		1	Investment budget.
(3.180)	$i_j = h_j^{(2)} c_R^{(2)} + f_j^{(2)}$	$j \notin J$	$9 - J^*$	Equations for handling exogenous investment.
(3.181)	$c_R^{(2)} = c^{(2)} - \xi^{(2)}$		1	Real investment expenditure.
(3.183)	$x_i^c = \sum_{j=1}^9 H_{ij}^{(1)c} x_{ij}^{(1)c} + \sum_{j=1}^9 H_{ij}^{(2)c} x_{ij}^{(2)c}$ $+ H_i^{(3)c} x_i^{(3)c} + H_i^{(4)c} x_i^{(4)c}$	$i = 1, 2, \ldots, 9$	9	Supply equals demand for effective goods.
(3.185)	$x_{(j1)}^0 = B_{(j1)}^c x_{(j1)}^c + B_{(j1)}^{(5)} x_{(j1)}^{(5)}$	$j = 1, 2, \ldots, 9$	9	Supply equals demand for domestic goods.
(3.187)	$x_{(i2)} = x_{(i2)}^c$	$i = 1, 2, \ldots, 9$	9	Supply equals demand for competing imports.
(3.189)	$x_0^c = \sum_{j=1}^9 H_{0j}^{(1)c} x_{0j}^{(1)c} + \sum_{j=1}^9 H_{0j}^{(2)c} x_{0j}^{(2)c}$ $+ H_0^{(3)c} x_0^{(3)c} + H_0^{(4)c} x_0^{(4)c}$		1	Supply equals demand for noncompeting imports.
(3.191)	$x_{(i1)5} = x_{(i1)}^{(5)}$	$i = 1, 2, \ldots, 9$	9	Supply equals demand for exports.
(3.193)	$k_j(0) = k_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	Supply equals demand for capital.
(3.196)	$l = \sum_{j=1}^9 B_{Lj}^{(1)} l_j^{(1)}$		1	Aggregate employment.
(3.197)	$p_L^{(1)} = h\xi^{(3)} + f_L$		1	Nominal wage rate.
(3.199)	$m = M_{(02)}(x_0^c + p_{(02)}^w) + \sum_{i=1}^9 M_{(i2)}$ $(x_{(i2)}^c + p_{(i2)}^w)$		1	Foreign currency value of imports.
(3.201)	$e = \sum_{i=1}^9 D_{(i1)}^{(5)}(x_{(i1)}^{(5)} + p_{(i1)}^w)$		1	Foreign currency value of exports.
(3.203)	$100\Delta B = Ee - Mm$		1	The balance of trade.

continued.....

Table A.1: (*continued*)

Identifier	Equation	Subscript range	Number	Description
(3.206)	$y^{(3)} = \sum_{j=1}^{9} G_j^L(p_L^{(1)} + l_j^{(1)}) + \sum_{j=1}^{9} G_j^K(p_{Kj}^{(1)} + k_j^{(1)})$		1	Total household income.
(3.207)	$c^{(3)} = q^{(3)} + y^{(3)} - \{T^H/(1-T^H)\}t^H$		1	Aggregate household expenditure.
(3.210)	$y^{(4)} = \sum_{j=1}^{9} R_{(j1)}^{(1)}(p_{(j1)} + x_{(j1)}^0) + \sum_{j=1}^{9} R_j^{(2)}(p_{Ij} + i_j) - \sum_{j=1}^{9} G_{(j1)}^{(1)} t_j^{(1)} - \sum_{j=1}^{9} G_j^{(2)} t_j^{(2)} + \sum_{i=1}^{9} G_{(i2)} t_{(i2)} + G_{(02)} t_{(02)} + \sum_{i=1}^{9} J_{(i2)}(p_{(i2)}^w + \phi + x_{(i2)}^c) + J_{(02)}(p_{(02)}^w + \phi + x_0^c) - \sum_{i=1}^{9} J_{(i1)}^{(5)}(p_{(i1)}^w + \phi + x_{(i1)}^{(5)}) - \sum_{i=1}^{9} G_{(i1)}^{(5)} t_{(i1)}^{(5)} + J^H(t^H + y^{(3)}) + \sum_{i=0}^{9} G_i^{(3)c} t_i^{(3)c} + \sum_{i=0}^{9} J_i^{(3)c}(p_i^c + x_i^{(3)c})$		1	Total government income net of subsidy.
(3.211)	$c^{(4)} = q^{(4)} + y^{(4)}$		1	Total government expenditure.
(3.215)	$\xi^{(3)} = \sum_{i=0}^{9} w_i^{(3)} p_i^{(3)c}$		1	The consumer price index.
(3.216)	$\xi^{(4)} = \sum_{i=0}^{9} w_i^{(4)} p_i^c$		1	The government price index.
(3.217)	$\xi^{(2)} = \sum_{j=1}^{9} w_j^{(2)} p_{Ij}$		1	The capital goods price index.
(3.219)	$k = \sum_{j=1}^{9} B_{Kj} k_j(0)$		1	Aggregate capital stock.
(3.221)	$c_R^{(3)} = c^{(3)} - \xi^{(3)}$		1	Real aggregate household expenditure.
(3.223)	$c_R^{(4)} = c^{(4)} - \xi^{(4)}$		1	Real aggregate government expenditure.
(3.227)	$c^{(4)} = c^{(3)} + f_{43}$		1	Ratio of government expenditure to household expenditure.
(3.228)	$c^{(4)} = c^{(2)} + f_{42}$		1	Ratio of government expenditure to investment expenditure.
(3.229)	$c^{(2)} = c^{(3)} + f_{23}$		1	Ratio of investment expenditure to household expenditure.
Total equations in each model			**466**	

Table A.2: A List of Variables (in Percentage Changes) Appearing in Each CGE Model.

Variable	Subscript range	Number	Description
$k_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	Demand for capital in sector j for current production.
$l_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	Demand for labour in sector j for current production.
$e_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	Demand for energy in sector j for current production.
$m_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	Demand for aggregate materials in sector j for current production.
$x_{ij}^{(1)c}$	$i = 1, 2, \ldots, 9$ $j = 1, 2, \ldots, 9$	81	Demand for effective good i by sector j for current production.
$x_{0j}^{(1)c}$	$j = 1, 2, \ldots, 9$	9	Demand for noncompeting imports in sector j for current production.
$e_j^{(2)}$	$j = 1, 2, \ldots, 9$	9	Demand for energy in sector j for capital production.
$m_j^{(2)}$	$j = 1, 2, \ldots, 9$	9	Demand for aggregate materials in sector j for capital production.
$x_{ij}^{(2)c}$	$i = 1, 2, \ldots, 9$ $j = 1, 2, \ldots, 9$	81	Demand for effective good i by sector j for capital production.
$x_{0j}^{(2)c}$	$j = 1, 2, \ldots, 9$	9	Demand for non-competitive imports in sector j for capital production.
$x_i^{(3)c}$	$i = 0, 1, \ldots, 9$	10	Demand for effective good i by the household sector.
$x_i^{(4)c}$	$i = 0, 1, \ldots, 9$	10	Demand for effective good i by the government sector.

continued.....

Table A.2: (*continued*)

Variable	Subscript range	Number	Description
$x^c_{(i1)}$	$i = 1, 2, \ldots, 9$	9	Demand for domestic good i in the creation of effective good i.
$x^c_{(i2)}$	$i = 1, 2, \ldots, 9$	9	Demand for imported good i in the creation of effective good i.
$x^{(5)}_{(i1)}$	$i = 1, 2, \ldots, 9$	9	Exports of i^{th} domestic good.
x^c_i	$i = 0, 1, \ldots, 9$	10	Supply of effective good i.
$x^0_{(j1)}$	$j = 1, 2, \ldots, 9$	9	Supply of domestic good i.
i_j	$j = 1, 2, \ldots, 9$	9	Production of capital good in sector j.
$x_{(i2)}$	$i = 1, 2, \ldots, 9$	9	Supply of imported (competing) good i.
$x_{(i1)5}$	$i = 1, 2, \ldots, 9$	9	Supply of export good i.
$p^w_{(i1)}$	$i = 1, 2, \ldots, 9$	9	Foreign currency price of export good i.
$p_{(j1)}$	$j = 1, 2, \ldots, 9$	9	Price of j^{th} domestic good.
$p^{(1)}_{Ej}$	$j = 1, 2, \ldots, 9$	9	Cost of energy to sector j for current production.
$p^{(1)}_{Mj}$	$j = 1, 2, \ldots, 9$	9	Cost of aggregate materials to sector j for current production.
p_{Ij}	$j = 1, 2, \ldots, 9$	9	Price of j^{th} capital good.
$p^{(2)}_{Ej}$	$j = 1, 2, \ldots, 9$	9	Cost of energy to sector j for capital formation.
$p^{(2)}_{Mj}$	$j = 1, 2, \ldots, 9$	9	Cost of aggregate materials to sector j for capital formation.

continued.....

Table A.2: (*continued*)

Variable	Subscript range	Number	Description
p_i^c	$i = 0, 1, \ldots, 9$	10	Price of effective good i.
$p_{(i2)}$	$i = 1, 2, \ldots, 9$	9	Domestic price of i^{th} competitive import good.
$p_{(i2)}^w$	$i = 0, 1, \ldots, 9$	10	Foreign currency price of i^{th} imported good including noncompeting imports.
$p_i^{(3)c}$	$i = 0, 1, \ldots, 9$	10	Price of i^{th} effective good to the household sector.
$p_{Kj}^{(1)}$	$j = 1, 2, \ldots, 9$	9	Rental rate of capital services in sector j.
$k_j(0)$	$j = 1, 2, \ldots, 9$	9	Current capital stock in sector j.
$k_j(1)$	$j = 1, 2, \ldots, 9$	9	Capital stock in sector j after one period.
l		1	Aggregate employment.
$p_L^{(1)}$		1	Nominal wage rate.
m		1	Foreign currency value of aggregate imports.
e		1	Foreign currency value of aggregate exports.
ΔB		1	Change in balance of trade.
$r_j(0)$	$j = 1, 2, \ldots, 9$	9	Current net rate of return on fixed capital in sector j.
ω		1	Expected rate of return on future capital stock.

continued.....

Table A.2: (*continued*)

Variable	Subscript range	Number	Description
$c^{(2)}$		1	Total investment expenditure.
$c_R^{(2)}$		1	Real investment expenditure.
$y^{(3)}$		1	Total income of the household sector.
$c^{(3)}$		1	Aggregate household expenditure.
$y^{(4)}$		1	Total government revenue net of subsidy.
$c^{(4)}$		1	Total government expenditure.
$\xi^{(3)}$		1	Consumer price index.
$\xi^{(4)}$		1	Government price index.
$\xi^{(2)}$		1	Capital goods price index.
k		1	Aggregate capital stock in base-period value units.
$c_R^{(3)}$		1	Real household expenditure.
$c_R^{(4)}$		1	Real government expenditure.
$f_i^{(4)c}$	$i = 0, 1, \ldots, 9$	10	Shift variable in the government demand equation for i^{th} commodity.
$f_{(i1)}^{w}$	$i = 1, 2, \ldots, 9$	9	Shift variable in the i^{th} export demand equation.
f_L		1	Shift variable representing changes in real wage rate.
$f_j^{(2)}$	$j \notin J$	$9 - J^*$	Exogenous investment terms.

continued.....

Table A.2: (*continued*)

Variable	Subscript range	Number	Description
f_{43}		1	Ratio of government expenditure to household expenditure.
f_{42}		1	Ratio of government expenditure to investment expenditure.
f_{23}		1	Ratio of investment expenditure to household expenditure.
q		1	Number of households.
$t_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	One minus the rate of current production tax in sector j.
$t_j^{(2)}$	$j = 1, 2, \ldots, 9$	9	One minus the rate of capital production tax in sector j.
$t_{(i2)}$	$i = 0, 1, \ldots, 9$	10	One plus the rate of *ad valorem* tariff applicable to import good i.
$t_{(i1)}^{(5)}$	$i = 1, 2, \ldots, 9$	9	One plus the rate of subsidy applicable to export good i.
t^H		1	Income tax rate.
$t_i^{(3)c}$	$i = 0, 1, \ldots, 9$	10	One plus the rate of consumption tax on effective good i.
ϕ		1	Nominal exchange rate.
$q^{(3)}$		1	Average propensity of the household sector to consume.
$q^{(4)}$		1	Average propensity of the government sector to consume.
Total		$567 - J^*$	

Table A.3: Variables (in Percentage Changes) Assumed Exogenous to Define the Macroeconomic Environment for the Present Simulations.

Variable	Subscript range	Number	Description
$x_{(i1)}^{(5)}$	$i = 2, 3, 4, 6, \ldots, 9$	7	Exports of sector i.
$p_{(i2)}^{w}$	$i = 0, 1, \ldots, 9$	10	Foreign currency price of imports.
$k_j(0)$	$j = 1, 2, \ldots, 9$	9	Current capital stock of sector j.
$c_R^{(2)}$		1	Real investment expenditure.
$c_R^{(3)}$		1	Real household expenditure.
$c_R^{(4)}$		1	Real government expenditure.
$f_i^{(4)c}$	$i = 0, 1, \ldots, 9$	10	Government demand shift terms.
$f_{(i1)}^{w}$	$i = 1, 2, \ldots, 9$	9	Shifts in foreign export demands.
f_L		1	Wage shift variable.
$t_j^{(1)}$	$j = 1, 2, \ldots, 9$	9	One minus the rate of current production tax in sector j.
$t_j^{(2)}$	$j = 1, 2, \ldots, 9$	9	One minus the rate of capital production tax in sector j.
$t_{(i2)}$	$i = 0, 1, \ldots, 9$	10	One plus the rate of *ad valorem* tariff applicable to import good i.
$t_{(i1)}^{(5)}$	$i = 1, 5$	2	One plus the rate of subsidy applicable to export good i.
t^H		1	Income tax rate.
$t_i^{(3)c}$	$i = 0, 1, \ldots, 9$	10	One plus the rate of consumption tax on effective good i.
ϕ		1	Nominal exchange rate.
q		1	Number of households.
TOTAL		**92**	

Appendix B

INPUT-OUTPUT DATA BASE

Acc p 105

Table B.1: Usage of Domestic Goods (in Million Dollars) in Different Sectors for Current Production (Matrix $\tilde{A}$).

From	To Sector								
Sector	1	2	3	4	5	6	7	8	9
1	1146.12	5169.79	203.30	923.20	31.94	87.16	7.85	6.88	0.39
2	5735.65	13456.12	1123.95	4393.87	122.45	17.98	22.61	23.72	9.36
3	229.96	229.48	336.14	927.52	20.41	3.69	1.21	1.57	0.48
4	1289.26	2753.24	1197.75	10481.55	112.47	31.16	33.89	145.28	27.33
5	0.84	216.08	7.34	7.25	74.60	0.00	0.00	211.88	1.92
6	0.92	19.16	0.89	3.33	18.90	28.14	470.98	92.56	51.06
7	311.54	242.12	469.01	231.09	12.14	1.23	198.33	61.78	18.07
8	153.42	459.70	56.65	653.93	61.69	11.05	4.33	791.95	3.01
9	6.00	71.88	10.01	66.58	1.17	0.52	1.72	2.82	0.60

Table B.2: Usage of Competing Imports (in Million Dollars) in Different Sectors for Current Production (Matrix $\tilde{F}$).

Category of	To Sector								
imports	1	2	3	4	5	6	7	8	9
1	15.75	210.56	0.51	21.89	0.32	0.08	0.19	0.02	0.00
2	829.30	3772.02	280.65	1254.01	38.02	5.05	12.65	6.99	2.03
3	44.56	45.59	256.22	149.99	2.85	0.20	0.26	0.59	0.22
4	18.76	58.79	18.86	196.36	2.14	0.61	0.47	1.13	0.30
5	0.00	0.32	0.01	0.02	0.19	0.00	0.00	0.23	0.00
6	0.00	0.03	0.00	0.01	0.05	0.07	869.04	0.10	0.06
7	46.66	100.23	152.30	41.76	2.19	0.22	51.46	39.96	0.53
8	0.52	1.56	0.19	2.22	0.21	0.04	0.02	2.69	0.01
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.3: Usage of Domestic Goods (in Million Dollars) in Different Sectors for Capital Goods Production (Matrix $\tilde{B}$).

From Sector	To Sector 1	2	3	4	5	6	7	8	9
1	1139.10	511.47	1023.18	9741.84	115.47	128.43	6.93	480.78	26.27
2	638.29	627.51	733.24	1308.87	35.21	39.17	19.25	329.04	26.44
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	54.61	29.66	28.82	475.20	3.23	3.59	0.41	5.05	0.28
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.4: Usage of Competing Imports (in Million Dollars) in Different Sectors for Capital Goods Production (Matrix $\tilde{G}$).

Category of imports	To Sector 1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	433.62	416.86	469.92	707.02	30.35	33.76	12.66	134.80	12.36
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	2.02	1.48	1.79	10.20	0.13	0.15	0.03	0.66	0.04
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.5: Usage of Domestic and Imported Goods (in Million Dollars) by the Final Users (Matrices $\tilde{C}$, $\tilde{D}$, $\tilde{E}$, $\tilde{H}$, $\tilde{J}$, $\tilde{M}$ and $\tilde{N}$).

Category of domestic output or imports	Household consumption	Government consumption	Exports
	Domestic goods		
Agriculture, mining and construction	914.15	142.04	4184.18
Manufacturing	13340.15	50.22	5269.00
Transportation	1512.59	632.54	1332.91
Communications, trade and services	20592.21	15377.00	245.44
Coal	1.61	0.06	1174.99
Crude oil	9.92	0.05	111.66
Petroleum and coal products	647.61	0.14	254.14
Electricity	876.37	0.22	9.39
Gas utilities	173.90	0.02	0.00
	Competing imports		
Agriculture, mining and construction	67.31	1.43	0.00
Manufacturing	2767.16	5.41	0.00
Transportation	395.10	14.73	0.00
Communications, trade and services	94.13	10.09	0.00
Coal	0.00	0.00	0.00
Crude oil	0.11	0.00	0.00
Petroleum and coal products	54.13	0.00	0.00
Electricity	2.97	0.00	0.00
Gas utilities	0.00	0.00	0.00
Non-competing imports	556.65	0.00	0.00

Table B.6: Sectoral Expenditures (in Million Dollars) on Labour, Capital, Non-Competing Imports and Tax for Current and Capital Production (Matrices $\tilde{U}$, $\tilde{V}$, $\tilde{K}$, $\tilde{Q}$, $\tilde{L}$ and $\tilde{R}$).

Sector	labour	capital	Non-competing imports	Tax
		Current production		
Agriculture, mining and construction	8499.29	5436.58	31.62	543.51
Manufacturing	11267.54	4474.30	323.04	738.16
Transportation	3903.43	621.92	9.28	486.83
Communications, trade and services	29311.06	17655.82	305.65	2475.48
Coal	449.09	660.89	0.27	28.07
Crude oil	50.18	544.60	0.12	16.08
Petroleum and coal products	87.16	72.80	8.01	451.60
Electricity	716.28	815.17	1.38	54.47
Gas utilities	96.98	93.51	0.60	10.99
		Capital production		
Agriculture, mining and construction	0.00	0.00	0.00	20.06
Manufacturing	0.00	0.00	0.00	11.44
Transportation	0.00	0.00	0.00	64.92
Communications, trade and services	0.00	0.00	0.00	74.98
Coal	0.00	0.00	0.00	0.39
Crude oil	0.00	0.00	0.00	0.43
Petroleum and coal products	0.00	0.00	0.00	0.09
Electricity	0.00	0.00	0.00	4.92
Gas utilities	0.00	0.00	0.00	0.73

Table B.7: Taxes (in Million Dollars) on Household Consumption and Exports (Matrices $\tilde{S}$ and $\tilde{T}$).

Type of of output	Household consumption tax	Export tax
Agriculture, mining and construction	-1.64	86.03
Manufacturing	3005.43	-21.65
Transportation	-9.09	0.33
Communications, trade and services	400.42	1.21
Coal	0.00	100.20
Crude oil	0.39	29.49
Petroleum and coal products	440.13	17.51
Electricity	13.44	0.00
Gas utilities	3.30	0.00

Table B.8: Tariffs (in Million Dollars) on Imports (Matrices $\tilde{Z}$ and $\tilde{P}$).

Type of imports	Total tariff
Agriculture, mining and construction	11.72
Manufacturing	920.03
Transportation	0.00
Communications, trade and services	0.16
Coal	0.00
Crude oil	0.00
Petroleum and coal products	0.36
Electricity	0.00
Gas utilities	0.00
Non-competing imports	0.01

REFERENCES

Allen, R.G.D. (1938), *Mathematical Analysis for Economists*, Macmillan, London.

Armington, P.S. (1969), 'The Geographic pattern of trade and the effects of price changes', *IMF Staff Papers* , 16(2), 179–199.

Armington, P.S. (1970), 'Adjustment of trade balances: some experiments with a model of trade among many countries', *IMF Staff Papers* , 17(3), 488–523.

Australian Bureau of Statistics (1983), *Australian National Accounts, Input-Output Tables 1977–78*, Catalogue No. 5209.0, Australian Government Publishing Service, Canberra.

Baughman, M.L. and Joskow, P.L. (1974), *A Regionalized Electricity Model*, Report No. MIT-EL 75-005, MIT Energy Laboratory, Cambridge, Mass.

Behling, Jr.D.J., Marcuse, W., Lukachinsky, J. and Dullien, R. (1977), 'The long-term economic and environmental consequences of phasing out nuclear electricity', In C.J. Hitch (ed.), *Modelling Energy-Economy Interactions: Five Approaches*, 46–134, Resources for the Future, Washington, D.C.

Berndt, E.R. and Wood, D.O. (1975), 'Technology, prices and the derived demand for energy', *Review of Economics and Statistics*, 57(3), 259–268.

Blampied, C.W. (1985), 'A Listing of the 1977–78 Balanced ORANI Data Base with the Typical-Year Agricultural Sector Implemented', IMPACT Research Memorandum, University of Melbourne, mimeo, 401 pp.

Borges, A.M. and Goulder, L.H. (1984), 'Decomposing the impact of higher energy prices on long-term growth', In H.E. Scarf and J.B. Shoven (eds.), *Applied General Equilibrium Analysis*, 319–362, Cambridge University Press.

Brock, H. and Nesbitt, D. (1977), *Large-Scale Energy Planning Models: A Methodological Analysis*, Stanford Research Institute, Menlo Park, Calif.

Bruce, I. (1985), 'The ORANI 78 Input-Output and Parameter Files for 1977–78', IMPACT preliminary Working Paper No. OP-51, University of Melbourne, mimeo.

Caddy, V. (1977), 'Calculation of the ORANI Investment Parameters and the Distribution of Gross Operating Surplus between Fixed and Working Capital', IMPACT Research Memorandum, University of Melbourne, mimeo.

Charles River Associates (1978), *Review and Evaluation of Selected Large-Scale Energy Models,* CRA Report No. 231, Cambridge, Mass.

Cherniavsky, E.A. (1974), *Brookhaven Energy System Optimization Model,* Brookhaven National Laboratory, Upton, N.Y.

Cherniavsky, E.A., Juang, L.L. and Abilock, H. (1977), *Dynamic Energy System Optimization Model,* Brookhaven National Laboratory, Upton, N.Y.

Christensen, L.R., Jorgenson, D.W. and Lau, L.J. (1971), 'Conjugate duality and the transcendental logarithmic function', *Econometrica,* 39(4), 255–256.

Christensen, L.R., Jorgenson, D.W. and Lau, L.J. (1973), 'Transcendental logarithmic production frontiers', *Review of Economics and Statistics,* 55(1), 28–45.

Clements, K.W. and Johnson, L.W. (1983), 'The demand for bear, wine and spirits: a systemwide analysis', *Journal of Business,* 56(3), 273–304.

Clements, K.W. and Nguyen, P. (1980), 'Money demand, consumer demand and relative prices in Australia', *Economic Record,* 56(155), 338–346.

Cook, L.H. (1981), Validation of a Johansen-type Multisectoral Model: Norway, 1949–61, unpublished Ph.D. thesis, Monash University.

Cronin, M.R. (1979), 'Export demand elasticities with less than perfect markets', *Australian Journal of Agricultural Economics,* 23(1), 69–72.

Deardorff, A.V. and Stern, R.M. (1986), *The Michigan Model of World Production and Trade,* MIT Press, Cambridge, Mass.

Dervis, K., de Melo, J. and Robinson, S. (1982), *General Equilibrium Models for Development Policy* , Cambridge University Press.

Diewert, W.E. (1971), 'An application of the Shephard duality theorem: a generalized Leontief production function', *Journal of Political Economy,* 79(3), 481–507.

Diewert, W.E. (1973), *Separability and a Generalization of the Cobb-Douglas Cost, Production and Indirect Utility Functions,* Research Branch, Department of Manpower and Immigration, Ottawa.

Dixon, P.B. (1975), *The Theory of Joint Maximization*, North-Holland, Amsterdam.

Dixon, P.B., Harrower, J.D. and Vincent, D.P. (1978), 'Validation of the SNAPSHOT Model', IMPACT Preliminary Paper No. SP-12, University of Melbourne, mimeo, 65 pp.

Dixon, P.B., Parmenter, B.R., Ryland, G.J. and Sutton, J. (1977), *ORANI, A General Equilibrium Model of the Australian Economy: Current Specification and Illustrations of Use for Policy Analysis* , First Progress Report of the IMPACT Project, Vol. 2, Australian Government Publishing Service, Canberra.

Dixon, P.B., Parmenter, B.R., Sutton, J. and Vincent, D.P. (1982), *ORANI: A Multisectoral Model of the Australian Economy* , North-Holland, Amsterdam.

Dixon, P.B. and Vincent, D.P. (1980), 'Some economic implications of technical change in Australia to 1990/91: an illustrative application of the SNAPSHOT model', *Economic Record,* 56(155), 347–361.

Donnelly, W.A. (1982), 'The Regional Demand for Petrol in Australia', *Economic Record,* 58(163), 317–327.

Donnelly, W.A. (1984), 'Energy Model for Australia', CRES Working Paper 1984/4, Centre for Resource and Environmental Studies, Australian National University.

Donnelly, W.A. and Dragun, A.K. (1984), 'Production Functions for Australian Coal', CRES Working Paper 1984/28, Centre for Resource and Environmental Studies, Australian National University.

Duncan, R.C. and Binswanger, H.P. (1974), *Production Parameters in Australian Manufacturing Industries,* mimeo.

Duncan, R.C. and Binswanger, H.P. (1976), 'Energy sources: substitutability and biases in Australia', *Australian Economic Papers,* 15(27), 289–301.

Edelman, D.J. (1977–78), 'Recent energy models: a review of methodologies', *Journal of Environmental Systems*, 7(3), 279–292.

Energy Modeling Forum (1977), *Energy and the Economy*, EMF Report, No.1, Stanford University, Ca.

Evans, H.D. (1972), *A General Equilibrium Analysis of Protection in Australia*, North-Holland, Amsterdam.

Field, B. and Grebenstein, C. (1980), 'Capital-energy substitution in U.S. manufacturing', *Review of Economics and Statistics*, 62(2), 207–212.

FitzGerald, V. (1979), 'A Variant of the ORANI Model for the Analysis of Short-Period Responses', IMPACT Preliminary Working Paper No. OP-23, University of Melbourne, mimeo, 61 pp.

Freebairn, J.W. (1978), 'Projections of Australia's World Trade Opportunities: Mid and Late Nineteen Eighties', IMPACT Working Paper, No. I-07, University of Melbourne, mimeo.

Fuss, M.A. (1977), 'The demand for energy in Canadian manufacturing: an example of the estimation of production structures with many inputs', *Journal of Econometrics*, 5, 89–116.

Geary, R.C. (1950–51), 'A note on "a constant-utility index of the cost of living" ', *Review of Economic Studies*, 18, 65–66.

Goulder, L.H. (1982), A general equilibrium analysis of U.S. energy policies, unpublished Ph.D. thesis, Department of Economics, Stanford University.

Grubel, H.G. and Lloyd, P.J. (1975), *Intra-Industry Trade: The Theory and Measurement of International Trade in Differentiated Products*, Macmillan and Halsted, London.

Harris, A. (1984), 'Applied general equilibrium analysis of small open economies with scale economies and imperfect competition', *American Economic Review*, 74(5), 1016–1032.

Harrison, G. (1984), 'A general equilibrium analysis of tariff reductions', Paper presented to the Conference on General Equilibrium Trade Policy Modeling, Columbia University, New York, April 5–6.

Hawkins, R.G. (1977), 'Factor demands and the production function in selected Australian manufacturing industries', *Australian Economic Papers*, 16(28), 97–111.

Hawkins, R.G. (1978) 'A vintage model of the demand for energy and employment in Australian manufacturing industry', *Review of Economic Studies,* 45(141), 479–494.

Higgs, P.J. (1985), 'Implementation of Adam's Typical Year for the Agricultural Sector in the ORANI 1977–78 Data Base', IMPACT Preliminary Working Paper No. OP-49, University of Melbourne, mimeo, 180 pp.

Higgs, P.J. (1986), *Adaptation and Survival in Australian Agriculture,* Oxford University Press, Melbourne.

Hitch, C.J. (ed.) (1977), *Modeling Energy-Economy Interactions: Five Approaches,* Resources for the Future, Washington, D.C.

Hoffman, K.C. (1973), 'A unified framework for energy system planning', In M.F. Searl (ed.), *Energy Modeling,* Resources for the Future, Washington, D.C.

Hoffman, K.C. and Jorgenson, D.W. (1977), 'Economic and technological models for evaluation of energy policy', *Bell Journal of Economics,* 8(2), 444–466.

Hoffman, K.C. and Wood, D.O. (1976), 'Energy system Modeling and forecasting', *Annual Review of Energy,* 1, 423–453.

Hudson, E.A. and Jorgenson, D.W. (1974), 'U.S. energy policy and economic growth, 1975–2000', *Bell Journal of Economics and Management Science* , 5(1), pp. 461–514.

Hudson, E.A. and Jorgenson, D.W. (1978), 'The economic impact of policies to reduce U.S. energy growth', *Resources and Energy* , 1(3), pp. 205–229.

Industries Assistance Commission (1976), *Crude Oil Pricing,* Australian Government Publishing Service, Canberra.

International Energy Agency (1980), *A Group Strategy for Energy Research, Development and Demonstration,* OECD, Paris.

James, D., Chambers, J., Gilbert, A. and Wright, H. (1983), *An integrated energy-economic-environmental model for Australia,* CEUS Report No. 82, Macquarie University.

Johansen, L. (1960), *A Multi-Sectoral Study of Economic Growth* , North-Holland, Amsterdam.

Jorgenson, D.W. (1982), 'Econometric and process analysis models for energy policy assessments', In R. Amit and M. Avriel (eds.) *Perspectives on Resource Policy Modelling: Energy and Minerals,* 9–62, Ballinger Publishing company.

Joskow, P.L. and Baughman, M.L. (1976), 'The future of the U.S. nuclear energy industry', *Bell Journal of Economics,* 7(1), 3–32.

Kennedy, M. (1974), 'An economic model of the world oil market', *Bell Journal of Economics and Management,* 5(2), 540–577.

Klein, L.R. and Rubin, H. (1948–49), 'A constant-utility index of the cost of living', *Review of Economic Studies*, 15, 84–87.

Kydes, A.S. (1980), 'The Brookhaven energy system optimisation model: its variants and uses', In W.T. Ziemba and S.L. Schwartz (eds.) *Energy Policy Modeling: United States and Canadian Experiences, Volume II,* 110–136, Martinus Nijhoff Publishing, Boston.

MacAvoy, P.W. and Pindyck, R.S. (1975), *The Economics of the Natural Gas Shortage 1960–1980*, North-Holland, Amsterdam.

Macrakis, S. (ed.) (1974), *Energy,* MIT Press, Cambridge, Mass.

Magnus, J.R. (1979), 'Substitution between energy and non-energy inputs in the Netherlands 1950–1976', *International Economic Review,* 20(2), 465–484.

Manne, A.S. (1976), 'ETA: a model for energy technology assessment', *Bell Journal of Economics,* 7(2), 379–406.

Manne, A.S. (1977), 'ETA-MACRO: a model of energy-economy interactions', In C.J. Hitch (ed.) *Modeling Energy-Economy Interactions: Five Approaches,* 1–45, Resources for the Future, Washington, D.C.

Manne, A.S., Richels, R.G. and Weyant, J.P. (1979), 'Energy policy modeling: a survey', *Operations Research,* 27(1), 1–36.

Marks, R.E. (1986), 'Energy issues and policies in Australia', *Annual Review of Energy,* 11, 47–75.

Meagher, G.A. and Parmenter, B.R. (1987), 'The Short-Run Macroeconomic Effects of Tax-Mix Changes: Option C Reconsidered', IAESR Working Paper No. 1/1987, University of Melbourne.

Murtagh, B.A. and Saunders, M.A. (1977), *MINOS: A Large-Scale Nonlinear Programming System,* Technical Report SOL 77-9, Department of Operations Research, Stanford University.

Musgrove, A.R., Stocks, K.J., Essam, P., Le, D. and Hoetzl, J.V. (1983) *Exploring Some Australian Energy Alternatives Using MARKAL,* Technical Report TR-2, CSIRO Division of Energy Technology, Lucas Heights, Australia.

Nordhaus, W.D. (ed.) (1977), *International Studies of the Demand for Energy,* North-Holland, Amsterdam.

Petri, P. (1976), 'A multilateral model of Japanese-American trade', In K.R. Polenske and J. Skolka (eds.), *Advances in Input-Output Analysis*, Ballinger, Cambridge.

Powell, A.A. (1974), *Empirical Analytics of Demand Systems*, Lexington Books, D.C. Heath and Company, Lexington, Mass.

Powell, A.A. (1977), *The IMPACT Project: An Overview–First Progress Report of the IMPACT Project,* Vol. 1, Australian Government Publishing Service, Canberra.

Powell, A.A. (1980), 'The major streams of economy-wide modelling: is rapprochement possible ?' In J. Kmenta and J.B. Ramsey (eds.), *Large Scale Econometric Models: Theory and Practice,* North-Holland, Amsterdam.

Rushdi, A. (1984), Electricity in South Australia: cost, price and demand 1950–80, unpublished Ph.D. thesis, Faculty of Economics, University of Adelaide.

Scobie, G.M. and Johnson, P.R. (1979), 'The price elasticity of demand for exports: a comment on Throsby and Rutledge', *Australian Journal of Agricultural Economics,* 23(1), 62–66.

Searl, M. (ed.) (1973), *Energy Modeling,* Resources for the Future, Washington, D.C.

Shephard, R.W. (1953), *Cost and Production Functions,* Princeton University Press.

Stoeckel, A. (1985), 'Intersectoral Effects of the CAP: Growth, Trade and Unemployment', Bureau of Agricultural Economics Occasional Paper No. 95, Australian Government Publishing Service, Canberra.

Stone, R. (1954), 'Linear expenditure systems and demand analysis: an application to the pattern of British demand', *Economic Journal*, 64, 511–527.

Taylor, L.D. (1975), 'The demand for electricity: a survey', *Bell Journal of Economics,* 6(1), 74–110.

Taylor, L.D. (1977), 'The demand for energy: a survey of price and income elasticities', In W.D. Nordhaus (ed.) *International Studies of the Demand for Energy,* North-Holland, Amsterdam.

Taylor, L. and Black, S.L. (1974), 'Practical general equilibrium estimation of resource pulls under trade liberalization', *Journal of International Economics* , 4(1), 37–58.

Theil, H. (1980), *The System-Wide Approach to Microeconomics,* University of Chicago Press, Chicago.

Throsby, C.D. and Rutledge, D.J.S. (1979), 'The elasticity of demand for exports: a reply', *Australian Journal of Agricultural Economics,* 23(1), 67–68.

Truong, T.P. (1985), 'Inter-fuel and inter-factor substitution in NSW manufacturing industry', *Economic Record* , 61(174), pp. 644–653.

Truong, T.P. (1986), 'ORANI-FUEL: Incorporating Interfuel Substitution into the Standard ORANI System', Preliminary Working Paper No. OP-58, IMPACT Project, University of Melbourne.

Truong, T.P., Chapman, D.R. and Gallagher, D.R. (1985), 'Extending the Production Side of the ORANI Model to include Energy Substitution', CAER Working Paper No. 72, Centre for Applied Economic Research, University of New South Wales.

Turnovsky, M.H.L. and Donnelly, W.A. (1984), 'Energy substitution, separability, and technical progress in the Australian iron and steel industry', *Journal of Business and Economic Statistics,* 2(1), 54–63.

Turnovsky, M., Folie, M. and Ulph, A. (1982), 'Factor substitutability in Australian manufacturing, with emphasis on energy inputs', *Economic Record,* 58(160), 61–72.

Ulph, A.M. (1980), 'World energy models—a survey and critique', *Energy Economics,* 2(1), 46–59.

Vincent, D.P. (1979), 'Calculation of Investment Parameters for the Agricultural Sector of ORANI 78', IMPACT Research Memorandum, University of Melbourne, mimeo.

Vincent, D.P., Dixon, P.B., Parmenter, B.R. and Sams, D.C. (1979), 'The short-run effect of oil price increases on the Australian economy with special reference to the agricultural sector', Paper presented to the Australian Economics Society Conference, Canberra, February 6–8.

Whalley, J. (1977), 'The U.K. tax system 1968–70: some fixed point indications of its economic impact', *Econometrica,* 45(8), 1837–1858.

Whalley, J. (1985), *Trade Liberalization among Major World Trading Areas,* MIT Press, Cambridge, Mass.

Zellner, A. (1962), 'An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias', *Journal of the American Statistical Association*, 57, 348–368.

Ziemba, W.T. and Schwartz, S.L. (eds.) (1980), *Energy Policy Modeling: United States and Canadian Experiences, Volume II,* Martinus Nijhoff, Boston.