MONASH UNIVERSITY

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ON............4 April 2003............

..................[redacted]........

for Sec. Research Graduate School Committee

One examiner, Professor Shih-Mo Lin, suggested that Ms. Lee make 2 minor amendments. These 2 queries, and Ms Lee's responses, are detailed below.

Professor Lin's first query:

In chapter 5, for BAU forecasting simulations, the whole period is divided into two sub-periods—one covering years 1995 to 2002 (historical) and the other 2003 to 2027 (forecasting). The data for shocking variables for the historical 1995-2002 period, according to the text, are obtained from "external sources". It is my opinion that specific sources should be identified in order that appropriate data have been utilized could be assured. Besides, official data for 2002 are still not available at the time the simulations were conducted. As such the data used in the thesis must be some for of estimates or guess-mates form certain agencies or experts. It is thus also very important to identify clearly from where those data were obtained.

Ms Lee's reply:

The growth forecasts of 2002 are approximate estimates based on the forecasts officially published in the Quarterly National Economic Trends, Taiwan Area, the Republic of China. The Directorate-General of Budget, Accounting and Statistics (DGBAS) conducts forecasting of the national economy on a quarterly basis. DGBAS macroeconomic forecasts can be accessed via the following internet address: http://www.stat.gov.tw/bs5/enghtm/engquarter.htm.

Professor Lin's second query:

The other minor point needs to be clarified is that the current policy debate regarding the taxation of energy use in Taiwan is that either FCT should be charged according to the volume of fuel purchased or based on car ownership. Therefore, for policy analysis purposes, it might be more reasonable to think of simulating a scenario that eliminates the FCT and, at the same time, increases the motor fuel tax (similar to the simulation already conducted in the thesis). Furthermore, it would be desirable to tell what the differences are between a partial and a complete elimination of FCT together with an increase in motor fuel taxes.

However, since the FCT is modeled as in inputs to the dummy industry PTS in the models with a connection to the car capital (p.119), eliminating it from the production structure might represent a change in the production technology of the PTS industry, and thus might request some additional modeling works. With respect to this, my suggestion is that at least one or two paragraphs be clearly stated in the thesis showing how such modification and application could be made.

Ms Lee's reply:

Up to date, the fuel consumption tax (FCT) is still charged on the basis of car ownership. That is why we associated FCT with car capital in versions DURA and TAIVINT of the TAIGEM model.

Here we propose a viable way to facilitate the elimination of per-car FCT while imposing a per-unit tax on motor fuels (including gasoline and diesel fuel) on a cost-neutral basis. This is a cheap way which minimizes modifications to the original production structure of PTS.

The following equations are to be added to the model (notations follow those in Chapter 4).

$$100*\Delta \text{V1FCTPTS} = \text{V1FCTPTS}*[\text{x1carcap} + \text{p1fctPTS}],$$
$$= \text{V1FCTPTS}*[\text{x1carcap} + \text{p3tot} + \text{f1fctPTS}], \qquad (1)$$

where ΔV1FCTPTS indicates changes in the per-car fuel consumption tax revenue (V1FCTPTS).

$$\Delta \text{TQMVPETROL\_F} = 0.01*\text{TQMVPETROL\_F}*\text{x1mvpetrol\_f} + \text{Q1MVPETROL\_F}*\Delta \text{NUPETROLTAX}. \qquad (2)$$

$$(\text{Initial})\ \text{Q1MVPETROL\_F} = \text{V1MVPETROL\_F}. \qquad (3)$$

$$\text{Update}\ \text{Q1MVPETROL\_F} = \text{x1mvpetrol\_f}. \qquad (4)$$

In Equation 2, TQMVPETROL_F is the per-unit motor fuel tax revenue, and ΔTQMVPETROL_F indicates changes in TQMVPETROL_F. ΔNUPETROLTAX indicates changes in per-unit motor fuel tax rate (NUPETROLTAX). We use ordinary change form for the per-unit more fuel tax rate considering it initial value is zero. Q1MVPETROL_F is the per-dollar worth quantity of motor fuel consumed. It is initially read in from the base-year dollar value of motor fuel use, V1MVPETROL_F (see Equation 3). Q1MVPETROL_F is subsequently updated by the percentage change in the quantity of motor fuel consumption, x1mvpetrol_f. TQMVPETROL_F is added to the total cost of PTS.

Equation 5 below is added to equate ΔV1FCTPTS and ΔTQMVPETROL_F.

$$\Delta \text{TQMVPETROL\_F} = \Delta \text{V1FCTPTS}. \qquad (5)$$

For simulations, we shock ΔV1FCTPTS to a negative amount which eliminates per-car FCT. f1fctPTS of Equation 1 and ΔNUPETROLTAX of Equation 2 are set endogenous. In this closure setting, Equation 1 determines f1fctPTS; Equation 5 determines ΔTQMVPETROL_F; and Equation 2 determines ΔNUPETROLTAX.

Modelling Private Vehicle Use in a Computable General Equilibrium Model of Taiwan

A thesis submitted to Monash University for the degree of Doctor of Philosophy

by

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Note: A more detailed table of contents, together with lists of tables and figures, appears at the start of each chapter. Similarly, a list of references follows each chapter.

Abstract

This thesis addresses several problems in modelling the demand for privately-owned motor vehicles in Computable General Equilibrium (CGE) models.

First, most models inappropriately treat cars and gasoline as substitutes, rather than complements, in household demand. This can produce odd results. For example, households buy less gasoline but more cars when gas prices rise—even though, in reality, motor vehicles require gasoline to provide transport services. Most conventional CGE models display this quirky behaviour, which arises from the use of additive demand systems, such as Linear Expenditure System (LES). But additivity is inappropriate for complementary commodities. In fact, the marginal utility of cars is closely related to petrol use.

Second, conventional CGE models fail to address the durable nature of privately owned motor vehicles. Households enjoy a long-lasting stream of transport services their cars provide. Yet, input-output accounts—the main data source for most CGE models—mention only newly-acquired cars and treat them as perishables in household consumption. In reality, households can still consume some transport services from their existing car stock even though they do not buy any new cars in some period. This leads to under-estimation of the economy's true consumption.

We tackle the above problems with TAIGEM, a CGE model of Taiwan. We create a dummy industry which produces transport services from gasoline and privately-owned motor vehicles. This approach has been used in input-output accounting to deal with owner-occupied dwellings. The new industry—named Private Transport Services (PTS)—uses motor vehicles as capital and gasoline as an intermediate input to produce transport services for households. We impute capital rentals for existing cars. Current car purchases are treated as additions to the capital stock of this industry. Consequently, households get utility from transport services yielded by their cars and gasoline. Moreover, household demand for gasoline is related to the whole stock of cars—both newly-acquired and existing. We specify a proper production structure for the PTS industry to ensure that cars and gasoline are complementary in producing transport services. We specify a substitution elasticity of 0.2 between car capital and motor fuels to account for price-induced fuel conservation. Vehicle license fees are also included in PTS production costs.

Car capital for the PTS industry has two special features. First, a car can be used immediately after purchase, while other industries in TAIGEM take one year to install capital. Second, cars with newer technology take time to filter into the stock:

technological changes do not affect pre-existing cars. We identify embodied technical change via the "vintage capital" approach, splitting the PTS industry into 11 sub-industries according to car age. We model the transport services produced by the different vintages as good, but not perfect, substitutes.

The new treatment allows better modelling of household demand for new cars. Assuming newer cars use less fuel, vehicle management policies that reduce the average service life of cars (such as heavier taxes on gas-guzzling cars) will also help abate greenhouse gas emissions.

Declaration

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

[redacted] [redacted]

Huey-Lin Lee

August, 2002

Acknowledgements

I wish to express my best gratitude to Dr. Mark Horridge and Professor Brian Parmenter for their excellent supervision during my candidature. I first met Dr. Horridge and Professor Parmenter while working on a Taiwan Environmental Protection Agency (EPA) sponsored research project in cooperation with the Center for Sustainable Development (CSD), Tsing Hua University, Taiwan. Their enthusiasm for computable general equilibrium (CGE) modelling inspired me to further study with the Centre of Policy Studies (CoPS), the home of many CGE experts. I have been bolstered by and benefited from Dr. Horridge's assistance with various essential aspects of CGE modelling and with my English writing. Due to his help, I acquired many skills to complete this thesis. It is a great privilege to be a student of Dr. Horridge. Professor Parmenter, a mentor indeed, introduced me to the issue of energy-using durables and enlightened me in the earlier stages of my Ph.D. candidature. Dr. Horridge and Professor Parmenter set standards to which I will always aspire.

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CHAPTER 1
Introduction

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1.1 The context of greenhouse gas emissions from transportation in Taiwan

Transportation pollution mitigation has become an important policy issue following the growing concerns over greenhouse gases (GHGs) emissions and global climate change. Economic activities involving combustion of fossil fuels are believed to be the main contributor to the fast build-up of GHGs in the atmosphere during the last few decades. The dramatic increase in atmospheric GHG inventories has caused global warming and changes in the earth's climate system. Via burning petrol, motor vehicles emit carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM) and volatile organic compounds (VOC). Road transport has become the single largest source of GHG emissions following the fast economic development in recent decades. These vehicle pollutants also reduce urban air quality and harm human health.

In Taiwan, the number of motor vehicles (for commercial and private use) has increased rapidly during the last two decades mainly due to fast economic development and increased per capita income (DGBAS, 2000; Lan, 1996). Motor vehicles are the single largest contributor to urban air pollution in Taiwan (EPA, 2001; Yang, 2001). EPA (2001) also indicates that transport sources of GHGs contribute a significant portion of total emissions in Taiwan. In 1995, motor vehicles emitted a 16% of the national CO_2 inventory. The transportation sector is also one of the main energy users. In recent years, the transport sector consumes about 35% of the total supply of petroleum products (MOEAEC, 2002).

Facing the increasing stress on global GHG emission abatement and Taiwan's dependence on imported energy, the Taiwan government convened the National Energy Conference (NEC) in May 1998 to discuss strategies for GHG emissions mitigation and energy conservation. To improve energy efficiency is the commonly promoted policy to cope with the current context of Taiwan's energy supply, environment and economic development. A target energy saving rate of 28% is set in the NEC for the whole economy to achieve by 2020. The transportation sector is supposed to contribute 17% of national energy savings. Since the NEC, the government has been implementing the "Comprehensive Plan for the Conservation of Energy and the Promotion of Energy Efficiency" (CPCEPEE), intending to progress towards the energy saving target. Regarding the transportation sector, the CPCEPEE plans to impose tougher fuel economy standards for vehicles, to introduce energy-saving vehicles, to establish comprehensive public transportation systems, to impose fuel tax in terms of consumption, rather than on the per-car basis, to implement strategies

for transportation management, and to develop intelligent transportation systems (MOEAEC, 2002).

The Taiwan EPA has been imposing tougher standards of fuel efficiency and emissions for new cars (EPA, 2001). Toman (1998) points out that technological progress has been commonly regarded as an ultimate approach to GHGs mitigation. As CO_2 emission is proportional to the amount of fuel burned, improving fuel efficiency can help reduce demands for motor fuels and CO_2 emissions as well. Yet, in the case of motor vehicles, it would take a certain period of time to reveal the effect of fuel efficiency improvement on energy consumption and emissions. This is due to slow scrapping of existing cars and small market penetration of new vehicle technologies. Vehicles fuelled by fuel cells, electricity and hydrogen fuel are more expensive to acquire and less convenient to refuel than conventionally fuelled vehicles. To promote the popularity of these clean vehicles, the Taiwan government has launched some projects to subsidize users of these "green vehicles"—e.g., hybrid petrol fuelled taxis and electric motorcycles. Judging from the continually increasing stress on environmental protection and sustainable development these "green vehicles" will eventually gain more market ground in the future.

Transportation management and the expansion of public transportation infrastructure are effective in reducing traffic congestion and thus motor fuel consumption and vehicle emissions. Construction of large-scale public transport infrastructure, such as Mass Rapid Transit (MRT) systems, has been undertaken or extended in the major metropolises—Taipei, Kaohsiung and Taichung. Since the launch of the MRT services, air quality of the Taipei metropolitan area has significantly improved. Encouraging passengers to switch to public transportation (e.g. the MRT, buses, and trains) can help offset the growth of motor fuel consumption and emissions due to increases of car number and car usage. The construction of the high-speed railway system linking the north and the south of Taiwan has also started recently. When completed, the high-speed railway system will significantly reduce both traffic on the existing major north-south freeways and air traffic between the two ends of the western corridor of Taiwan. This will reduce emissions from burning petrol.

Another frequently raised proposal to curb transportation emissions is to reduce the average age of the national fleet. Mandatory scrapping of old and gas-guzzling vehicles will improve the overall fuel efficiency and reduce GHGs emissions.

1.2 Overview of the thesis

The aim of this research is to achieve a more realistic and sensible modelling of transport services in TAIGEM, an environmentally-focussed computable general equilibrium (CGE) model of Taiwan. As fossil fuels are essential inputs in economic activities, the imposition of GHG abatement policies would have extensive effects on all sectors of the economy. Changes in the structure of the economy and energy intensity contribute significantly to changes in the projections of energy consumption and GHG emissions. The imposition of gasoline taxes for transport emissions abatement purpose would reduce distances travelled by passenger cars and thus shrink petroleum demand; may speed up the scrapping of old cars and thus affect sales of motor vehicles and household expenditure as well. CGE models are rich in sectoral details and are capable of capturing interaction between economic agents. TAIGEM adopts the ORANI/MONASH-style model structure (Dixon, Parmenter, Sutton, and Vincent, 1982; Dixon and Rimmer, 2002) for comparative static and recursive dynamic general equilibrium analyses. Considering the context of intensifying calls for GHG abatement, TAIGEM gives special treatment of electricity generation technologies and acknowledges inter-fuel and inter-fuel-factor substitution in production. CO_2 emissions accounting is attached to the model. We intend to incorporate the above mentioned context in TAIGEM so as to facilitate the general equilibrium analyses of policies that are proposed to reduce transportation emissions and fuel consumption.

In TAIGEM, the Railway Transport industry and the Land Transport (buses and taxis) industry provide commercial transport services. Trains, buses and taxis are treated as capital goods in combination with energy and other operating goods to produce commercial transport services. However, transport services provided by privately-owned motor vehicles are not explicitly modelled in TAIGEM. Like most CGE models, TAIGEM treats privately-owned motor vehicles as perishable goods and does not identify the special relation between motor vehicles and petrol in producing private transport services.

Our first innovation in TAIGEM involves the explicit modelling of private transport services, where we realistically recognise the durable nature of privately-owned motor vehicles and the complementarity between vehicles and petrol. We also recognise the special feature of cars: a newly-acquired car can be used immediately to provide transport services. This leads to our first new version of TAIGEM, named DURA. In version DURA, we set up a dummy industry to assume the production of transport services from petrol and privately-owned motor vehicles (as capital). Current car purchases are treated as additions to the capital stock of this industry. Households get utility from transport services yielded by petrol and their cars (both newly-acquired and existing).

Our second new version of TAIGEM, name TAIVINT, identifies vintages of privately-owned motor vehicles[1]. In version TAIVINT, we identify 11 vintages of cars, ranging from zero year old (brand-new) to ten years old. We assume that different vintages may have different fuel efficiency and cars are entirely retired after 11 years of use. This vintage distinction is to account for "embodied technical change" via the new-car additions to the capital stock. Version TAIVINT facilitates simulations of policies that impose tougher standards of fuel efficiency for new cars. In both versions, we also recognize the special substitution relationships between railway transport, land transport and private transport services.

1.3 The contribution of the thesis

We tackle several problems in modelling the demand for privately-owned motor vehicles in conventional CGE models. First, most models inappropriately treat cars and gasoline as substitutes, rather than complements, in household demand. This can produce odd results. For example, households buy less gasoline but more cars when gas prices rise—even though, in reality, motor vehicles require gasoline to provide transport services. Most conventional CGE models display this quirk due to use of additive demand systems which exclude complementarity between cars and petrol.

Second, conventional CGE models fail to address the durable nature of privately owned motor vehicles. Households enjoy a long-lasting stream of transport services their cars provide. Yet, input-output accounts—the main data source for most CGE models—mention only newly-acquired cars and treat them as perishables in household consumption. This leads to mis-measurement of the economy's true consumption.

Further, additions of new cars with better fuel efficiency and scrapping of older and gas-guzzling cars *gradually* change the intensity of fuel consumption and GHG emissions of the fleet. We identify embodied technical change via the "vintage capital" approach. New technology (e.g., vehicles with tougher standards of fuel efficiency) takes time to filter into the stock of cars: technological changes do not affect pre-existing cars. The MONASH model assumes that technical change affects the whole of capital stock immediately, which is not an appropriate assumption for cars.

[1] We are not able to identify vintages of commercial vehicles in TAIGEM as the capital stock of the Railway Transport and the Land Transport industries comprises vehicles (trains, buses and taxis) and other enterprise assets as well.

In addition, we account for the immediate provision of services of cars after purchase. The incorporation of vehicle license fees and per-car fuel consumption tax gives a more accurate account of car-use costs. The vintage treatment facilitates simulations of vehicle management policies concerning the average service life of cars, which has significant effects on the demand for new cars and on the estimation of CO_2 emissions from car use. We also recognise the special substitution relationship between private and public (train and buses) transport services. These attempts achieve our aim of improving the existing modelling of the transport services in TAIGEM and produce more sensible simulation results of demands for motor fuels and privately-owned cars.

1.4 Outline of the thesis

In Chapter 2, we do some literature survey on: models that recognise the complementarity relationship between energy-using durables and the associated energy; multi-sectoral models with vintage distinction for capital; partial equilibrium (single-sector) models with vintage distinction; and the advantages of the vintage distinction in energy-environmental policy analyses. In Chapter 3, we introduce the TAIGEM model, in both comparative static and recursive dynamic modes.

In Chapter 4, we introduce the first new version of TAIGEM—version DURA. We set up a new industry, named Private Transport Services (PTS), which uses motor fuels and privately-owned motor vehicles to produce transport services specifically for households. This "dummy industry" approach is commonly used in Input-Output accounting and in many CGE models to treat household dwelling use. For the PTS industry, car purchases are treated as additions to its capital stock. We impute capital rentals for existing cars. The PTS industry combines the services of car capital and motor fuels to produce transport services for households. We also take account of the immediate provision of services of newly acquired cars.

In Chapter 5, we introduce the second new version of TAIGEM—version TAIVINT. To identify embodied technical change, we split the car stock of the PTS industry into 11 vintages according to car age. Vintages of cars are assumed to have different fuel economy standards: newer vintages are more efficient. We model the transport services produced by the different vintages as good, but not perfect, substitutes.

With both versions DURA and TAIVINT, we run an illustrative simulation of gasoline tax to show the advantages of our innovations regarding household demands for new cars and motor fuels, and the estimation of CO_2 emissions from transportation.

Chapter 6 summaries the main findings of this research and proposes a future research agenda.

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CHAPTER 2
Literature Review

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2.1 Introduction

Following our main ideas about a more realistic and sensible modelling of private transport services, we review literature on the following themes:

(1) models that recognise the complementarity relationship between energy-using durables and the associated energy (in Section 2.2);

(2) energy-environment-economy focussed multi-sectoral models with vintage distinction for capital (in Section 2.3);

(3) partial equilibrium (single-sector) models with vintage distinction and the advantages of the vintage distinction in energy-environmental policy analyses (in Section 2.4).

2.2 Models with recognition of the complementarity relationship between energy-using durables and the associated energy

Conrad (1983), Conrad and Schröder (1991a) and Conrad and Schröder (1991b) developed an integrated framework of consumer demands for 20 non-durable goods (e.g., food, gasoline, electricity, heating energy and services) and for 3 durable goods (i.e., cars, electric appliances and heating apparatuses) to simulate the impact of an energy tax on demands for durables. Gasoline, electricity and heating energy are related to the stock of automobiles, electrical appliances and the heating apparatuses (see Conrad and Schröder (1991b)). They assume short-run quasi-fixity for durables. Consumer utility comes from consumption of non-durables and the services provided by the quasi-fixed durables. The prices of utilising durables include the costs of their operating energy. The representative consumer invests to adjust the stock of consumer durables towards their long-run optimal levels. This framework is later transplanted into the GEM-E3 model (Capros *et al.*, 1997).

A brief algebraic expression is given below.

Minimise $e(\mathbf{u}, \mathbf{p}, \mathbf{z})$

s.t.

$\mathbf{u}$: utility level,

$\mathbf{p}$: the price vector of non-durable goods, and

$\mathbf{z}$: the vector of quasi-fixed stock of durables.

$e(\bullet)$ is the variable expenditure function of non-durable goods. The unit user-cost, $\bar{p}_z$, for using durables is the sum of the rental of capital, p_z, and the cost of operating energy. Expenditures on energy are split into two parts: the first part is associated with the energy requirement (e.g., litres of gasoline) of energy-using durables (e.g., automobiles), a portion of the energy expenditure is associated with the stock of durables. The remaining is at the consumer's disposition.

The optimal stock of the durables is determined from the inter-temporal minimisation of total expenditures on non-durables, net investment of new durables, replacement, and taxes on durables (e.g., vehicle tax). For the long run, the representative consumer minimises the present value of the expected sum of variable expenditures on non-durables, quasi-fixed durables, and adjustment costs.

2.3 Energy-environment-economy models with vintage distinction for capital

Following the growing concerns over energy conservation and greenhouse gases emissions, distinguishing between different vintages of energy-using capital is becoming increasingly common. As Jacobsen (2000) points out, technological progress is an important factor in long-term energy demand projections and in environmental analyses. Newer vintages of capital account for technological progress via embodied technical change. "Bottom-up" and "top-down" models differ in the treatment of technological progress and the introduction of new technologies. This contributes to differences in their results for greenhouse gases mitigation analyses.

Wilson and Swisher (1993) explore differences between "bottom-up" and "top-down" approaches for greenhouse gases abatement analyses. Embedded with rich engineering details, "bottom-up" models tend to distinguish capital vintages and explicitly recognise the introduction of new technologies. "Top-down" models highlight interactions between sectors of the economy and solve for sectoral derived demands for energy following highly aggregate production functions. "Bottom-up" models are more realistic than "top-down" models in terms of the description of energy-related technologies. "Top-down" models are good at capturing economically optimal behavioural response. This feature is normally scant in "bottom-up" models. Recently efforts have been put to the linkage of a "top-down" and a "bottom-up" model.

In this section, we review three energy-environment-economy models that have endeavoured to integrate the features of "top-down" and "bottom-up" models. We highlight their treatment of capital vintages and the introduction of new technologies. The three models selected are: (1) the OECD GREEN model, (2) the National Energy Modeling System, (3) the MARKAL model and its enhanced versions—MARKAL-MACRO and TIMES.

The OECD GREEN model

The OECD GREEN model (Burniaux, Nicoletti, and Oliveira-Martins, 1992; Lee, Oliveira-Martins, and van der Mensbrugghe, 1994; van der Mensbrugghe, 1994) is a global, recursive dynamic applied general equilibrium (AGE) model, with a special focus on the relationships between depletion of fossil fuels, energy production and consumption, and CO_2 emissions. It is descended from the World Agricultural Liberalization Study (WALRAS) (OECD, 1990), which was developed for analyses of global trade reform.

As a recursive dynamic model, GREEN is solved periodically as a single-period (5-year or 20-year interval) model. Labour, capital accumulation, fossil fuel resource depletion, and energy and factor efficiency improvements of sequential years are linked together via the transition equations. In forecasting, GREEN is calibrated on exogenous growth rates of population, labour, GDP per capita, and autonomous energy efficiency improvement (AEEI). The exogenous AEEI is specific to regions, sectors, capital vintages, and solution periods. Changes in labour efficiency (productivity) are exogenous. For the model to produce balanced economic growth, capital efficiency is endogenously determined in the business-as-usual (no energy policies imposed) simulations. This is equivalent to a constant capital-labour ratio (where the factors are measured in efficiency units).

Each sector in GREEN produces vintage-specific output: from old or new capital. New capital is acquired in the last period and starts service in the current period. New capital becomes old capital after one period's service. Sectoral vintage-specific output sums to meet the demand for sectoral output. If the demand for sectoral output is less than its total supply, the sector will disinvest old (installed) capital. On the other hand, the sector will increase investment if the demand for sectoral output exceed sectoral production. Sectoral output from new capital is determined as a residual of demand for sectoral output minus sectoral output from old capital. Sectoral output from old capital is defined as the amount of old capital divided by the capital/output ratio.

Vintaged capital stock in GREEN reveals the putty/semi-putty assumption. New capital is putty: it is more substitutable for other inputs (e.g., a substitution elasticity of 2.0). Old capital is sector-specific and is semi-putty: it is less substitutable for other inputs (e.g., a substitution elasticity of 0.25). New capital is fully mobile among sectors. Industries may disinvest old capital in response to the difference between the rental values of old and new capital. Disinvested old capital is assumed to be homogeneous to new capital and has the same price per efficiency unit. The substitution possibilities between sectoral total capital and other inputs will be the

vintage-share weighted average of the two vintage-specific capital-materials substitution elasticities.

GREEN recognises short-run complementarity and long-run substitution relationships between energy and capital. It specifies a lower capital-energy substitution elasticity for the short run, and a higher substitution elasticity for the long run. The vintage composition would affect the substitution possibilities between sectoral total capital and energy, as newer capital is more energy substitutable than older capital. The short-run substitution elasticities will converge to the long-run ones (Burniaux *et al.*, 1992, Figure 5, p.66). The convergence of short- and long-run substitution elasticities is facilitated by the capital stock adjustment, the pace of which is positively related to the rate of depreciation and investment growth.

GREEN incorporates seven energy backstop substitutes to be commercially available in the foreseeable future. Solar, wind, biomass, and nuclear fusion energy are potential backstops. Two sorts of backstop substitutes—carbon intensive (tar sands) and carbon free (biomass)—are identified for coal, crude oil, and natural gas. Carbon-free backstops (e.g., solar, wind, and nuclear fusion energy) are to serve as substitutes for electricity. Baseline scenarios (with energy planning policies) for GREEN contain assumptions about backstops: unit costs, unit costs per tera-joule, carbon emissions coefficients, substitution elasticities between backstops and conventional fuels, and penetration shares.

GREEN has a broad category called transportation and communication in household demand. It is a fixed proportion relationships between energy composite and non-energy composite.

The National Energy Modeling System

The National Energy Modeling System (NEMS) (EIA, 2000) is an energy-economy forecasting model of the U.S. energy markets for the medium term (20 to 25 years). It is developed and implemented by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE). NEMS performs annual forecasting for various aspects of energy—production, imports, conversion, consumption, and prices—subject to assumptions on macroeconomic conditions, world energy markets, resource availability and costs, and costs and performance characteristics of energy technologies, and demographics.

NEMS consists of four modules of end-use demands for fuels: residential, commercial, transportation, and industrial sectors. NEMS has detailed treatment of sectoral-specific technologies (e.g., initial costs, operating costs, date of availability, efficiency, and other sector-specific characteristics) and technology improvement over time. NEMS identifies vintaged (time-of-installation dependent) energy equipment and structures (e.g., building shells) and tracks vintaged capital stock turnover. NEMS also considers the potential for the development and use of new energy-related technologies, increased use of renewable sources of energy, and increases in the efficiency of energy use.

The industrial demand module of NEMS identifies three vintages of industry capital:

(1) old vintage consists of capital acquired prior to 1994 and is assumed to retire at a fixed rate each year;

(2) middle vintage refers to capital added between 1994 and the year when forecasting begins; and

(3) new vintage of capital is added during the forecasting period to augment the production capacity.

All vintages of capital are assumed to depreciate at the same annual rate.

The transportation demand module (TRAN) of NEMS has very detailed description of vehicle technologies: six car sizes, six light truck sizes, fifty-nine conventional fuel-saving technologies for light-duty vehicles, gasoline, diesel, and thirteen alternative-fuel vehicle technologies for light-duty vehicles, and twenty vintages of light-duty vehicles. The TRAN module forecasts the fuel consumption (including renewables and alternative fuels) of various transportation modes, vehicle-miles travelled, fuel efficiencies by technology type, and sales of alternative-fuel vehicles. All these forecasts are based on fuel prices and macroeconomic forecasts[1] from NEMS, and other exogenous information[2]. Changes in fuel prices would affect fuel efficiency, vehicle-miles travelled, and the market penetration of alternative-fuel vehicles. Shares of alternative fuels are projected on the basis of a multinomial logit vehicle attribute model, subject to State and Federal government mandates.

The Vehicle-Miles Travelled (VMT) sub-module of TRAN projects travel demand for automobiles and light trucks. VMT per capita is estimated in terms of fuel costs of per-mile-driven, per capita disposable personal income, an index that reflects the ageing of the population, and an adjustment for female-to-male driving ratios. Total VMT is calculated by multiplying VMT per capita by the driving age population.

---

1 Examples are disposable personal income, GDP, imports and exports, industrial output, and new car and light truck sales.

2 Exogenous information incorporated in the TRAN module includes current and projected demographics, existing vehicle stocks by vintage and fuel efficiency, vehicle survival rates, characteristics of new vehicle technology, commercial availability of alternative fuels and new-technology vehicles, vehicle safety and emissions regulations, and vehicle-miles-per-gallon degradation rates.

The MARKAL model and its enhanced versions—MARKAL-MACRO and TIMES

The MARKAL model

The MARKAL (MARKet ALlocation) model (International Resources Group, 1999; Seebregts, Goldstein, and Smekens, 2001) is a bottom-up energy system engineering model. It was developed by the International Energy Agency (IEA) sponsored Energy Technology Systems Analysis Programme (ETSAP).

MARKAL uses a linear programming approach to solve for least-cost energy supply technologies subject to exogenous demands for energy services. The MARKAL database contains great detail of future demands for "energy service" by sector (i.e., residential, manufacturing, transportation, and commercial sectors) and by specific functions within a sector (e.g., residential air conditioning, boilers, and automobiles). New technologies of energy service demands, e.g., less energy- or less carbon-intensive technologies, can be incorporated in the model. Therefore MARKAL can assess the effects of the introduction of new technologies on total costs of the energy system, changes in fuel and technology mix, and greenhouse gases emissions.

MARKAL also has a detailed description of domestic and imported energy supply (including fossil fuels, nuclear, and renewables). The energy supply technologies range from extracting, transporting, converting, and using energy, to both existing and prospective technologies in the foreseeable future. The MARKAL database contains details of the energy supply technologies: investment costs, operating and maintenance costs, service life, fuel use, fuel efficiency, availability, output capacity, and maximum expected market penetration. With rich details of energy supply and demand technologies, MARKAL is capable of evaluating policies concerning R&D programs, energy performance standards, building codes, demand-side management and renewable technology programs.

The MARKAL-MACRO model

The MARKAL-MACRO model (Manne and Richels, 1991) is a non-linear, dynamic optimisation model that links MARKAL to a two-sector (producer and consumer), "top-down" neoclassical macroeconomic growth model—MACRO. Unlike in MARKAL, energy demands are endogenously determined in MACRO and are then fed to MARKAL.

Similar to many energy-environment focussed "top-down" models, MACRO has the following features:

(a) the trade-off between energy expenditure and investment;

(b) consumer utility maximisation and the trade-off between consumption and investment;

(c) lagged demand response to changes in prices;

(d) capital accumulation over time;

(e) substitution between energy services; substitution between capital and labour; substitution between the energy service composite and the capital/labour bundle in production;

(f) autonomous conservation of energy; and

(g) market penetration of supply technologies.

The MARKAL-MACRO model operates with the following steps:

(1) MARKAL solves for the least-cost mix of energy supply technologies to meet demands for energy services;

(2) MARKAL passes the energy costs to MACRO;

(3) MACRO considers the energy costs in the economic activities (to maximise economic growth and discounted consumer utility) and endogenously determines demands for energy services; and

(4) MACRO passes the energy demands to MARKAL.

This solving process iterates until both models obtain an optimal solution. Figure 2.1 shows an overview of MARKAL-MACRO modelling system.

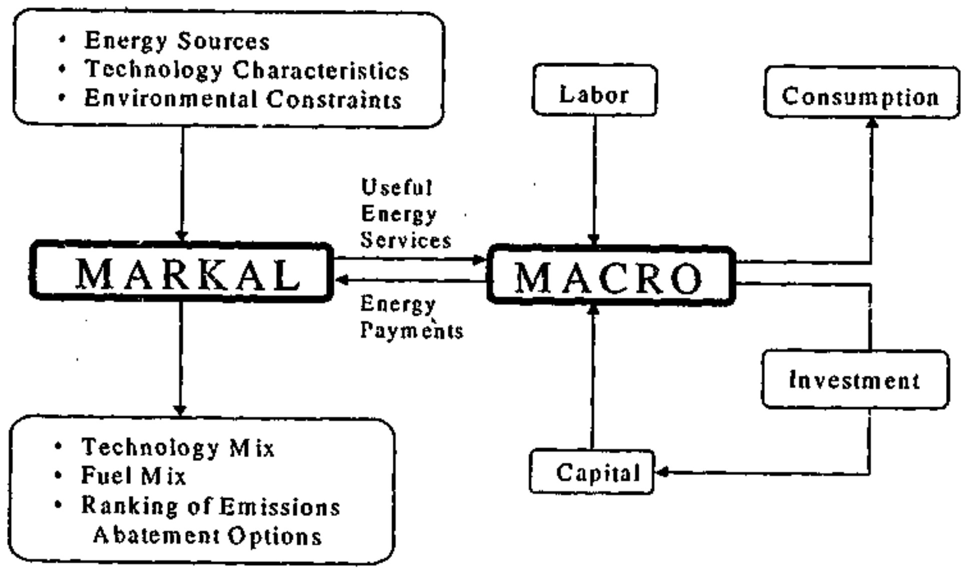

Figure 2.1 Overview of the MARKAL-MACRO modelling system

Source: U.S. Department of Energy, Country Studies Management Team (1995).

The TIMES model

The TIMES (The Integrated MARKAL-EFOM System) model (International Resources Group, 1999; Seebregts *et al.*, 2001) is a quite recent (1999) member of the MARKAL family. TIMES models the vintaging processes of capital by recognising the increasing costs for ageing energy supply technologies (e.g., electricity generation apparatuses) due to deterioration or more frequent maintenance). The vintage enhancement in TIMES facilitates analyses of policies that subsidise less carbon- or energy-intensive technologies and encourage the replacement of obsolete capital equipment.

2.4 Literature on the advantages of the vintage capital distinction in energy-related policy analyses (partial equilibrium approach)

Jacobsen (2000) finds that embodied technological change is often the main contributor to changes in input (e.g., energy) efficiencies of capital-intensive industries. Technological progress looms large in long-term energy demand projections and in environmental analyses. As noted above, the differences between "bottom-up" and "top-down" approaches to greenhouse gases mitigation costs can be ascribed to the different assumptions on technological progress and diffusion of new technologies.

Ruth, Amato, and Davidsdottir (2002) use a dynamic computer model of the U.S. ethylene production to explore effects of alternative climate change policies on the industry's energy use and carbon emissions. The model endogenously calculates production rates, capacity and investment requirements, efficiency changes, energy and feedstock use, and carbon emissions, given historic and forecast energy prices, GDP, and fuel-specific carbon coefficients.

The model distinguishes the industry's main cracker[3] types, fuels used as feedstocks and for process energy. It also recognises the vintage structure and vintage-specific efficiencies of the industry's capital. The model traces a set of age-specific efficiency characteristics by production process. Changes in efficiency occur through the replacement of old capital with new and more efficient capital. The changing capital vintage structure gradually increases overall efficiency of the industry and reduces the intensity of feedstock and/or of process energy use of new capital relative to existing capital stock of that year. Aggregate efficiency of the ethylene industry is calculated as a weighted sum of vintage-specific efficiencies of all processes, where the weights are determined by production capacity of the respective vintage class used in each process. The model assumes that within a vintage

[3] A cracker is used to convert ethane and liquefied petroleum gas (LPG) into ethylene.

class efficiencies remain constant and that each capital vintage class is fully retired after 25 years.

The research suggests: policies that directly affect the relative efficiencies of new to old capital (e.g., R&D stimuli or investment tax credit, and accelerated depreciation schedule) are more effective in reducing carbon emissions from the ethylene industry than policies that increase the cost of carbon emissions from process energy such as carbon taxes or a carbon permit system.

Sterner (1990) applies a similar approach and finds that capital-embodied technological progress accounts for 90% of the changes in energy use of the Mexican cement industry. For the U.S. cement industry, capital stock turnover helps improve the industry's energy efficiency. Retrofitting existing capital does not improve energy efficiency by much (Worrell, Martin, and Price, 2000).

Ruth and Amato (2002) point out that the vintage distinction in capital facilitates analyses of the vintage-specific impacts of industrial and climate change policies. Vintage-specific impacts are important because of the following reasons:

(1) the flexibility of industry response to policies is subject to the service lives of capital units and the vintage structure of the existing capital stock;

(2) capital vintages differ in energy and emissions intensities; and

(3) capital vintages differ in production capacity and utilisation rates.

For policies to be effective, vintage structure of industry capital and capital turnover rates are essential. Yet, only a few models acknowledge this issue in analysing climate change policies.

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CHAPTER 3
The Theoretical Structure of TAIGEM

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3.1 Introduction

TAIGEM[1] is a computable general equilibrium (CGE) model of Taiwan, based on the ORANI-G model (Horridge, Parmenter, and Pearson, 1998). The TAIGEM model contains a system of simultaneous equations describing the interrelation between all markets. There is no excess demand or supply in any market. All markets interact to determine prices and quantities. With its focus on greenhouse gases (GHGs) issues, TAIGEM has a special treatment of the electricity industry. TAIGEM also has a recursive mechanism of dynamics, which facilitates simulations of GHGs issues.

In Section 3.2 we introduce our computation procedure for TAIGEM. In Section 3.3, we give a brief overview of the naming system in TAIGEM. In Section 3.4 we introduce the database of TAIGEM, and in Section 3.5 we describe the model's theoretical structure. We describe in Section 3.6 the mechanism of investment allocation across industries for comparative static simulations. The investment mechanism for recursive dynamic simulations is introduced in Section 3.9. Section 3.7 points out differences between comparative static and recursive dynamic simulations with TAIGEM. We convert the static TAIGEM into a year-on-year recursive dynamic model by adding explicit capital accumulation formulae. These are described in Section 3.8. Section 3.10 describes the operation of the labour market in dynamic simulations—we specify explicitly a labour supply function and a mechanism of real wage adjustment. We conclude this chapter with a discussion of closure rules.

3.2 The computation procedure of TAIGEM

The TAIGEM model consists of a series of equations that depict the economy in equilibrium for some period t. The equation system can be denoted algebraically as:

[1] This chapter describes the pre-existing TAIGEM model, which is in turn based on the Australian ORANI-G model. TAIGEM was constructed by a team of Australian and Taiwanese economists (of which the author was a member). Thus, TAIGEM is neither novel for this thesis nor the work of the author alone. It has been included as a necessary background to the model enhancements (which are due solely to the author) described in subsequent chapters. It is the first comprehensive English description of the TAIGEM model (some descriptions have been published in Chinese, see Hsu, Lee, Li, and Huang (1999a), Hsu, Lee, Li, and Huang (1999b), Huang, Hsu, Li, Lin, and Liu (1999), Lee, Li, Hsu, and Huang (1998), and Huang, Hsu, Li, Hsu, and Liang (1998)). Some parts of the text draw on the Horridge, Parmenter, and Pearson (1998) description of the ORANI-G model. However, TAIGEM differs from ORANI-G in many respects.

$$\mathbf{F}(\mathbf{V}^t) = \mathbf{0}. \quad (3.1)$$

Vector **V** contains n economic variables in levels, such as prices, quantities, taxes and technological coefficients for the period t. **F** represents a system of m non-linear equations, such that arise from: market-clearing for all goods and factors; optimisation behaviour of economic agents (utility and profit maximisation); and zero-pure-profits conditions (prices equal to unit costs); and for each year run of the recursive dynamic simulations the quantities of closing capital stocks equal to the sum of the quantities of investment and depreciated opening capital stocks[2]. The number of variables, n, is greater than that of equations, m.

To solve the equation system for period t, we need to set (n-m) variables exogenous. That is, the model computes the numerical results of the n endogenous variables, given values of the (n-m) exogenous variables. Having made this choice, we rewrite Equation 3.1 as:

$$\mathbf{F}(\mathbf{Y}^t,\mathbf{X}^t) = \mathbf{0}, \quad (3.1a)$$

where **Y** is a n-length vector of endogenous variables and **X** is a (n-m)-length vector of exogenous variables for period t.

We adopt the Johansen (1960) linearisation approach to solve the model. This involves transforming all the levels variables into percentage change form by totally differentiating the model, and computing the percentage changes in **Y** for given changes in **X**. We first assume that there already exists some solution to the model, $\{\mathbf{Y}^0,\mathbf{X}^0\}$, such that:

$$\mathbf{F}(\mathbf{Y}^0,\mathbf{X}^0) = \mathbf{0}.$$

As is the CGE convention, we draw on the input-output data of some year (t = 0) to be the initial solution, $\{\mathbf{Y}^0,\mathbf{X}^0\}$. That is, we assume that the economy as indicated by the input-output data was in equilibrium as our equation system suggests.

Next, we totally differentiate the equation system and evaluate it at $\{\mathbf{Y}^0,\mathbf{X}^0\}$:

$$\mathbf{F}_Y(\mathbf{Y}^0,\mathbf{X}^0)\mathbf{dY} + \mathbf{F}_X(\mathbf{Y}^0,\mathbf{X}^0)\mathbf{dX} = \mathbf{0}. \quad (3.2)$$

$\mathbf{F}_Y(\mathbf{Y}^0,\mathbf{X}^0)$ and $\mathbf{F}_X(\mathbf{Y}^0,\mathbf{X}^0)$ are matrices of the first-order derivatives of **F** with respect to **Y** and **X**, evaluated at the initial solution $\{\mathbf{Y}^0,\mathbf{X}^0\}$. We transform the variables into percentage change form and rewrite Equation 3.2 as:

[2] The closing capital stocks for one year appear as the opening stocks for the next year. This is done via the capital accumulation formulae as introduced in Section 3.9. These links reveal the proceeding of the economy in time and thus formulate the forecasting paths (see detailed introduction in Section 3.7).

$$\mathbf{G}_Y(\mathbf{Y}^0,\mathbf{X}^0)\mathbf{y} + \mathbf{G}_X(\mathbf{Y}^0,\mathbf{X}^0)\mathbf{x} = \mathbf{0}, \quad (3.3)$$

with

$$\mathbf{G}_Y(\mathbf{Y}^0,\mathbf{X}^0) = \mathbf{F}_Y(\mathbf{Y}^0,\mathbf{X}^0)\hat{\mathbf{Y}} \quad \text{and} \quad \mathbf{G}_X(\mathbf{Y}^0,\mathbf{X}^0) = \mathbf{F}_X(\mathbf{Y}^0,\mathbf{X}^0)\hat{\mathbf{X}},$$

where $\hat{\mathbf{Y}}$ and $\hat{\mathbf{X}}$ are diagonal matrices. **y** and **x** are vectors of percentage change variables:

$$\mathbf{y} = 100\hat{\mathbf{Y}}^{-1}\mathbf{dY} \quad \text{and} \quad \mathbf{x} = 100\hat{\mathbf{X}}^{-1}\mathbf{dX}.$$

Rearranging Equation 3.3 gives:

$$\mathbf{y} = -\,\mathbf{G}_Y(\mathbf{Y}^0,\mathbf{X}^0)^{-1}\mathbf{G}_X(\mathbf{Y}^0,\mathbf{X}^0)\mathbf{x}. \quad (3.4)$$

The Johansen approach produces a linear approximation around the initial solution. It makes the computation of the model rather simple and requires less computing resources, especially when it comes to large-scale models. However, it produces accurate results only for small changes in **Y** and **X**. The accuracy of the results depends on the magnitude of exogenous shocks: linearisation errors increase in proportion to the size of the exogenous changes. To reduce linearisation errors, we adopt the multi-step solution procedure: divide the size of the exogenous shock into several portions, and solve, in sequence, for the endogenous variables in terms of each portion of the exogenous shock (Harrison and Pearson, 1996; Harrison and Pearson, 2000)[3].

3.3 Notation system of TAIGEM

Variables, coefficients and parameters are the basic elements of the TAIGEM model. Variables in levels form are used in describing the specifications of the model's theory and they are presented in uppercase. Variables in percentage change form are the results of the linearisation of the model's equation system and they are presented in lowercase. Coefficients refer mainly to shares calculated from the values of the products of the price and quantity variables in levels. Examples are cost shares and sales shares[4]. Parameters[5] are associated with the functional forms specified in the model. A good example is the CES (constant elasticity of substitution) substitution elasticities between primary factors.

[3] We use GEMPACK (General Equilibrium Modelling PACKage) to solve the model. GEMPACK is developed by Ken R. Pearson and colleagues at the Centre of Policy Studies, Monash University, Australia.

[4] Flow values are held constant at any step in a Johansen-style computation, but are updated (re-evaluated) at the end of each step in a multi-step computation with the resulting percentage changes in their corresponding price and quantity variables. The shares are re-evaluated using the updated values.

[5] Parameters are held constant through the whole process of the computation.

We name the variables, coefficients and parameters of TAIGEM following the Horridge, Parmenter, and Pearson (1998) convention as listed in Table 3.1. Table 3.2 lists the sets over which variables, coefficients and parameters are defined. In Table 3.3 we give some examples of the variable and coefficient names coupled with their dimensions. Detailed lists of variables, coefficients, commodities, and industries are consolidated in Appendix 1.

Table 3.1 The system of TAIGEM notation

Notation		Description
Levels form	Percentage/ordinary change form	
(A) The prefixes		
P	p	price, in local currency
PF	pf	price, in foreign currency
X	x	quantity
V	w	value = price × quantity
A	a	technological coefficient
F	f	shifter
T	delv (CHANGE*)	power** of commodity tax, *ad valorem*
ST	dels (CHANGE)	rate of commodity tax, specific
LEV	LEV (CHANGE)	levels
SIGMA		elasticity of substitution
S		share
(B1) The first part of the root		
1		current production
2		fixed capital formation
3		household consumption
4		exports
5		government demands
6		changes in inventories
0		for all users, or user distinction irrelevant

* The expression, (CHANGE), in GEMPACK's TABLO language indicates ordinary change.

** The power of a tax is one plus the *ad valorem* rate of tax.

....continued

Table 3.1 (continued)

Notation		Description
Levels form	Percentage/ordinary change form	
(B2) The second part of the root		
BAS	bas	basic—not including margins or taxes
PUR	pur	at purchasers' prices
CIF	cif	imports at border prices
TOT	tot	total or average over all inputs for some user
LOC	loc	local
DOM	dom	domestic
IMP	imp	imports (duty paid)
CAP	cap	capital
LAB	lab	labour
LND	lnd	land
LUX	lux	linear expenditure system (supernumerary part)
MAR	mar	margins
OCT	oct	other cost tickets
PRIM	prim	all primary factors (land, labour or capital)
SUB	sub	linear expenditure system (subsistence part)
TAR	tar	tariffs
TAX	tax	indirect taxes
MAKE		commodity supplies of industries
(C) The suffixes		
_S	_s	summation over the SRC (index s) dimension
_I	_i	summation over the IND (index i) dimension
_IO	_io	summation over both IND and OCC (index o) dimensions
_CSI	_csi	summation over the COM (index c), SRC, and IND dimension

Table 3.2 Sets used in TAIGEM

Set	Description	Association of sets
COM	all commodities	= MAR + NONMAR = TRADEXP + NTRADEXP
IND	all industries	= ELECIND + ORDINARY = EXOGINV + ENDOGINV
ELECIND	power-generating industries plus the distributor industry	subset of IND
ELECGEN	power-generating industries/output	subset of ELECIND subset of IND subset of COM
NONELECCOM	output of non-power-generating industries	= COM - ELECGEN
ORDINARY	industries other than ELECIND	subset of IND
EXOGINV	industries whose investment plans are regulated	subset of IND
ENDOGINV	industries other than EXOGINV	subset of IND
LOCALUSERS	local users of CO_2-emitting commodities	= IND + "Invest" + "HouseH" + "GovGE"
MAR	margins commodities	subset of COM
NONMAR	non-margins commodities	subset of COM
TRADEXP	commodities that are highly export oriented	subset of COM
NTRADEXP	commodities other than TRADEXP	subset of COM = MAREXP + OTHEREXP
MAREXP	commodities, the demands for which are closely related to international trade volume	subset of NTRADEXP subset of COM
OTHEREXP	NTRADEXP commodities other than MAREXP	subset of NTRADEXP subset of COM
ENERCOM	energy commodities subject to CES substitution	subset of COM
NONENERCOM	commodities not subject to the inter-fuel CES substitution	= COM - ENERCOM
BADCOM	CO_2-emitting commodities	subset of COM
SRC	sources of commodities: domestic ("dom"); imported ("imp")	
DST	destinations of domestically-produced commodities: the local market; export	
OCC	occupations of labour	
FAC	primary factors—labour, capital, and land	

Table 3.3 Some examples of the notation system

Variable/coefficient: Levels form	Variable/coefficient: Percentage or ordinary change form	Index range	Description
P1LAB(i,o)	p1lab(i,o)	i∈ IND o∈ OCC	wage paid to labour of occupation o by industry i
X1(c,s,i)	x1(c,s,i)	c∈ COM i∈ IND o∈ OCC	demand of industry i for good c from source s for current production
V3PUR_S(c)		c∈ COM	value of household consumption of good c from both sources, at purchaser's price
X2MAR(c,s,i,m)	x2mar(c,s,i,m)	c∈ COM s∈ SRC i∈ IND m∈ MAR	demand for margins services m to deliver good c from source s purchased by industry i for fixed capital formation
T5(c,s)	delv5(c,s)	c∈ COM s∈ SRC	power of *ad valorem* commodity tax on good c from source s purchased by government
A1CAP(i)	a1cap(i)	i∈ IND	capital-using technological variable of industry i
SIGMA1PRIM(i)		i∈ IND	elasticity of substitution between primary factors for industry i
V0TAR(c)		c∈ COM	tariff on good c

3.4 The database of TAIGEM

The database of TAIGEM contains four categories of data: (a) Input-Output (I-O) data, (b) elasticity parameters and base-period[6] values for other parameters, (c) data for carbon dioxide (CO_2) emissions, and (d) data needed for the recursive dynamic mechanism of investment. TAIGEM uses the Input-Output (I-O) tables as building blocks. The Input-Output data and the parameters constitute an initial solution to the model. They are reviewed in Section 3.4.1. In Section 3.4.2, we describe the input-output features of the electricity industry, which gives special treatment in our modelling. The CO_2 emissions data—used as the tax base for carbon taxes—are required in producing the CO_2 emissions growth path. A description of the CO_2 emissions accounting is in Section 3.4.3. Data needed for the extension to a recursive dynamic model include industry-specific capital stocks, rates of depreciation, and parameters required by the investment function. They are described in Section 3.4.4.

3.4.1 Input-output data and parameters

The Input-Output (I-O) Accounts have two parts: the absorption table and the make table. The absorption table shows input compositions of domestic producers and several categories of final demands for commodities—household consumption, fixed capital formation, exports, government demands and changes in inventories. The make table shows the output compositions of industries and the industrial origins of commodity supplies. The output levels in the make table are valued at basic values—excluding margins and commodity taxes.

Figure 3.1 summaries the I-O database of TAIGEM. The absorption table follows the commodity-by-industry convention. There are six broad groups of users identified across the columns:

(1) domestic producers, totalling I industries,

(2) investors of industry-specific fixed capital, distinguished by I industries,

(3) a single representative household,

(4) an aggregate exporter of domestically produced commodities to overseas,

(5) government, and

(6) changes in inventories.

Changes in inventories are either positive or negative. A positive value indicates accumulation of commodities over the base period. A negative value indicates dissipation. We also assume that no imports are re-exported. Hence, the import source is not applicable to exports.

[6] The base period is the year of the Input-Output data.

The first row identifies the basic values of commodity flows from domestic and imported sources. The second and the third rows respectively show margins and *ad valorem* commodity taxes associated with the domestic and imported commodity flows to the users. The fourth row shows specific taxes associated with CO_2 emissions from use of fossil fuels. We identify M out of the domestically produced commodities to be used as margins services. Examples are wholesale, retail, and transport. For each margins commodity, a portion of its volume is used to facilitate the delivery of commodities from producers' sites or ports of entrance to the users or ports of exit. The other portion is used as direct consumption. For example, train freight for the delivery of computers from the producer's factory to the purchaser is regarded as a margin on the demand for computers. The train fare for commuters is counted as direct consumption. There are no margins, sales taxes nor specific taxes on inventories. Following the Input-Output convention, only producers use primary factors—labour, capital, and land. Occupations of labour are identified. "Other costs" in the penultimate row covers various miscellaneous costs associated with production, such as vehicle license taxes and stamp duties.

The size of the TAIGEM input-output database

The TAIGEM input-output database is based on the I-O Tables of year 1994, which identify 150 commodities and industries. These dimensions are enlarged by a series of disaggregations. We disaggregate the output of the oil and gas exploitation industry into crude oil and natural gas. We also disaggregate the output of the oil refinery industry into 10 petroleum products:

(1) gasoline,	(6) lubricants,
(2) diesel fuel,	(7) naphtha,
(3) aviation fuel,	(8) refined gas,
(4) fuel oils,	(9) asphalts, and
(5) kerosene,	(10) other petroleum products.

We also divide the single electricity industry into 10 power-generating industries and one electricity distributor. We describe the data for the electricity industries in Section 3.4.2.

As a result of these disaggregations, the TAIGEM input-output database has 170 commodities produced by 160 industries[7]. Two industries—the oil and gas exploitation industry and the oil refinery industry—produce multiple products.

In the TAIGEM I-O database, we recognise 8 types of margins commodities:

(1) wholesale trade services,
(2) retail trade services,
(3) international trade services,
(4) rail transport,
(5) land transport,
(6) water transport,
(7) air transport, and
(8) transport services.

We identify 6 occupations of labour:

(1) managers,
(2) professionals and specialists,
(3) white-collar workers,
(4) technicians,
(5) clerks, and
(6) unskilled labourers.

The building blocks of TAIGEM

We label the data blocks in Figure 3.1 with the coefficient names used in the model. Following the notation system introduced in Section 3.3, the V-initialled coefficients are the products of their corresponding prices and quantities. Table 3.4 lists the coefficients and the associated price and quantity variables (in levels). The percentage-change coordinates of the levels price and quantity variables constitute the core of the model.

Balance in the TAIGEM input-output database

To assure balance of our I-O database, the following relationship between the use and the make tables must hold.

$$\mathrm{V1TOT(i)} \equiv \mathrm{MAKE\_C(i)},\ \forall i \in \mathrm{IND}, \text{ and}$$

$$\mathrm{SALES(c)} \equiv \mathrm{MAKE\_I(c)},\ \forall c \in \mathrm{COM},$$

where V1TOT(i) is the total production cost of industry i, MAKE_C(i) is the total output value of industry i, SALES(c) is the total sales of good c, and MAKE_I(c) is the total supply of good c by all industries. Formulae used to calculate these coefficients are as follows.

[7] To speed simulations described in later chapters, we aggregated this database to 76 commodities and 66 industries. The mapping between original and aggregated sectors is set out in Appendix 1.

$$\begin{aligned}\mathrm{V1TOT(i)} = & \sum_{c\in COM}\sum_{s\in SRC}\mathrm{V1BAS(c,s,i)} + \sum_{c\in COM}\sum_{s\in SRC}\sum_{m\in MAR}\mathrm{V1MAR(c,s,i,m)} + \sum_{c\in COM} \\ & \sum_{s\in SRC}\mathrm{V1TAX(c,s,i)} + \sum_{c\in COM}\sum_{s\in SRC}\mathrm{V1STX(c,s,i)} + \\ & \sum_{o\in OCC}\mathrm{V1LAB(i,o)} + \mathrm{V1CAP(i)} + \mathrm{V1LND(i)} + \mathrm{V1OCT(i)}.\end{aligned}$$

$$\begin{aligned}\mathrm{SALES(c)} = & \sum_{i\in IND}\mathrm{V1BAS(c,"dom",i)} + \sum_{i\in IND}\mathrm{V2BAS(c,"dom",i)} + \\ & \mathrm{V3BAS(c,"dom")} + \mathrm{V4BAS(c)} + \\ & \mathrm{V5BAS(c,"dom")} + \mathrm{V6BAS(c,"dom")}.\end{aligned}$$

$$\mathrm{MAKE\_C(i)} = \sum_{c\in COM}\mathrm{MAKE(c,i)}.$$

$$\mathrm{MAKE\_I(c)} = \sum_{i\in IND}\mathrm{MAKE(c,i)}.$$

Elasticity parameters and the base-period values for other parameters in TAIGEM

Parameters are associated with the functional forms specified in the model. After linearisation, we need for model calibration only estimates of substitution elasticities and the cost, revenue and sales shares, which can be easily calculated from the model's input-output data. For TAIGEM, we need to obtain estimates for the following parameters:

(1) elasticities of substitution between inputs for industries' current production and capital formation,
(2) household expenditure elasticities for commodities, and the Frisch parameter,
(3) export demand elasticities, and
(4) investment elasticities and coefficients—the elasticities of the expected rate of return schedules, the ratios of gross to net rates of return, the annual gross investment to future capital stock ratios, depreciation rates, and base-period industry capital stocks.

As is the common practice in CGE modelling, we draw upon econometric literature for estimates of the elasticities.

		Absorption Table					
		1	2	3	4	5	6
		Domestic Producers	Investors of Fixed Capital	Household Demand	Exports	Government Demand	Changes in Inventories
	Size	← I →	← I →	← 1 →	← 1 →	← 1 →	← 1 →
Basic Flows	↑ C×S ↓	V1BAS	V2BAS	V3BAS	V4BAS*	V5BAS	V6BAS
Margins	↑ C×S×M ↓	V1MAR	V2MAR	V3MAR	V4MAR*	V5MAR	n/a
Commodity Taxes	↑ C×S ↓	V1TAX	V2TAX	V3TAX	V4TAX*	V5TAX	n/a
Specific Taxes	↑ C×S ↓	V1STX	V2STX	V3STX	V4STX*	V5STX	n/a
Labour	↑ O ↓	V1LAB					
Capital	1	V1CAP					
Land	1	V1LND					
"Other Costs"	1	V1OCT					
Total Costs	1	V1TOT					

C = Number of Commodities
I = Number of Industries

S = 2: Domestic, Imported,
O = Number of Occupation Types
M = Number of Commodities used as Margins
* Import source is not applicable to exports.

	Make Table
Size	← I →
↑ C ↓	MAKE

	Import Duty
Size	1
↑ C ↓	V0TAR

Figure 3.1 The input-output database of TAIGEM

Table 3.4 Coefficients and their constituents

Data description	Coefficient [= (A)*(B)]	Price or Tax rate (A)	Quantity or Tax base (B)
Basic values of commodities, domestic or imported, purchased by various demanders	V1BAS(c,s,i)	P0(c,s)	X1(c,s,i)
	V2BAS(c,s,i)	P0(c,s)	X2(c,s,i)
	V3BAS(c,s)	P0(c,s)	X3(c,s)
	V4BAS(c)	PE(c)	X4(c)
	V5BAS(c,s)	P0(c,s)	X5(c,s)
	V6BAS(c,s)	LEVP0(c,s)	X6(c,s)
Margins associated with the delivery of commodities, domestic or imported, to their purchasers	V1MAR(c,s,i,m)	P0DOM(c)	X1MAR(c,s,i,m)
	V2MAR(c,s,i,m)	P0DOM(c)	X2MAR(c,s,i,m)
	V3MAR(c,s,m)	P0DOM(c)	X3MAR(c,s,m)
	V4MAR(c,m)	P0DOM(c)	X4MAR(c,m)
	V5MAR(c,s,m)	P0DOM(c)	X5MAR(c,s,m)
Commodity tax, *ad valorem*, payable on the purchases of commodities, domestic or imported, by various demanders	V1TAX(c,s,i)	[T1(c,s,i) - 1]	[P0(c,s)*X1(c,s,i)]
	V2TAX(c,s,i)	[T2(c,s,i) - 1]	[P0(c,s)*X2(c,s,i)]
	V3TAX(c,s)	[T3(c,s,i) - 1]	[P0(c,s)*X3(c,s)]
	V4TAX(c)	[T4(c) - 1]	[PE(c)*X4(c)]
	V5TAX(c,s)	[T5(c,s) - 1]	[P0(c,s)*X5(c,s)]
CO_2 tax, specific, levied on the amount of CO_2 emissions from combustion of fossil fuels (commodities), domestic or imported, by various demanders	V1STX(c,s,i)	ST1(c,s,i)	TAXBASE1(c,s,i)
	V2STX(c,s,i)	ST2(c,s,i)	TAXBASE2(c,s,i)
	V3STX(c,s)	ST3(c,s)	TAXBASE3(c,s)
	V4STX(c)	ST4(c)	TAXBASE4(c)
	V5STX(c,s)	ST5(c,s)	TAXBASE5(c,s)
Wage payments to labour of various occupations by industries	V1LAB(i,o)	P1LAB(i,o)	X1LAB(i,o)
Rental values of industry-specific fixed capital	V1CAP(i)	P1CAP(i)	X1CAP(i)
Rental values of land used by industries	V1LND(i)	P1LND(i)	X1LND(i)
"Other costs" of industries	V1OCT(i)	P1OCT(i)	X1OCT(i)
Output-mixes of industries, at basic value	MAKE(c,i)	P0COM(c)	Q1(c,i)
Tariffs payable on imports	V0TAR(c)	[T0IMP(c) - 1]	[P0IMP(c)*X0IMP(c)]

Note: Suffixes c, s, i, m, o, refer to:

c: commodity

s: source (domestic, imported)

i: industry

m: margin commodity

o: occupation

Variable P0DOM(c) is shorthand for the domestic part of P0(c,s), i.e., P0DOM(c) = P0(c,"dom"). The tax variables starting with "T" are powers (equal to one plus the *ad valorem* rate).

3.4.2 The special treatment of the electricity industry

Motivation

We model the electricity industry—the heaviest single emitter of greenhouse gases—in a way that allows for possibilities in fuel substitution. In Taiwan, the electricity industry alone accounts for 37% of the national CO_2 emissions[8] due to its heavy consumption of fossil fuels. The energy balances data (MOEAEC, 1999) of year 1994 suggest that the total consumption of electricity is 98 peta-calories—some 22% of total energy consumption[9]. Table 3.5 shows that in 1994 coal and fuel oils together make up 87% of the total fuel inputs to power generation in 1994. These two fuels have relatively high carbon emissions coefficients (tonnes of carbon/tera-joule of energy)—25.8 and 21.1, respectively (IPCC/OECD, 1993).

We intend to model the electricity industry by giving more flexibility in the selection of fuel inputs. Substitution away from dirty fuels is a sensible reaction of the electricity industry facing policies designed to encourage CO_2-emissions abatement.

Table 3.5
Energy used for power generation* and carbon emissions coefficients**

Energy commodity	Consumption (10^7 Kcal)	Share (%)	Carbon emissions coefficient (tonne carbon/tera-joule)
Coal	10086040	57.37	25.8
Natural Gas	6621	0.04	15.3
Gasoline	76	0.00	18.9
Diesel Fuel	597626	3.40	20.2
Fuel Oils	5215650	29.67	21.1
Refinery Gas	9411	0.05	17.2
Coal Products	348861	1.98	25.8
Gas (LNG)	1316477	7.49	15.3
Total	17580762	100.00	

* 1. Co-generation plants are accounted.
2. Data year: 1994.
3. Data source: MOEAEC (1999).
** Data source: IPCC/OECD (1996).

8 Data of emission inventories are provided by the Environmental Protection Agency (EPA) of Taiwan, R.O.C.

9 Total energy consumption in 1994 is 441 peta-calories.

Methodology

We divide the single electricity industry into 11—one electricity distributor and 10 power-generating industries according to apparatuses and associated fuels. The 10 power-generating technologies are:

(1) Hydro,
(2) Oil-fired Steam turbines,
(3) Coal-fired Steam turbines,
(4) Gas-fired Steam turbines,
(5) Oil-fired Combined-cycle,
(6) Gas-fired Combined-cycle,
(7) Oil-fired Gas turbines,
(8) Gas-fired Gas turbines,
(9) Diesel engines, and
(10) Nuclear power plants.

The electricity generated flows entirely to the end-use supplier (hereafter EUS). EUS then distributes electricity to the end-users. Table 3.6 summaries the 10 power-generating industries and their specific inputs. Table 3.7 shows the specific fuel usage of the 10 power-generating industries. The following considerations support the disaggregation of the electricity industry.

First, we consider the technological differences of power plants. Each plant has a specific fuel input. Nuclear reactors use uranium as a fuel. Hydroelectric plants use water to drive their turbines. Coal, oil and gas are burned to drive turbines in conventional thermal power plants. In addition, nuclear power plants and coal-fired power plants normally serve base-load supply, while gas- and oil-fired power plants—less economic but easier to start up and shut down—are used for peak-load service. Another technological factor that distinguishes power plants is physical constraint. The output levels of gas-fired power plants are subject to the capacity of the storage facility for natural gas. The output levels of hydroelectric plants are subject to the sizes of reservoirs, while the output levels of coal- and oil-fired power plants are subject to the supply of coal and oils (petroleum products), domestic and imported[10].

Second, we consider the incentive for the electricity industry to substitute towards cleaner forms of power plants. According to the 1994 statistics of the Taiwan Power Company, thermal power plants (excluding nuclear power plants) accounted for some 69% of total electricity supply; coal-fired power plants alone supplied 33% of the total; oil-fired (mainly Fuel Oils) power plants supplied 26% of the total. Hydroelectric and nuclear power plants contributed 7% and 24% to the total electricity supply. As indicated in Table 3.5, coal and fuel oils have relatively higher carbon emissions coefficients than other fuels. Substituting cleaner technology, e.g.,

10 Taiwan's demand for coal is highly import-dependent—imported coal supplied 94% of the total demand. Petroleum products, 41% imported, are also subject to the supply of crude oil, 99% of which is imported.

gas-fired power plants, for coal-fired power plants would help reduce CO_2 emissions.

Third, Hinchy and Hanslow (1996) point out that the division of the single electricity industry into various technologies precludes infeasible input compositions for electricity generation. They refer to this as the "technology bundle" approach. By implementing the "technology bundle" approach, input substitution possibilities are forced to conform to the available power-generating technologies. For example, the production capacity of a hydroelectric plant is subject to the sizes of available reservoirs; the production capacity of a gas-fired plant is subject to the bulk of the storage tanks.

We assume that these 10 sources of electricity are imperfect substitutes to each other. That is, the EUS may substitute between the 10 technologies in response to changes in their production costs. With this treatment, the Electricity industry may use more Natural Gas and less Coal as fuel to generate electricity in response to higher production costs due to environmental concerns.

The substitution also reflects differences in the production of power-generating industries. The justification is as follows. In the real-world context, the power company can moderate costs via arranging in an economic way the operating time shifts for power plants of different economic characteristics. For example, less economic stations, e.g., oil- and gas-fired plants, are run only during peak-load time; stations that are cheaper to run, e.g., coal-fired and nuclear power plants, are designated to supply base-load demand.

Further, it is not physically viable to instantly increase the production capacity of some plant. For example, the construction of a new dam or a nuclear power plant normally takes several years. Or, environmentalists' protests against the construction of new dams and nuclear power plants make the substitutability more confined.

Details of the production structure of the power-generating industries and the EUS are given in Section 3.5.1.

Table 3.6 Specific input requirements of the 10 power industries

	Generator type	Main fuel inputs	Other essential inputs
(1)	Hydro		39%*: capital (dams, power plants); 22%: electricity.
(2)	Oil-fired steam turbines	48%: Fuel oils; 21%: Diesel fuel.	
(3)	Coal-fired steam turbines	43%: Coal	32%: capital (power plants)
(4)	Gas-fired steam turbines	67%: Natural gas	
(5)	Oil-fired combined-cycle	42%: Fuel oils; 19%: Diesel fuel.	22%: capital (power plants)
(6)	Gas-fired combined-cycle	51%: Natural gas	31%: capital (power plants)
(7)	Oil-fired gas turbines	31%: Diesel fuel	40%: capital (power plants)
(8)	Gas-fired gas turbines	14%: Natural gas	29%: electricity
(9)	Diesel engines	37%: Fuel oils; 16%: Diesel fuel.	
(10)	Nuclear power plants	13%: Uranium minerals	36%: capital (power plants); 23%: electricity.

* refers to the input share in the total costs of the corresponding power generating industry.

Table 3.7 Fuel flows* to the power-generating industries (NT$ million)

	Power-generating industries										*Total electricity generation*
	(1) Hydro	(2) Steam—oil	(3) Steam—coal	(4) Steam—gas	(5) CombCycle—oil	(6) CombCycle—gas	(7) Gas turbine—oil	(8) Gas turbine—gas	(9) Diesel	(10) Nuclear	
Coal	0	0	1335	0	0	0	0	0	0	0	1335
Natural gas	0	0	0	2166	0	904	0	30	0	0	3100
Gasoline	2	1	3	1	1	0	0	0	0	5	48
Diesel fuel	0	1957	0	0	1099	0	176	0	71	0	3303
Aviation fuel	0	0	0	0	0	0	0	0	0	0	0
Fuel oils	0	4434	0	0	2490	0	0	0	161	0	7085
Kerosene	0	0	0	0	0	0	0	0	0	0	0
Lubricants	1	0	1	0	0	0	0	0	0	2	15
Naphtha	0	0	0	0	0	0	0	0	0	0	0
Refinery gas	0	0	0	13	0	5	0	0	0	0	18
Asphalt	0	0	0	0	0	0	0	0	0	0	0
Other refined petrol. products	0	0	0	0	0	0	0	0	0	0	3
Coal products	0	493	1234	222	296	99	49	54	20	0	2467

* valued at basic prices.

3.4.3 CO_2 emissions accounting

We account for carbon dioxide (CO_2) emissions arising from the combustion of fossil fuels—coal, natural gas, and petroleum products—and from the crushing and burning of limestone in manufacture processes—cement, basic iron and pig iron. We assume that carbon dioxide emissions are closely related to energy consumption[11]. We assign user-, fuel-, and source-specific emissions coefficients (CO_2 per dollar, at 1994 value) and prorate the fuel-specific 1994 national CO_2 inventories among users. This produces the CO_2 emissions matrix by fuel commodities, commodity sources and users. Table 3.8 shows CO_2 emissions from 13 fuels (domestic plus imported): coal, natural gas, non-metallic minerals (calcium carbonate), 9 petroleum products, and coal products.

CO_2 emitted from the usage of coal comes mainly from the coal-fired steam engines power industry. CO_2 emitted from the usage of gasoline comes most from the household sector (mainly for driving). CO_2 emitted from the usage of fuel oils comes most from the oil-fired steam engines power industry. We assume that only the cement products industry and the iron industry release CO_2 in using non-metallic minerals. 23.56% of total CO_2 emissions comes from the coal-fired steam engines power industry. Next is the cement products industry, which releases 12.5% of the national CO_2 emissions. Land transport and the household sector together release 11.18% of the national CO_2 emissions.

The TAIGEM input-output data indicate: the coal expense of the coal-fired steam engines power industry is 21630 million NT dollars; and the natural gas expense of the gas-fired steam engines power industry is 6226 million NT dollars. CO_2 per dollar of coal is five times CO_2 per dollar of natural gas[12]. To reduce Taiwan's CO_2 emissions, nuclear power plants and gas-fired power plants can be alternatives to coal-fired power plants. To import cement or to reduce uses of privately-owned cars can also help Taiwan abate CO_2 emissions.

[11] Over the long run, carbon dioxide emissions are related to the trend in economic activity, energy consumption and fuel choices.

[12] The CO_2 emissions coefficients of coal and natural gas used by steam engine power plants are 1.82 ($=\frac{39383}{21630}$) and 0.34 ($=\frac{2161}{6226}$) respectively.

Table 3.8 CO_2 emissions by users (Unit: thousand tonnes)

Users	CO_2 emissions from: Coal	Natural gas	Non-metallic Min.	Gasoline	Diesel fuel	Aviation fuel	Fuel oils	Kerosene	Lubricants	Naphtha	Refined gas	Other petroleum	Coal products	Total	Emissions shares by users (%)
Agriculture	0	0	0	127	627	0	67	0	12	0	0	9	0	843	0.50
Fisheries	0	0	0	2	1917	0	562	0	16	0	0	0	0	2498	1.49
Mining	3	74	0	29	7	0	54	0	0	0	0	1101	712	1979	1.18
Manufacturing-light	207	79	0	279	1163	0	2645	4	13	0	87	0	39	4521	2.70
Paper	560	36	0	87	77	0	855	2	2	0	23	0	25	1667	1.00
Petrol. chemistry	0	1171	0	25	14	0	1509	10	4	1683	57	1087	1	5560	3.33
Industrial chemistry	1510	131	0	110	141	0	1726	5	19	0	26	1800	37	5506	3.29
Oil refinery	0	1668	0	542	68	13	1509	58	45	0	266	0	125	4295	2.57
Coal products	0	0	0	2	2	0	1	1	0	0	0	18	843	868	0.52
Material manufact.	1842	1670	0	827	458	1	3386	27	39	5	593	190	541	9580	5.73
Cement products	9623	0	10290	104	336	0	360	0	4	0	0	159	22	20899	12.50
Iron	1027	196	2224	46	15	0	1490	2	7	0	92	0	8094	13194	7.89
Hydro	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0.00
Steam_oil	0	0	0	0	1087	0	10469	0	0	0	0	1	0	11557	6.91
Steam_coal	39380	0	0	0	0	0	0	0	0	0	0	3	0	39383	23.56
Steam_gas	0	2160	0	0	0	0	0	0	0	0	0	1	0	2161	1.29
CombCy_oil	0	0	0	0	611	0	5878	0	0	0	0	1	0	6489	3.88
CombCy_gas	0	902	0	0	0	0	0	0	0	0	0	0	0	902	0.54
GasTur_oil	0	0	0	0	98	0	0	0	0	0	0	0	0	98	0.06
GasTur_gas	0	30	0	0	0	0	0	0	0	0	0	0	0	30	0.02
Diesel	0	0	0	0	39	0	380	0	0	0	0	0	0	419	0.25
Nuclear electricity	0	0	0	0	0	0	0	0	0	0	0	5	0	5	0.00
End use supplier	0	0	0	0	0	0	0	0	0	0	0	16	0	16	0.01
Gas/Water	0	0	0	20	0	0	0	0	0	0	3305	0	0	3325	1.99
Construction	0	0	0	463	424	0	3	0	1	0	0	0	0	891	0.53
Margin services	0	105	0	1504	247	0	9	0	10	0	29	325	7	2237	1.34
Rail transport	0	0	0	5	138	0	12	0	1	0	0	0	0	155	0.09
Land transport	0	0	0	3255	6728	0	729	5	44	0	0	0	0	10761	6.44
Water transport	77	0	0	124	390	0	3816	1	22	0	0	0	0	4431	2.65
Air transport	0	0	0	26	4	883	0	2	12	0	0	0	0	926	0.55
Services	0	55	0	832	445	0	540	7	56	0	26	22	25	2007	1.20
Public admin.	0	0	0	634	626	122	620	5	6	0	0	0	0	2013	1.20
Households	0	1	0	7819	69	0	0	0	31	0	0	0	1	7921	4.74
Total	54230	8279	12514	16863	15730	1020	36619	129	350	1688	4503	4741	10474	167140	100.00

3.4.4 Data required for dynamic extension

Data needed for the extension to a recursive dynamic model include industry-specific capital stocks, rates of depreciation for industry-specific capitals, and rate-of-return elasticities required by the investment functions. The data for industry-specific capital stock are produced by aggregating the more disaggregated data published by the statistics bureau to the industry classification of TAIGEM. Due to lack of estimates, we arbitrarily set the depreciation rates to 0.06 for all industries. The rate-of-return elasticities of industry investments are set to 2.0.

3.5 The equations of TAIGEM

The core of the TAIGEM model describes the operation of the economy in which optimisation underlies the behaviour of most agents. Producers minimise their input costs with constant-returns-to-scale production technologies. Consumers (households) maximise utility according to their preferences. We assume that all firms are perfectly competitive and all agents are price-takers. The "zero-pure-profits" condition applies to all producers. Separability assumptions are frequently adopted to reduce the complexity in each agent's optimisation problem.

We describe the equations in the core of TAIGEM in the following order:

- Producers' demands for intermediate inputs and primary factors,
- Supplies of commodities by domestic producers;
- Input demands for capital formation;
- Final demands by households, exporters and the government, and inventory changes;
- Demands for margins which facilitate the delivery of commodities from producers' sites or ports of entrance to purchasers or ports of exit;
- The price system;
- Market-clearing equations for commodities; and
- Various macro-economic or summary indices.

Section 3.5.11 describes equations and variables related to CO_2 emissions. Investment mechanisms for both the static and the dynamic version of TAIGEM are described in Sections 3.6 and 3.9, respectively.

3.5.1 Current production

We assume that all producers are price-takers for inputs and outputs. Industries[13] are able to produce multiple products with available capacity. With the "separability" assumption, the multi-input, multi-output production function for industry i:

$$H^i(Y^i_c, X^i_{cs}, L^i_o, K^i, N^i, M^i) = 0 \tag{3.5}$$

may be rewritten as[14]:

$$Q^i(X^i_{cs}, L^i_o, K^i, N^i, M^i) = Z^i = B^i(Y^i_c). \tag{3.6}$$

The X's and Y's denote inputs and outputs, respectively; the Q function gives the input requirement to create the capacity to produce[15], *Z*, of industry i (i∈IND); and the B function is the production possibility frontier. The producer minimises total input costs to create the production capacity (Z^i) subject to the available technology (Q^i). On the other hand, producers choose the revenue-maximising combination of outputs to produce subject to the production possibility frontier (B^i) furnished by the production capacity (Z^i). Note that X^i_{cs} for all c∈COM, and all s∈SRC, denotes the intermediate input demand of industry i for commodity c from source s with s = "dom" referring to domestic product and s = "imp" referring to imports[16]; L^i_o for all o∈OCC, denotes labour of occupational group o employed by industry i; and K^i, N^i, and M^i are, respectively, capital stock, land and miscellaneous production costs of industry i.

Further, we apply the "separability" assumption to the Q function, such that:

$$Z^i = Q^i(X^i_{cs}, L^i_o, K^i, N^i, M^i) = V^i\{ f^i_c(X^i_{cs}), u^i[g^i(L^i_o), K^i, N^i], M^i \}. \tag{3.7}$$

Apart from "other costs" (M^i), the V^i function of industry i has nested functions for source-specific intermediate inputs (X^i_{cs}), for primary factors (i.e., capital (K^i), land (N^i) and labour), and for occupation-specific labour (L^i_o). The f^i_c function governs the source composition of intermediate inputs demanded by industry i. The u^i function governs the composition of primary factors of industry i. The g^i function governs the occupation composition of labour employed by industry i.

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[13] We use "producer" and "industry" interchangeably in the text.

[14] The *input-output separability* assumption is valid only in the context that the inputs can be used for all purposes.

[15] This is also called activity level.

[16] We identify commodities from domestic and foreign sources as imperfect substitutes, following the Armington (1969; 1970) assumption.

We differentiate the total supply of each domestically-produced commodity by its sale destination: the local market and export. Algebraically,

$$Y_c = \sum_{i\in IND} Y^i_c = W(Y_{cd}), \qquad c\in COM,\ d\in DST, \qquad (3.8)$$

where Y^i_c is the supply of commodity c by industry i; Y_c is the total supply of domestically-produced commodity c; Y_{cd} denotes the sales of domestically-produced commodity c to destination d; and the W function is the transformation frontier governing the proportions of sales to destinations.

In TAIGEM, we categorise all industries into three groups, for which different production structures are specified. They are: (i) the electricity-generating industries, tagged as 'ELECGEN' industries, (ii) the end-use-supplier (EUS) of electricity; and (iii) the industries other than those in the first two groups, tagged as 'ORDINARY' industries.

We show in Figures 3.2(A), 3.2(B) and 3.2(C), respectively, the nesting production structures of the 'ELECGEN' industries, the EUS industry and the 'ORDINARY' industries. In each of the figures, the sale-destination nests are located at level 1, the output-mix nest is at level 2, the activity nest is at level 3', the commodity-source nests are at level 6; the primary-factor nest is at level 4a, and the labour nest is at level 5. Level 3a in Figure 3.2(B) is for the electricity nest. Levels 4' and 4b in Figure 3.2(C) are, respectively, for the energy-primary-factor nest and the energy nest.

The nested production structure of the 'ELECGEN' industries can be expressed algebraically as follows (see also Figure 3.2(A)).

$$Z^i = \underset{c\in COM}{\text{Leontief}}\{\underset{s\in SRC}{CES}(X^i_{cs}), CES[\underset{o\in OCC}{CES}(L^i_o), K^i, N^i], M^i\}, \qquad i\in ELECGEN. \qquad (3.9)$$

The notation, $\underset{o\in OCC}{CES}(L^i_o)$, indicates the occupation (for all o∈OCC) composite of labour, aggregated by the CES (constant elasticity of substitution) function. The notation, $\underset{s\in SRC}{CES}(X^i_{cs})$, indicates the source (for all s∈SRC) composite of intermediate input c. The notation, $CES[\underset{o\in OCC}{CES}(L^i_o), K^i, N^i]$, indicates the primary factor composite of the composite labour, capital (K^i) and land (N^i). Equation 3.9 indicates that industry i uses source composite of intermediate input c (for all c∈COM), the primary factor composite, and "other costs" (M^i) in fixed proportions.

In algebra, the nested production structure of the EUS industry can be written as follows (see also Figure 3.2(B)).

$$Z^i = \underset{c\in NONELECCOM}{\text{Leontief}}\{\underset{s\in SRC}{CES}(X^i_{cs}), \underset{j\in ELECGEN}{CES}[\underset{s\in SRC}{CES}(X^i_{js})], CES[\underset{o\in OCC}{CES}(L^i_o), K^i, N^i], M^i\}, \qquad i\in\text{"EUS"}. \qquad (3.10)$$

For the 'ORDINARY' industries, the specification is (see also Figure 3.2(C)):

$$Z^i = \underset{c\in NONENERCOM}{\text{Leontief}}\{\underset{s\in SRC}{CES}(X^i_{cs}), CES[\underset{r\in ENERCOM}{CES}[\underset{s\in SRC}{CES}(X^i_{rs})], CES[\underset{o\in OCC}{CES}(L^i_o), K^i, N^i]], M^i\}, \qquad i\in ORDINARY. \qquad (3.11)$$

Producers choose their input combinations for current production to minimise costs subject to the production function of the subordinate nests. As shown at level 3' in Figures 3.2(A), an 'ELECGEN' industry requires each composite good c, a composite primary factor and "other costs"[17] in fixed proportions to the activity level. The nest at level 6 indicates that composite good c is a cost-minimising combination of domestically-produced and imported good c subject to a CES (Constant Elasticity of Substitution) function. At level 4a, the primary-factor composite is a cost-minimising CES aggregation of capital, composite labour and land. At level 5, composite labour is a cost-minimising CES combination of labour from O (= 6) occupational groups[18]. The production structures for the EUS industry and the 'ORDINARY' industries are slightly different from the one for the 'ELECGEN' industries. We allow the EUS industry to substitute between electricity outputs from different 'ELECGEN' industries. This is shown at level 3a in Figure 3.2(B). The 'ORDINARY' industries are allowed to substitute between energy inputs and primary factors. This is shown at levels 4' and 4b in Figure 3.2(C).

We specify for all industries the CET (constant elasticity of transformation) function to govern the revenue-maximising output mix:

$$Z^i = \underset{c\in COM}{CET}(Y^i_c), \qquad i\in IND. \qquad (3.12)$$

In practice, however, most industries are essentially single-product.

We again specify the CET function to govern the sales distributions among the local market and export:

$$Y_c = \underset{d\in DST}{CET}(Y_{cd}), \qquad c\in COM. \qquad (3.13)$$

[17] "Other costs" includes production taxes and other miscellaneous production-related costs.

[18] All these composites are user-specific. For example, the share of an occupational labour group in the labour composite varies between industries.

The output-mix nest at level 2 in Figures 3.2(A), 3.2(B), and 3.2(C) shows that industries select the revenue-maximising output mix at prevailing market prices using a CET (constant elasticity of transformation) production possibility frontier. The sale-destination nest at level 1 shows the revenue-maximising distribution of the total supply of each good to local and overseas markets. The optimisation at this level operates as if there is an economy-wide proxy agent maximising total revenue from local sales and exports of each commodity. A CET transformation function determines the destination-specific distribution of commodity supplies.

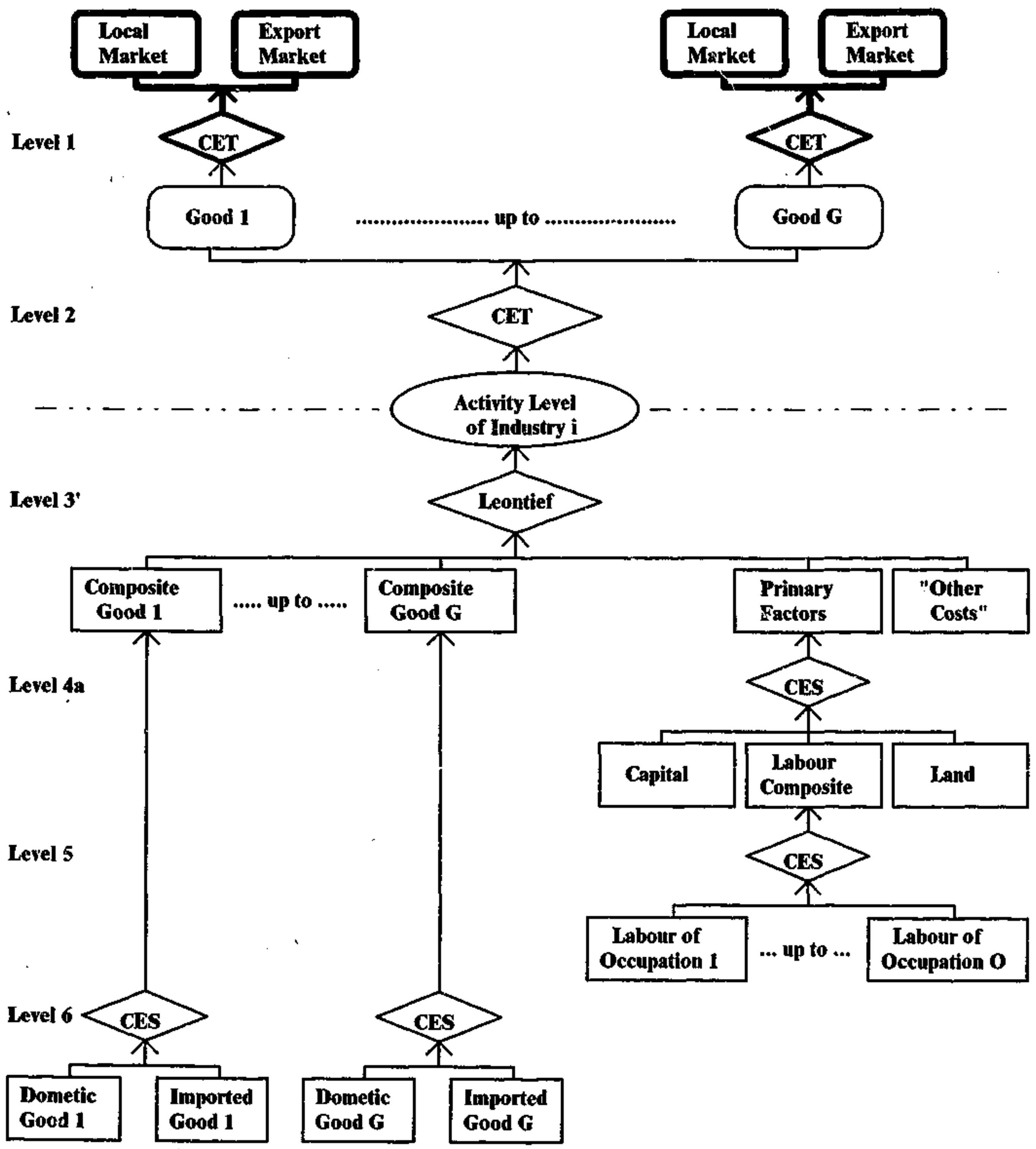

Figure 3.2(A) Structure of current production for the 'ELECGEN' industries

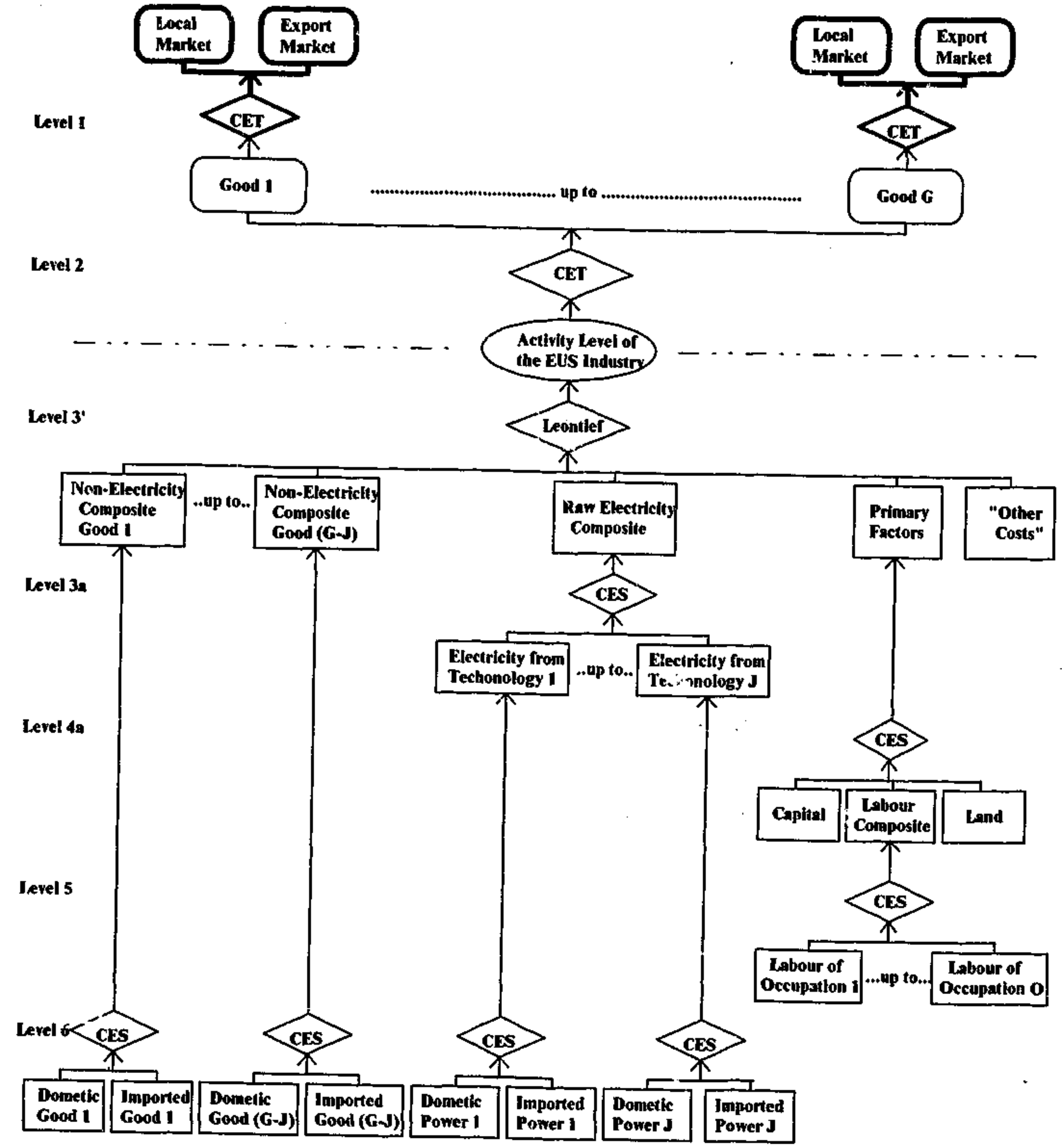

Figure 3.2(B) The production structure of the EUS (end-use-supplier) industry

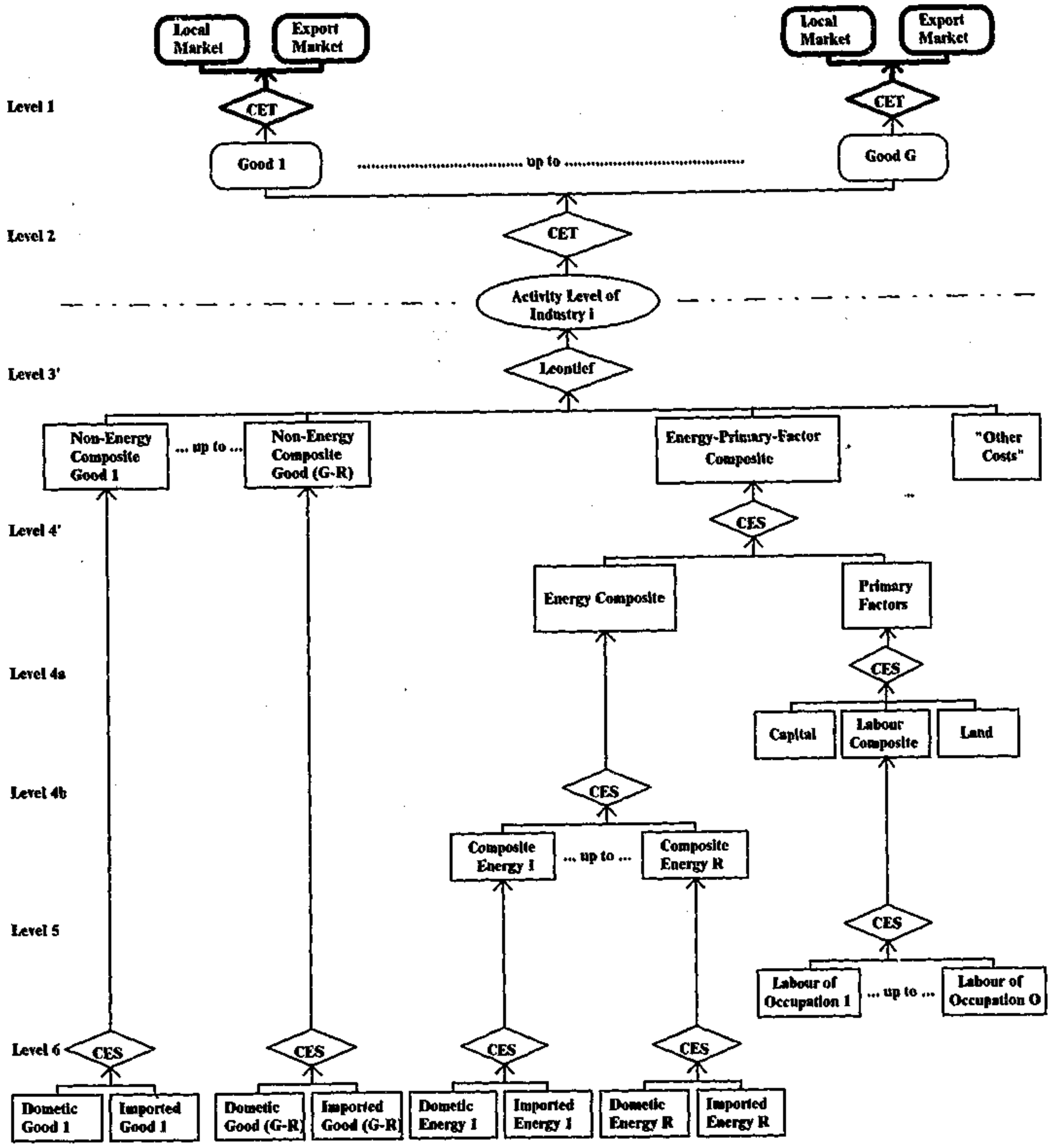

Figure 3.2(C) Structure of current production for the 'ORDINARY' industries

We describe in Section 3.5.1(A) the input cost minimisation of producers, which corresponds to the V part of Equation 3.7. We start the explanation from the commodity-source nests at level 6 in the production structure figures. In Section 3.5.1(B), we describe the derivation of the revenue-maximising output mix by producers (see also Equation 3.12) and the sales destination of domestically-produced goods (see also Equation 3.13).

3.5.1(A) Demand for inputs and primary factors

As the three categories of industries have different specifications in some parts of the nesting production structures, we start from the nests which are common for all industries, followed by industry-specific sub-nests.

All industries have common cost minimisation problems with regard to demands for: (a) commodities from different sources (see level 6 of Figures 3.2(A), 3.2(B) and 3.2(C)), (b) labour from different occupational groups (see level 5), and (c) primary factors (see level 4a). Below we discuss these cost minimisation problems.

The intermediate input demand of industry i for good c from source s, X1(c,s,i)

(see also the source nests at level 6 of Figures 3.2(A), 3.2(B) and 3.2(C))

Choose X1(c,s,i) to minimise the total cost of good c from either domestic (s = "dom"), or foreign (s = "imp") sources:

$$\sum_{s \in SRC} P1(c,s,i) * X1(c,s,i), \qquad c \in COM,\ i \in IND, \quad (3.14)$$

subject to

$$X1\_S(c,i) = \underset{s \in SRC}{CES}\left[\frac{X1(c,s,i)}{A1(c,s,i)}\right], \qquad c \in COM,\ i \in IND. \quad (3.15)$$

where the purchaser's price[19] of good c from source s, P1(c,s,i), is exogenous to the problem elsewhere; the effective input of composite good c, X1_S(c,i), is determined in the superordinate nested optimisation problem; and A1(c,s,i) is the technological coefficient for source-specific intermediate inputs, with reductions in A1(c,s,i) indicating efficiency improvements in using good c of source s.

In our model, the demand functions[20] derived from the cost-minimisation problems are linearised and the associated percentage change variables are presented in

[19] Purchaser's prices include the basic value of goods plus margins and tax paid by purchasers. Details will be introduced in Section 3.5.8 (Zero-pure-profits conditions).

[20] A example for deriving the linearised demand function under the CES technology is given in Appendix 3.

lower case. The linearised equation of source-specific intermediate input demand is presented below.

$$x1(c,s,i) - a1(c,s,i) = x1\_s(c,i) - SIGMA1(c)*[p1(c,s,i) + a1(c,s,i) - p1\_s(c,i)], \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.16)$$

where SIGMA1(c) is the Armington elasticity of substitution between intermediate inputs of good c from domestic and foreign sources; p1_s(c,i) denotes the percentage change in the average unit cost of the effective input of composite good c, P1_S(c,i). The equation below defines p1_s(c,i) as a cost-share weighted Divisia index of the source-specific commodity prices adjusted for technical change:

$$p1\_s(c,i) = \sum_{s\in SRC}\left(\frac{V1PUR(c,s,i)}{V1PUR\_S(c,i)}\right)*[p1(c,s,i) + a1(c,s,i)], \quad c\in COM,\ i\in IND. \quad (3.17)$$

where V1PUR(c,s,i) is the value at the purchaser's price of the intermediate input of good c from source s used by industry i; V1PUR_S(c,i) is the total cost of good c from both sources used by industry i. V1PUR_S(c,i) is calculated as:

$$V1PUR\_S(c,i) = \sum_{s\in SRC} V1PUR(c,s,i), \quad c\in COM,\ i\in IND.$$

Equation 3.16 indicates that the intermediate input demand of industry i for good c from each source is proportional to its demand for the effective composite good, X1_S(c,i), and to a price term:

$$\left(\frac{P1(c,s,i)*A1(c,s,i)}{P1\_S(c,i)}\right)^{-SIGMA1(c)}, \quad c\in COM,\ s\in SRC,\ i\in IND.$$

Changes in the price ratio of domestic to imported good c prompt industry i to substitute in favour of the cheaper source.

For Equation 3.16, we add two cost-neutral twist variables to account for non-price induced changes in the usage ratio of domestic to imported good c. In simulations where import volumes and prices are exogenously given, we specify the twist variables endogenous to account for the observed changes in import volumes. Equations 3.16 and 3.17 are rewritten as:

$$x1(c,s,i) = x1\_s(c,i) + RS1(c,s,i)*\{twistsrc(c)+ twistsrc\_c - SIGMA1(c)*[p1(c,"dom",i) - p1(c,"imp",i)]\}, \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.16a)$$

and

$$p1\_s(c,i) = RS1(c,"dom",i)*p1(c,"imp",i) - RS1(c,"imp",i)*p1(c,"dom",i), \quad c\in COM,\ i\in IND. \quad (3.17a)$$

where twistsrc(c) is the twist variable effective for good c; twistsrc_c is the twist variable effective for all goods; RS1(c,s,i) is the reverse source share of good c used by industry i. The formula for RS1(c,s,i) is:

$$RS1(c,"dom",i) = \left(\frac{V1PUR(c,"imp",i)}{V1PUR\_S(c,i)}\right), \quad c\in COM,\ i\in IND,$$

and

$$RS1(c,"imp",i) = RS1(c,"dom",i) - 1 = -\left(\frac{V1PUR(c,"dom",i)}{V1PUR\_S(c,i)}\right), \quad c\in COM,\ i\in IND.$$

Replacing $\left(\frac{V1PUR(c,s,i)}{V1PUR\_S(c,i)}\right)$ with RS1(c,s,i) helps speed up the computation by GEMPACK. Note that the reverse-share method applies only to the two-input case. Detailed description about the reverse share method is in Appendix 3.

We interpret the role of the twist variables in Equation 3.16a as follows. In the absence of price changes, an one percent change in twist(c) will cause an $\left[1 - \left(\frac{V1PUR(c,"dom",i)}{V1PUR\_S(c,i)}\right)\right]$% increase in demand for domestically-produced good c, and an $\left(\frac{V1PUR(c,"dom",i)}{V1PUR\_S(c,i)}\right)$% reduction in demand for imported good c. Variable twistsrc_c functions the same as the commodity-specific twistsrc(c), except that it affects all commodities once varied. See Appendix 3 for detailed introduction about the twist variables.

The demand of industry i for labour of occupation o, X1LAB(i,o)

(see also the labour nests at level 5 of Figures 3.2(A), 3.2(B) and 3.2(C))

Choose X1LAB(i,o) to minimise the total labour cost:

$$\sum_{o\in OCC} P1LAB(i,o)*X1LAB(i,o), \quad i\in IND, \quad (3.18)$$

subject to

$$X1LAB\_O(i) = \underset{o\in OCC}{CES}\left[X1LAB(i,o)\right], \quad i\in IND, \quad (3.19)$$

where the nominal wage paid by industry i for labour of occupation o, P1LAB(i,o), is exogenous to the problem as we assume producers are price-takers; and the effective labour composite for industry i, X1LAB_O(i), is determined elsewhere in the superordinate nested optimisation problem.

The linearised equation of occupational labour demand is presented below.

$$x1lab(i,o) = x1lab\_o(i) - SIGMA1LAB(i)*[p1lab(i,o) - p1lab\_o(i)], \quad i\in IND,\ o\in OCC, \quad (3.20)$$

where SIGMA1LAB(i) is the elasticity of substitution between labour of different occupational groups; p1lab_o(i) denotes the percentage change in the average wage rate for all labour employed by industry i, P1LAB_O(i). The equation defining p1lab_o(i) is:

$$p1lab\_o(i) = \sum_{o \in OCC} \left(\frac{V1LAB(i,o)}{V1LAB\_O(i)} \right) * p1lab(i,o), \qquad i \in IND, \quad (3.21)$$

where V1LAB(i,o) is the wage bill for labour of occupation o employed by industry i, and V1LAB_O(i) is the total labour cost of industry i. V1LAB_O(i) is calculated as:

$$V1LAB\_O(i) = \sum_{o \in OCC} V1LAB(i,o), \qquad i \in IND.$$

Equation 3.20 indicates that the demand for labour of occupation o by industry i, X1LAB(i,o), is proportional to its demand for the effective labour composite, X1LAB_O(i), and to a price term:

$$\left(\frac{P1LAB(i,o)}{P1LAB\_O(i)} \right)^{-SIGMA1LAB(i)}, \qquad i \in IND, o \in OCC.$$

Changes in the relative wages of the occupations prompt industry i to substitute in favour of relatively cheaper occupations.

The percentage change variable of the labour composite, x1lab_o(i), is derived by multiplying through Equation 3.20 with the occupational share, $\left(\frac{V1LAB(i,o)}{V1LAB\_O(i)} \right)$, and then summing over the occupation dimension (i.e., index o). This gives:

$$x1lab\_o(i) = \sum_{o \in OCC} \left(\frac{V1LAB(i,o)}{V1LAB\_O(i)} \right) * x1lab(i,o), \qquad i \in IND, \quad (3.22)$$

which is the CES aggregation over labour of all occupations.

The demand of industry i for primary factors, X1LAB_O(i), X1CAP(i), and X1LND(i)

(see also the primary-factor nests at level 4a of Figures 3.2(A), 3.2(B) and 3.2(C))

Choose primary factor inputs: labour composite, X1LAB_O(i); capital, X1CAP(i); and land, X1LND(i), to minimise the total cost of primary factors:

$$[P1LAB\_O(i)*X1LAB\_O(i)] + [P1CAP(i)*X1CAP(i)] + [P1LND(i)*X1LND(i)], \qquad i \in IND, \quad (3.23)$$

subject to

$$X1PRIM(i) = CES\left[\frac{X1LAB\_O(i)}{A1LAB\_O(i)}, \frac{X1CAP(i)}{A1CAP(i)}, \frac{X1LND(i)}{A1LND(i)} \right], \qquad i \in IND, \quad (3.24)$$

where the nominal wage paid by industry i for the labour composite, P1LAB_O(i), the capital rental, P1CAP(i), and the land rental, P1LND(i), are exogenous to the problem; the effective primary-factor composite, X1PRIM(i), is determined elsewhere in the superordinate nested optimisation problem; and A1LAB_O(i), A1CAP(i), and A1LND(i) are technological coefficients for labour composite, capital and land, respectively, with reductions in these coefficients indicating factor-saving technical improvements.

The linearised primary factor demand equations are presented below.

$$x1lab\_o(i) - a1lab\_o(i) = x1prim(i) - SIGMA1PRIM(i)*[p1lab\_o(i) + a1lab\_o(i) - p1prim(i)], \qquad i \in IND. \quad (3.25)$$

$$x1cap(i) - a1cap(i) = x1prim(i) - SIGMA1PRIM(i)*[p1cap(i) + a1cap(i) - p1prim(i)], \qquad i \in IND. \quad (3.26)$$

$$x1lnd(i) - a1lnd(i) = x1prim(i) - SIGMA1PRIM(i)*[p1lnd(i) + a1lnd(i) - p1prim(i)], \qquad i \in IND. \quad (3.27)$$

SIGMA1PRIM(i) is the elasticity of substitution between primary factors; p1prim(i) denotes the percentage change in the average unit cost of the effective primary-factor composite of industry i, P1PRIM(i). Equation 3.28 below defines p1prim(i) as a cost-share weighted Divisia index of individual factor prices adjusted for technological change:

$$p1prim(i) = \left(\frac{V1LAB\_O(i)}{V1PRIM(i)} \right) * [p1lab\_o(i) + a1lab\_o(i)] + \left(\frac{V1CAP(i)}{V1PRIM(i)} \right) * [p1cap(i) + a1cap(i)] + \left(\frac{V1LND(i)}{V1PRIM(i)} \right) * [p1lnd(i) + a1lnd(i)], \qquad i \in IND, \quad (3.28)$$

where V1LAB_O(i), V1CAP(i), and V1LND(i) are, respectively, the total labour cost, capital rental, and land rental of industry i, and V1PRIM(i) is the total value of these primary factors used by industry i. V1PRIM(i) is calculated as:

$$V1PRIM(i) = V1LAB\_O(i) + V1CAP(i) + V1LND(i), \qquad i \in IND.$$

Equations 3.25, 3.26, and 3.27 indicate that, demands of industry i for: the effective labour composite, $\left(\frac{X1LAB\_O(i)}{A1LAB\_O(i)} \right)$, effective capital, $\left(\frac{X1CAP(i)}{A1CAP(i)} \right)$, and effective land, $\left(\frac{X1LND(i)}{A1LND(i)} \right)$, are proportional to its demand for the effective primary factor composite, X1PRIM(i), and to the relative price terms:

$$\left(\frac{P1LAB\_O(i)*A1LAB\_O(i)}{P1PRIM(i)} \right)^{-SIGMA1PRIM(i)}, \text{ for the labour composite,}$$

$$\left(\frac{P1CAP(i)*A1CAP(i)}{P1PRIM(i)} \right)^{-SIGMA1PRIM(i)}, \text{ for capital, and}$$

$$\left(\frac{P1LND(i)*A1LND(i)}{P1PRIM(i)} \right)^{-SIGMA1PRIM(i)}, \text{ for land.}$$

[P1LAB_O(i)*A1LAB_O(i)], [P1CAP(i)*A1CAP(i)], and [P1LND(i)*A1LND(i)], denote, respectively, the costs of an effective unit of composite labour, capital, and land. Relatively cheaper factors gain more share in the total usage of primary factors.

Next, we introduce the electricity nest as shown at level 3a in Figure 3.2(B). This nest is particular for the EUS industry.

The intermediate input demand of the EUS industry for electricity generated by various technologies, X1_S(j,"EUS")

(see also the raw-electricity nest at level 3a of Figure 3.2(B))

Choose X1_S(j,"EUS"), with j referring to the electricity outputs of the 'ELECGEN' industries, to minimise the total electricity cost of the EUS industry:

$$\sum_{j\in ELECGEN} P1\_S(j,\text{"EUS"})*X1\_S(j,\text{"EUS"}), \qquad (3.29)$$

subject to

$$XRAWELEC = \underset{j\in ELECGEN}{CES}\left[\frac{X1\_S(j,\text{"EUS"})}{A1\_S(j,\text{"EUS"})}\right], \qquad (3.30)$$

where the purchaser's price of electricity generated by power technology j, P1_S(j,"EUS"), is exogenous to the problem; the demand of the EUS industry for the "raw electricity" composite, XRAWELEC, is determined elsewhere in the superordinate nested optimisation problem; and A1_S(j,"EUS") is the technological coefficient for electricity from power technology j. Reductions in these technology coefficients indicate technical improvements in using electricity.

The linearised demand equation for electricity from various power technologies is presented below.

$$x1\_s(j,\text{"EUS"}) - a1\_s(j,\text{"EUS"}) = xRawElec - SIGELEC*[p1\_s(j,\text{"EUS"}) + a1\_s(j,\text{"EUS"}) - pRawElec], \quad j\in ELECGEN, \qquad (3.31)$$

where pRawElec is defined as:

$$pRawElec = \sum_{j\in ELECGEN}\left(\frac{V1PUR\_S(j,\text{"EUS"})}{VRAWELEC}\right)*[p1\_s(j,\text{"EUS"}) + a1\_s(j,\text{"EUS"})]. \qquad (3.32)$$

We also add two cost-neutral twist variables to account for non-price induced changes in the usage ratios of electricity from various power technologies. Equations 3.31 and 3.32 are rewritten as:

$$x1\_s(j,\text{"EUS"}) - a1\_s(j,\text{"EUS"}) = xRawElec + electwist(j) - electwist\_c - SIGELEC*[p1\_s(j,\text{"EUS"}) - pRawElec], \quad j\in ELECGEN, \qquad (3.31a)$$

and

$$pRawElec = \sum_{j\in ELECGEN}\left(\frac{V1PUR\_S(j,\text{"EUS"})}{VRAWELEC}\right)*p1\_s(j,\text{"EUS"}). \qquad (3.32a)$$

SIGELEC is the elasticity of substitution between electricity generated by the J 'ELECGEN' industries. We set a value of 5.0 for SIGELEC. pRawElec denotes the

percentage change in the average effective price of electricity input to the EUS industry, PRAWELEC. Equation 3.32a defines pRawElec as a cost-share weighted Divisia index of the technology-specific electricity prices. V1PUR_S(j,"EUS") is the cost at the purchaser's price of electricity from power technology j used by the EUS industry. VRAWELEC is the total electricity cost of the EUS industry and it is calculated as:

$$VRAWELEC = \sum_{j\in ELECGEN} V1PUR\_S(j,\text{"EUS"}).$$

electwist(j) and electwist_c are the cost-neutral twist variables, with electwist_c defined as:

$$electwist\_c = \sum_{j\in ELECGEN}\left(\frac{V1PUR\_S(j,\text{"EUS"})}{VRAWELEC}\right)*electwist(j). \qquad (3.33)$$

Equation 3.31 indicates that demand of the EUS industry for electricity produced by power technology j is proportional to its demand for the effective electricity composite, XRAWELEC, and to a price term:

$$\left(\frac{P1\_S(j,\text{"EUS"})}{PRAWELEC}\right)^{-SIGELEC}, \qquad j\in ELECGEN.$$

The EUS industry tends to buy more electricity from relatively less costly power technologies. Note that technological variables, A1_S(j,"EUS"), are replaced after the introduction of twist variables. In the absence of price changes, an one percent change in electwist(c) will cause an $\left[1-\left(\frac{V1PUR\_S(j,\text{"EUS"})}{VRAWELEC}\right)\right]$% increase in demand for electricity generated by power technology j, and an $\left(\frac{V1PUR\_S(j,\text{"EUS"})}{VRAWELEC}\right)$% reduction in the usage electricity generated by power technologies other than j.

Next, we introduce the production nests particularly for the 'ORDINARY' industries. As shown in Figure 3.2(C), we allow the 'ORDINARY' industries to substitute between energy inputs (level 4b) and primary factors (level 4'). We discuss the energy nest first, followed by the energy-primary-factor nest.

The intermediate input demands of the 'ORDINARY' industries for energy inputs, X1_S(r,i)

(see also the energy nest at level 4b of Figure 3.2(C))

Choose X1_S(r,i), with r referring to R energy commodities to minimise the total energy cost of the 'ORDINARY' industry i:

$$\sum_{r\in ENERCOM} P1\_S(r,i)*X1\_S(r,i), \qquad i\in ORDINARY, \qquad (3.34)$$

subject to

$$X1ENER(i) = \underset{r\in ENERCOM}{CES}\left[\frac{X1\_S(r,i)}{A1\_S(r,i)}\right], \qquad i\in ORDINARY, \quad (3.35)$$

where the purchaser's price of energy input r used by industry i, P1_S(r,i), is exogenous to the problem; the demand of industry i for the composite energy, X1ENER(i), is determined elsewhere in the superordinate nested optimisation problem; and A1_S(r,i) is the technological coefficient measuring efficiency of industry i in using energy input r. Reductions in these technology coefficients indicate technical improvements in using energy inputs.

The linearised demand equation for energy inputs is presented below.

$$x1\_s(r,i) - a1\_s(r,i) = x1ener(i) - SIGMA1ENER(i)*[p1\_s(r,i) + a1\_s(r,i) - p1ener(i)], \qquad r\in ENERCOM,\ i\in ORDINARY, \quad (3.36)$$

where p1ener(i) is defined as:

$$p1ener(i) = \sum_{r\in ENERCOM}\left(\frac{V1PUR\_S(r,i)}{V1ENER(i)}\right)*[p1\_s(r,i) + a1\_s(r,i)], \qquad i\in ORDINARY. \quad (3.37)$$

SIGMA1ENER(i) is the elasticity of substitution between energy inputs for industry i. For all 'ORDINARY' industries, we set a value of 0.3 for SIGMA1ENER(i). p1ener(i) denotes the percentage change in the average effective price of the composite energy input for industry i, P1ENER(i). Equation 3.37 defines p1ener(i) as a cost-share weighted Divisia index of the energy prices. V1PUR_S(r,i) is the cost at the purchaser's price of energy input r of industry i. V1ENER(i) is the total energy cost of industry i and it is calculated as:

$$V1ENER(i) = \sum_{r\in ENERCOM} V1PUR\_S(r,i), \qquad i\in ORDINARY.$$

Equation 3.36 indicates that demand by 'ORDINARY' industry i for energy input r is proportional to its demand for the effective composite energy, X1ENER(i), and to a price term:

$$\left(\frac{P1\_S(r,i)*A1\_S(r,i)}{P1ENER(i)}\right)^{-SIGMA1ENER(i)}, r\in ENERCOM,\ i\in ORDINARY.$$

[P1_S(r,i)*A1_S(r,i)] denotes the effective unit costs of energy inputs used by 'ORDINARY' industry i. Relatively more costly energy goods would be substituted away.

The intermediate input demands of the 'ORDINARY' industries for the composite energy (X1ENER(i)) and the primary-factor composite (X1PRIM(i))

(see also the energy-primary-factor nest at level 4' of Figure 3.2(C))

Choose X1ENER(i) and X1PRIM(i), to minimise the total cost of the composite energy and primary-factor inputs of the 'ORDINARY' industry i:

$$[P1ENER(i)*X1ENER(i)] + [P1PRIM(i)*X1PRIM(i)], \qquad i\in ORDINARY, \quad (3.38)$$

subject to

$$X1ENERPRIM(i) = CES\left[\frac{X1ENER(i)}{A1ENER(i)}, \frac{X1PRIM(i)}{A1PRIM(i)*A1PRIM\_I}\right], \quad (3.39)$$

where the purchaser's price of the composite energy used by industry i, P1ENER(i), is exogenous to the problem; the demand of industry i for the energy-primary-factor composite, X1ENERPRIM(i), is determined elsewhere in the superordinate nested optimisation problem; and A1ENER(i) and A1PRIM(i) are technological coefficients, respectively, measuring the overall efficiency of industry i in using energy inputs and primary factors. A1PRIM_I is the economy-wide technological coefficient for primary factors[21]. Reductions in these technology coefficients indicate technical improvements in efficiency.

The linearised demand equations for the composite energy and the primary-factor composite are presented below.

$$x1ener(i) - a1ener(i) = x1enerprim(i) - SIGMA1ENERPRIM(i)*[p1ener(i) + a1ener(i) - p1enerprim(i)], \qquad i\in ORDINARY, \quad (3.40)$$

and

$$x1prim(i) - a1prim(i) = x1enerprim(i) - SIGMA1EPRIM(i)*[p1prim(i) + a1prim(i) + a1prim\_i - p1enerprim(i)], \qquad i\in ORDINARY, \quad (3.41)$$

where p1enerprim(i) is defined as:

$$p1enerprim(i) = \left(\frac{V1ENER(i)}{V1ENERPRIM(i)}\right)*[p1ener(i) + a1ener(i)] + \left(\frac{V1PRIM(i)}{V1ENERPRIM(i)}\right)*[p1prim(i) + a1prim(i) + a1prim\_i], \qquad i\in ORDINARY. \quad (3.42)$$

SIGMA1EPRIM(i) is the elasticity of substitution between the composite energy and the primary-factor composite for industry i. For all 'ORDINARY' industries, we

[21] In historical simulations, we observe growth of aggregate employment and all GDP components at the expenditure side. Capital stocks are accumulated from investments in previous years. We set a1prim_i endogenous to assure the equality between both sides of GDP.

set a value of 0.2 for SIGMA1EPRIM(i). p1enerprim(i) denotes the percentage change in the average effective price of the energy-primary-factor composite for industry i, P1ENERPRIM(i). Equation 3.42 defines p1enerprim(i) as a cost-share weighted Divisia index of the prices for the composite energy and the primary-factor composite. V1ENER(i) is the cost at the purchaser's price of all energy inputs of industry i. V1PRIM(i) is the total cost of primary factors of industry i. V1ENERPRIM(i) is the total cost of energy inputs and primary factors of industry i and it is calculated as:

$$\text{V1ENERPRIM(i)} = \text{V1ENER(i)} + \text{V1PRIM(i)}, \quad \text{i} \in \text{ORDINARY}.$$

Equation 3.40 indicates that demands of 'ORDINARY' industry i for the composite energy and the primary-factor composite are proportional to its demand for the effective energy-primary-factor composite, X1ENERPRIM(i), and to the relative price terms:

$$\left(\frac{\text{P1ENER(i)*A1ENER(i)}}{\text{P1ENERPRIM(i)}}\right)^{-\text{SIGMA1EPRIM(i)}}, \text{ for the composite energy,}$$

and

$$\left(\frac{\text{P1PRIM(i)*A1PRIM(i)*A1PRIM\_I}}{\text{P1ENERPRIM(i)}}\right)^{-\text{SIGMA1EPRIM(i)}}, \text{ for the primary-factor composite.}$$

[P1ENER(i)*A1ENER(i)] and [P1PRIM(i)*A1PRIM(i)*A1PRIM_I] denote, respectively, the effective prices of the energy composite and the primary-factor composite used by 'ORDINARY' industry i. Industries would substitute primary factors for energy inputs when energy inputs are relatively more costly.

Next, we introduce the activity nest at level 3' of Figures 3.2(A), 3.2(B) and 3.2(C) for the 'ELECGEN' industries, the EUS industry and the 'ORDINARY' industries, respectively.

Demand by 'ELECGEN' Industry i for all inputs

(see also the activity nest at level 3' of Figure 3.2(A))

Choose inputs of:

(a) composite good c, X1_S(c,i);

(b) the primary-factor composite, X1PRIM(i); and

(c) "other costs", X1OCT(i);

to minimise the total input cost:

$$\sum_{c \in \text{COM}} \{\text{P1\_S(c,i)*X1\_S(c,i)}\} + \text{P1PRIM(i)*X1PRIM(i)} + \text{P1OCT(i)*X1OCT(i)}, \quad \text{i} \in \text{ELECGEN}, \quad (3.43)$$

subject to

$$\text{A1TOT(i)*X1TOT(i)} = \min_{c \in \text{COM}} \left[\frac{\text{X1\_S(c,i)}}{\text{A1\_S(c,i)}}, \frac{\text{X1PRIM(i)}}{\text{A1PRIM(i)*A1PRIM\_I}}, \frac{\text{X1OCT(i)}}{\text{A1OCT(i)}}\right], \quad \text{i} \in \text{ELECGEN}, \quad (3.44)$$

where the purchaser's price of composite good c, P1_S(c,i); the price of the primary-factor composite, P1PRIM(i); the price of "other costs", P1OCT(i); and the activity level of industry i, X1TOT(i), are regarded as exogenous to the problem[22]. A1_S(c,i), A1PRIM(i), and A1OCT(i) are, respectively, technological coefficients for composite good c, the primary-factor composite, and "other costs" used by industry i. A1PRIM_I is the economy-wide technological coefficient for primary factors. A1TOT(i) is the Hicks-neutral technological coefficient for all inputs used by industry i as a whole. Reductions in these coefficients indicate technical improvements in input-using efficiency. The "Min" operator indicates that input demands of industry i are subject to the activity level, [A1TOT(i)*X1TOT(i)], and productivity of inputs. That is,

$$\text{X1\_S(c,i)} = \text{A1TOT(i)*X1TOT(i)*A1\_S(c,i)}, \quad \text{for all } c \in \text{COM};$$
$$\text{X1PRIM(i)} = \text{A1TOT(i)*X1TOT(i)*A1PRIM(i)*A1PRIM\_I};$$
$$\text{X1OCT(i)} = \text{A1TOT(i)*X1TOT(i)*A1OCT(i)}.$$

The linearised demand equations of composite commodities, the primary-factor composite and "other costs" are presented below.

$$\text{x1\_s(c,i)} - [\text{a1\_s(c,i)} + \text{a1tot(i)}] = \text{x1tot(i)}, \quad \text{i} \in \text{ELECGEN}. \quad (3.45)$$
$$\text{x1prim(i)} - [\text{a1prim(i)} + \text{a1prim\_i} + \text{a1tot(i)}] = \text{x1tot(i)}, \quad \text{i} \in \text{ELECGEN}. \quad (3.46)$$
$$\text{x1oct(i)} - [\text{a1oct(i)} + \text{a1tot(i)}] = \text{x1tot(i)}, \quad \text{i} \in \text{ELECGEN}. \quad (3.47)$$

Effective demands for composite commodities, primary factors, and "other costs" of industry i are proportional to its activity level regardless of price changes.

Demand by the EUS industry for all inputs

(see also the activity nest at level 3' of Figure 3.2(B))

Choose inputs of:

(a) non-electricity composite good c, X1_S(c,i);

(b) the raw electricity composite, XRAWELEC;

(c) primary-factor composite, X1PRIM(i); and

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22 Under (a) constant returns to scale, and (b) the assumption that producers are price-takers, the average input cost of industry i should equal the average price of commodities produced by industry i. Hence, output price of industry i, P1TOT(i), is determined by the average input cost. We use P1TOT(i) to denote both average input cost and average output price of industry i. In Section 3.5.1(B), P1TOT(i) is defined as the average output price for industry i. In Section 3.5.8, P1TOT(i) is defined as the average input cost.

(d) "other costs", X1OCT(i);

to minimise the total input cost:

$$\sum_{c\in NONELECCOM} \{P1\_S(c,i)*X1\_S(c,i)\} + PRAWELEC*XRAWELEC + P1PRIM(i)*X1PRIM(i) + P1OCT(i)*X1OCT(i), \quad i = \text{"EUS"}, \quad (3.48)$$

subject to

$$A1TOT(i)*X1TOT(i) = \underset{c\in NONELECCOM}{Min}\left[\frac{X1\_S(c,i)}{A1\_S(c,i)}, \frac{XRAWELEC}{AELEC}, \frac{X1PRIM(i)}{A1PRIM(i)*A1PRIM\_I}, \frac{X1OCT(i)}{A1OCT(i)}\right], \quad i = \text{"EUS"}, \quad (3.49)$$

where PRAWELEC is the purchaser's price of the raw electricity composite; AELEC is a technological coefficient measuring input-using efficiency of raw electricity. Reductions in AELEC indicate technical improvements in efficiency.

The linearised demand equations of non-electricity composite commodities, the raw electricity composite, the primary-factor composite and "other costs" are presented below.

$$x1\_s(c,i) - [a1\_s(c,i) + a1tot(i)] = x1tot(i), \quad c\in NONELECCOM, \quad i = \text{"EUS"}. \quad (3.50)$$

$$xRawElec - [aelec + a1tot(i)] = x1tot(i), \quad i = \text{"EUS"}. \quad (3.51)$$

$$x1prim(i) - [a1prim(i) + a1prim\_i + a1tot(i)] = x1tot(i), \quad i = \text{"EUS"}. \quad (3.52)$$

$$x1oct(i) - [a1oct(i) + a1tot(i)] = x1tot(i), \quad i = \text{"EUS"}. \quad (3.53)$$

Effective demands for non-electricity composite commodities, raw electricity, primary factors, and "other costs" of the EUS industry are proportional to its activity level regardless of price changes.

Demand by 'ORDINARY' industry i for all inputs

(see also the activity nest at level 3' of Figure 3.2(C))

Choose inputs of:

(a) non-energy composite good c, X1_S(c,i);

(b) the energy-primary-factor composite, X1ENERPRIM(i); and

(c) "other costs", X1OCT(i);

to minimise the total input cost:

$$\sum_{c\in NONENERCOM} \{P1\_S(c,i)*X1\_S(c,i)\} + P1ENERPRIM(i)*X1ENERPRIM(i) + P1OCT(i)*X1OCT(i), \quad i\in ORDINARY, \quad (3.54)$$

subject to

$$A1TOT(i)*X1TOT(i) = \underset{c\in NONENERCOM}{Min}\left[\frac{X1\_S(c,i)}{A1\_S(c,i)}, \frac{X1ENERPRIM(i)}{A1ENERPRIM(i)}, \frac{X1OCT(i)}{A1OCT(i)}\right], \quad i\in ORDINARY, \quad (3.55)$$

where P1ENERPRIM(i) and A1ENERPRIM(i) are, respectively, the purchaser's price of and technological coefficient for the energy-primary-factor composite. Reductions in A1ENERPRIM(i) indicate technical improvements in efficiency.

The linearised demand equations of non-energy composite commodities, the energy-primary-factor composite and "other costs" are presented below.

$$x1\_s(c,i) - [a1\_s(c,i) + a1tot(i)] = x1tot(i), \quad c\in NONENERCOM, \ i\in ORDINARY. \quad (3.56)$$

$$x1enerprim(i) - [a1enerprim(i) + a1tot(i)] = x1tot(i), \quad i\in ORDINARY. \quad (3.57)$$

$$x1oct(i) - [a1oct(i) + a1tot(i)] = x1tot(i), \quad i\in ORDINARY. \quad (3.58)$$

Effective demands for non-energy composite commodities, the energy-primary-factor composite, and "other costs" of the 'ORDINARY' industry i are proportional to its activity level regardless of price changes.

3.5.1(B) Supplies of commodities

All industries share a common specification for output supply decisions. For given levels of production capacity and technology, industries select their revenue-maximising output mixes at the prevailing market prices following a CET (constant elasticity of transformation) production possibility frontier. As relative prices of commodities vary, producers adjust their output mixes. This is illustrated by the output-mix nest at level 2 of Figures 3.2(A), 3.2(B) and 3.2(C). The revenue maximisation problem is summarised as follows.

Supply of good c by industry i, Q1(c,i)

(see also the output-mix nest at level 2 of Figures 3.2(A), 3.2(B) and 3.2(C))

Choose Q1(c,i) to maximise the total revenue from all goods produced by industry i:

$$\sum_{c\in COM} P0COM(c)*Q1(c,i), \quad i\in IND, \quad (3.59)$$

subject to

$$\underset{c\in COM}{CET}\left[Q1(c,i)\right] = X1TOT(i), \quad i\in IND, \quad (3.60)$$

where the basic price[23] of good c, P0COM(c), is exogenous to the problem as we assume that producers are price-takers in output markets; the activity level of industry i, X1TOT(i), is exogenous to the problem.

The linearised equation of output supply is presented below.

$$q1(c,i) = x1tot(i) + SIGMA1OUT(i)*[p0com(c) - p1tot(i)], \quad c\in COM,\ i\in IND, \quad (3.61)$$

where SIGMA1OUT(i) is the CET transformation elasticity[24] between commodities; p1tot(i) denotes the percentage change in the average price received by industry i for the commodities it produces, P1TOT(i)[25]. The equation below defines p1tot(i) as a revenue-share weighted Divisia index of the commodity prices:

$$p1tot(i) = \sum_{c\in COM}\left(\frac{MAKE(c,i)}{MAKE\_C(i)}\right)*p0com(c), \qquad i\in IND, \quad (3.62)$$

where MAKE(c,i) is the basic value of good c produced by industry i; MAKE_C(i) is the total revenue from commodities produced by industry i. MAKE_C(i) is calculated as:

$$MAKE\_C(i) = \sum_{c\in COM} MAKE(c,i), \qquad i\in IND.$$

Equation 3.61 relates the commodity supplies of industry i to its activity level and to the relative prices of commodities. Industry i would produce more of the commodity of a relatively higher price, with the supply share of the commodity, $\left(\frac{Q1(c,i)}{X1TOT(i)}\right)$, proportional to the price term of transformation:

$$\left(\frac{P0COM(c)}{P1TOT(i)}\right)^{SIGMA1OUT(i)}, \qquad c\in COM,\ i\in IND.$$

Note that there is no industry index in the variable, P0COM(c). This is because we assume that outputs of good c produced by different industries are perfect substitutes. Hence, industries receive the same unit price for their product c.

This output-mix nest is applicable to both multi- and single-product industries in the model. Most of the industries in TAIGEM are single-product producers. There is only one multi-product industry—the Oil Refinery industry. Its output bundle contains the following 10 petroleum products:

[23] The basic price is the price received by producers, excluding commodity tax and charges of margins. Detailed information about the price system is in Section 3.5.8 (Zero-pure-profits conditions).

[24] The functional form of CET is the same as that of CES, except that the CET transformation parameter has the opposite sign to the CES substitution parameter.

[25] See also Footnote 22.

(1) Gasoline,	(6) Lubricants,
(2) Diesel Fuel,	(7) Naphtha,
(3) Aviation Fuel,	(8) Refinery Gas,
(4) Fuel Oils,	(9) Asphalt, and
(5) Kerosene,	(10)Other Refined Petroleum Products.

Next, we introduce the distribution of commodity supplies to different destinations. We assume that there is a proxy agent taking charge of the distribution of commodities to either local or overseas markets. We describe the optimisation problem as follows.

Distribution of commodity supplies to different destinations

(see also the sale-destination nest at level 1 of Figures 3.2(A), 3.2(B) and 3.2(C))

Choose supplies of good c for:

(a) local sale, X0DOM(c), and

(b) export, X4(c),

to maximise total revenue from commodity supplies to local and overseas markets:

$$[P0DOM(c)*X0DOM(c)] + [PE(c)*X4(c)], \qquad c\in COM, \quad (3.63)$$

subject to

$$X0COM(c) = CET\left[\,X0DOM(c), X4(c)\,\right], \qquad c\in COM, \quad (3.64)$$

$$X0COM(c) = \sum_{i\in IND} Q1(c,i), \qquad c\in COM, \quad (3.65)$$

where the basic price of good c for local sale, P0DOM(c), and the local currency basic price of good c for export, PE(c), are regarded as exogenous to the problem as producers are assumed to be price-takers; total supply of good c, X0COM(c), is the aggregate supply of good c by all industries. The direct summation of Q1(c,i) over industries reflects our assumption that outputs of good c produced by different industries are perfect substitutes.

The linearised equations derived from the above problem are presented below.

$$x0dom(c) = x0com(c) + SIGMA1DEST(c)*[p0dom(c) - p0com(c)], \qquad c\in COM. \quad (3.66)$$

$$x4(c) = x0com(c) + SIGMA1DEST(c)*[pe(c) - p0com(c)], \qquad c\in COM. \quad (3.67)$$

$$x0com(c) = \sum_{i\in IND}\left(\frac{MAKE(c,i)}{MAKE\_I(c)}\right)*q1(c,i), \qquad c\in COM. \quad (3.68)$$

SIGMA1DEST(c) is the CET transformation elasticity between local sales and export. p0com(c) denotes the percentage change in the basic price of good c received by domestic producers, P0COM(c). The equation below defines p0com(c) as a revenue-share weighted Divisia index of local-sale and export basic prices:

$$p0com(c) = \left(\frac{DOMSALES(c)}{SALES(c)}\right)*p0dom(c) + \left(\frac{V4BAS(c)}{SALES(c)}\right)*pe(c), \quad c\in COM, \quad (3.69)$$

where DOMSALES(c) and V4BAS(c) are basic values of good c for local sale and export; SALES(c) is the total sales at basic value of domestically-produced good c and is calculated as the sum of DOMSALES(c) and V4BAS(c). MAKE_I(c) is the total supply of good c by all industries. The formula for MAKE_I(c) is:

$$MAKE\_I(c) = \sum_{i\in IND} MAKE(c,i), \quad c\in COM. \quad (3.70)$$

We consolidate Equations 3.66 and 3.67 into a single equation. This is written after the addition of a twist variable as:

$$TAU(c)*[x0dom(c) - x4(c) - twistexp] = p0dom(c) - pe(c), \quad c\in COM, \quad (3.71)$$

where TAU(c) is the reciprocal of SIGMA1DEST(c); and twistexp[26] is the across-the-board revenue-neutral twist variable for all commodities. We can set a zero value for TAU(c) to nullify the sale-destination CET transformation. In that case, the proxy agent receives the same basic values from the sale of good c to local and overseas markets. That is, P0DOM(c) is equal to PE(c). In the absence of price changes, an one percent change in twistexp will cause an one percent increase in the ratio of local sale to export for all goods. In simulations where export volumes and prices are exogenously given, we can set twistexp endogenous to account for the observed changes in export volumes.

3.5.2 *Capital formation*

In this section, we introduce the cost minimisation problem in creating fixed capital for industries. We assume that capital is fabricated with domestically-produced and imported inputs. Figure 3.3 schematises the nesting structure of input demand for capital formation under the separability assumption. At level 1, a unit of capital good for use in industry i is created with fixed proportions of composite goods. At level 2, each composite good c is a cost-minimising CES aggregation of domestically-produced and imported good c. Note that capital formation does not require primary factor inputs. The cost minimisation problems based on the two-tiered capital formation technology are set out below.

[26] See Appendix 3 for a longer explanation of the twist variable.

The input demand for composite good c to create capital for use in industry i, X2_S(c,i)

(see also the capital-formation nest at level 1 of Figure 3.3).

Choose X2_S(c,i) to minimise the total cost of capital formation:

$$\sum_{c\in COM} P2\_S(c,i)*X2\_S(c,i), \quad i\in IND, \quad (3.72)$$

subject to

$$A2TOT(i)*X2TOT(i) = \underset{c\in COM}{Min}\left[\frac{X2\_S(c,i)}{A2\_S(c,i)}\right], \quad i\in IND, \quad (3.73)$$

where the purchaser's price of composite good c, P2_S(c,i), is exogenous to the problem as we assume all users are price-takers; the total real investment in industry i, X2TOT(i), is are regarded as exogenous to the problem[27]. A2_S(c,i) a positive technological coefficients for composite good c used as input to create capital good for industry i. A2TOT(i) is the Hicks-neutral technological coefficient for all inputs as a whole. Reductions in these coefficients indicate technical improvements in input-using efficiency.

The linearised input demand equation of composite commodities for capital formation is presented below.

$$x2\_s(c,i) - [a2\_s(c,i) + a2tot(i)] = x2tot(i), \quad c\in COM, i\in IND. \quad (3.74)$$

Effective demands for composite commodities to create capital for industry i are proportional to the total real investment in industry i regardless of price changes.

The demand for good c from source s to create capital for use in industry i, X2(c,s,i)

(see also the source nest at level 2 of Figure 3.3)

Choose X2(c,s,i) to minimise the total cost of capital-creating good c from all sources:

$$\sum_{s\in SRC} P2(c,s,i)*X2(c,s,i), \quad c\in COM, i\in IND, \quad (3.75)$$

subject to

$$X2\_S(c,i) = \underset{s\in SRC}{CES}\left[\frac{X2(c,s,i)}{A2(c,s,i)}\right], \quad c\in COM, i\in IND, \quad (3.76)$$

where the purchaser's price of the capital-creating good c from source s, P2(c,s,i), is exogenous to the problem; the effective input of composite good c, X2_S(c,i), is

[27] The determination of total real investment in industry i is introduced in Sections 3.6 (comparative static mode) and 3.9 (recursive dynamic mode).

determined in the cost minimisation problem as shown at level 1 in Figure 3.3 and is treated as exogenous to the current problem; A2(c,s,i) is a technological coefficient.

The linearised source-specific capital-creating input demand equation (with a twist variable added) is written as:

$$x2(c,s,i) = x2\_s(c,i) + RS2(c,s,i)*\{twistsrc(c) + twistsrc\_c - SIGMA2(c)*[p2(c,"dom",i) - p2(c,"imp",i)]\}, \quad c\in COM,\ i\in IND. \quad (3.77)$$

SIGMA2(c) is the Armington elasticity of substitution between capital-creating inputs of good c from domestic and foreign sources; RS2(c,s,i) is the reverse source share of good c used to create capital for use in industry i. The formula for RS2(c,s,i) is:

$$RS2(c,"dom",i) = \left(\frac{V2PUR(c,"imp",i)}{V2PUR\_S(c,i)}\right), \quad c\in COM,\ i\in IND,$$

and

$$RS2(c,"imp",i) = RS2(c,"dom",i) - 1 = -\left(\frac{V2PUR(c,"dom",i)}{V2PUR\_S(c,i)}\right), \quad c\in COM,\ i\in IND,$$

where V2PUR(c,s,i) is the value at the purchaser's price of the input of good c from source s used to create capital for use in industry i; V2PUR_S(c,i) is the total cost of capital-creating good c from both sources. V2PUR_S(c,i) is calculated as:

$$V2PUR\_S(c,i) = \sum_{s\in SRC} V2PUR(c,s,i), \quad c\in COM,\ i\in IND.$$

The cost-share weighted Divisia index of the source-specific commodity prices for capital formation, p2_s(c,i), is rewritten as:

$$p2\_s(c,i) = RS2(c,"dom",i)*p2(c,"imp",i) - RS2(c,"imp",i)*p2(c,"dom",i), \quad c\in COM,\ i\in IND. \quad (3.78)$$

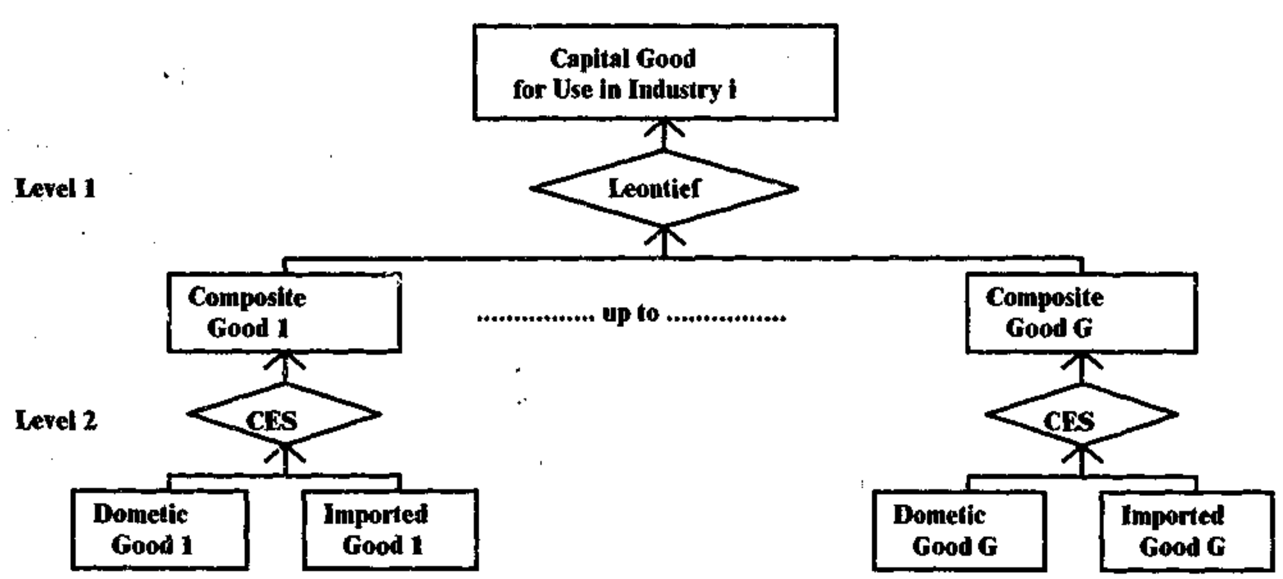

Figure 3.3 Structure of input demands for capital formation

3.5.3 *Household demands*

Household demands are derived from a per-household[28] Klein-Rubin utility maximisation problem. Figure 3.4 shows the nesting structure of the representative household's demand for commodities. At level 1, the household selects a bundle of composite goods that maximises their utility. At level 2, a CES function is specified to distinguish domestically-produced and imported commodities as imperfect substitutes.

Note that the Klein-Rubin utility function has the property that commodities are strongly separable. The marginal utility for good c is independent of the consumption of good k. Due to this property, the Klein-Rubin function is not appropriate for commodities which require complementarity in consumption. We grapple with this problem in Chapter 4.

The two-tiered optimisation problem of the average household is set out as follows.

Demand for composite good c per household, $\left(\frac{X3\_S(c)}{Q}\right)$

(see also the utility nest at level 1 of Figure 3.4)

Choose $\left(\frac{X3\_S(c)}{Q}\right)$ to maximise utility per household:

$$\underset{c\in COM}{U}\left[\frac{X3\_S(c)}{Q*A3\_S(c)}\right] = \prod_{c\in COM}\left(\left(\frac{X3\_S(c)}{Q*A3\_S(c)}\right) - A3SUB(c)\right)^{S3LUX(c)} \quad (3.79)$$

subject to

$$\left(\frac{V3TOT}{Q}\right) = \sum_{c\in COM} P3\_S(c)*\left(\frac{X3\_S(c)}{Q}\right), \quad (3.80)$$

with

$$X3\_S(c) = X3LUX(c) + X3SUB(c), \quad c\in COM, \quad (3.81)$$

$$A3SUB(c) = \left(\frac{X3SUB(c)}{Q}\right), \quad c\in COM, \quad (3.82)$$

and

$$P3\_S(c)*X3LUX(c) = S3LUX(c)*\sum_{c\in COM} P3\_S(c)*X3LUX(c) = S3LUX(c)*V3LUX\_C, \quad c\in COM, \quad (3.83)$$

where the purchaser's price of composite good c, P3_S(c), is exogenous to the problem as we assume consumers are price takers; A3_S(c) is a taste coefficient,

[28] We assume that overall consumer utility is the aggregation of individual household utility. Here we focus on the utility maximisation of an average household.

reductions in which indicate taste changes in favour of composite good c; Q is the number of households; and S3LUX(c) is positive and is regarded as the marginal budget share of composite good c. S3LUX(c) is defined as:

$$\text{S3LUX(c)} = \left(\frac{\partial[\text{P3\_S(c)*X3\_S(c)}]}{\partial \text{V3TOT}}\right), \quad c\in\text{COM},$$

with

$$\sum_{c\in \text{COM}} \text{S3LUX(c)} = 1. \qquad (3.84)$$

The total household expenditure, V3TOT, is regarded as exogenous to the current problem but is linked to nominal Gross Domestic Product (GDP) (See Section 3.5.10); aggregate demand for composite good c, X3_S(c), is decomposed into two parts: (a) aggregate "subsistence" requirement of composite good c, X3SUB(c), and (b) aggregate "supernumerary" expenditure on composite good c, X3LUX(c); the parameter A3SUB(c) is the "subsistence" requirement of composite good c per household.

The maximisation problem above produces the Linear Expenditure System (LES):

$$\text{P3\_S(c)*X3\_S(c)} = \text{X3SUB(c)*P3\_S(c)*A3\_S(c)} + \text{S3LUX(c)*\{V3TOT} - \sum_{k\in \text{COM}} \text{X3SUB(k)*P3\_S(k)*A3\_S(k)\}}, \quad c\in\text{COM}. \qquad (3.85)$$

The linearised version of Equation 3.85, temporarily ignoring taste variable, A3_S(c), is as follows.

$$\text{x3lux(c)} + \text{p3\_s(c)} = \text{w3lux} + \text{a3lux(c)}, \quad c\in\text{COM}; \qquad (3.86)$$

$$\text{x3\_s(c)} = \text{B3LUX(c)*x3lux(c)} + [1 - \text{B3LUX(c)}]\text{*x3sub(c)}, \quad c\in\text{COM}; \qquad (3.87)$$

and

$$\text{x3sub(c)} = \text{q} + \text{a3sub(c)}, \quad c\in\text{COM}. \qquad (3.88)$$

a3lux(c) and w3lux denote percentage changes in S3LUX(c) and V3LUX_C, respectively. B3LUX(c) is the ratio of "supernumerary" to total expenditure on composite good c:

$$\text{B3LUX(c)} = \frac{\text{P3\_S(c)*[X3\_S(c) - X3SUB(c)]}}{\text{P3\_S(c)*X3\_S(c)}}, \quad c\in\text{COM}. \qquad (3.89)$$

We also linearise the Klein-Rubin utility function (Equation 3.79) to gauge percentage changes in utility per household, utility:

$$\text{utility} + \text{q} = \sum_{c\in \text{COM}} \text{S3LUX(c)*x3lux(c)}. \qquad (3.90)$$

The parameter, S3LUX(c), is normally unobservable. Expenditure elasticities can be readily borrowed from literature. We can deduce S3LUX(c) from the expenditure elasticity, EPS(c), via the following formulae:

$$\text{EPS(c)} = \left(\frac{\partial[\text{P3\_S(c)*X3\_S(c)}]}{\partial \text{V3TOT}}\right)*\left(\frac{\text{V3TOT}}{[\text{P3\_S(c)*X3\_S(c)}]}\right) = \frac{\text{S3LUX(c)}}{\text{S3\_S(c)}}, \quad c\in\text{COM}, \qquad (3.91)$$

where S3_S(c) is the share of expenditure on composite good c, (P3_S(c)*X3_S(c)), in total household expenditure, V3TOT, and can be obtained from the Input-Output accounts. As S3LUX(c) and S3_S(c) are positive for all c, there is no inferior good in the Linear Expenditure System. B3LUX(c) can be calculated from the following formula:

$$\text{B3LUX(c)} = -\frac{\text{EPS(c)}}{\text{FRISCH}}, \quad c\in\text{COM}, \qquad (3.89a)$$

where FRISCH refers to the "money flexibility"[29], or the expenditure elasticity of the marginal utility of expenditure. FRISCH is defined as follows.

$$\text{FRISCH} = -\frac{\text{V3TOT}}{\text{V3TOT} - \sum_{c\in \text{COM}} \text{P3\_S(c)*X3SUB(c)}} = -\frac{\text{V3TOT}}{\text{V3LUX\_C}}. \qquad (3.92)$$

In TAIGEM, we specify a number of -1.82[30] for the FRISCH parameter[31].

Equation 3.89a suggests that commodities with larger "subsistence" requirements—with smaller B3LUX(c)—are associated with smaller expenditure elasticities, EPS(c). We specify smaller expenditure elasticities for agricultural commodities to reflect larger "subsistence" requirements for them. Air Transport is normally regarded as a luxury good, and hence has a larger expenditure elasticity.

As Klein-Rubin utility function has the property of additivity, we can deduce cross- and own-price elasticities, ETA(c,k), via the Frisch formula (see Frisch (1959)):

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[29] See Frisch (1932).

[30] Frisch (1959, pp. 189) noted the possible assumption for the "money flexibility" as follows.

ω = -10, for an extremely poor and apathetic part of the population;

ω = -4, for the slightly better off but still poor part of the population with a fairly pronounced desire to become better off;

ω = -2, for the middle income bracket, "the median part" of the population;

ω = -0.7, for the better-off part of the population;

ω = -0.1, for the rich part of the population with ambitions towards "conspicuous consumption".

[31] Note that S3LUX(c) and A3SUB(c) are held constant to feature the Klein-Rubin utility function. Hence, we need to update EPS(c) and FRISCH to accommodate changes in S3_S(c) and Q in our multi-step computation.

$$ETA(c,k) = -EPS(c)*S3\_S(k)*\left(1 + \frac{EPS(k)}{FRISCH}\right) + KD(c,k)*\left(\frac{EPS(c)}{FRISCH}\right),$$
$$c \in COM,\ k \in COM, \quad (3.93)$$

where KD(c,k) is the Kronecher delta, with the value set as one for c = k and zero otherwise.

Changes in S3LUX(c) and A3SUB(c) indicate taste changes as well. We link the taste coefficient, A3_S(c), to these two Klein-Rubin parameters in percentage change form as follows.

$$a3lux(c) = a3sub(c) - \sum_{k \in COM} S3LUX(k)*a3sub(k), \qquad c \in COM. \quad (3.94)$$

$$a3sub(c) = a3\_s(c) - \sum_{k \in COM} S3\_S(k)*a3\_s(k), \qquad c \in COM. \quad (3.95)$$

In deriving the above two equations, we assume that S3LUX(c) and A3SUB(c) move in proportion. Thus a one percent shift in household tastes in favour of good c relative to others, i.e.,

$$a3\_s(c) - \sum_{k \in COM} S3\_S(k)*a3\_s(k) = 1, \quad (3.96)$$

translates into a one percent increase in A3SUB(c) plus an approximately one percent increase in S3LUX(c)[32]. Note that the movements of a3lux(c) must abide by the restriction of Equation 3.84: the sum of S3LUX(c) across c is one.

Aggregate household demand for good c from source s, X3(c,s)

(see also the source nest at level 2 of Figure 3.4)

Choose X3(c,s) to minimise the total cost of good c from all sources for households:

$$\sum_{s \in SRC} P3(c,s)*X3(c,s), \qquad c \in COM, \quad (3.97)$$

subject to

$$X3\_S(c) = \underset{s \in SRC}{CES}\left[\frac{X3(c,s)}{A3(c,s)}\right], \qquad c \in COM, \quad (3.98)$$

where the purchaser's price of good c from source s for households, P3(c,s), is exogenous to the problem; aggregate household demand for composite good c, X3_S(c), is determined in the utility maximisation problem shown at level 1 in Figure 3.4 and is treated as exogenous to the current problem; and A3(c,s) is the positive taste coefficients for good c from source s.

The linearised equation of aggregate household demand for source-specific commodities (with twist variables added) are written as:

[32] Normally, S3LUX(c) is close to S3_S(c).

$$x3(c,s) = x3\_s(c) + RS3(c,s)*\{twistsrc(c) + twistsrc\_c - SIGMA3(c)*[p3(c,"dom") - p3(c,"imp")]\}, \qquad c \in COM,\ s \in SRC. \quad (3.99)$$

SIGMA3(c) is the Armington elasticity of substitution between consumer good c from domestic and foreign sources; RS3(c,s) is the reverse source share of good c purchased by households. The formula for RS3(c,s) is:

$$RS3(c,"dom") = \left(\frac{V3PUR(c,"imp")}{V3PUR\_S(c)}\right), \qquad c \in COM,$$

and

$$RS3(c,"imp") = RS3(c,"dom") - 1 = -\left(\frac{V3PUR(c,"dom")}{V3PUR\_S(c)}\right), \qquad c \in COM,$$

where V3PUR(c,s) is the value at the purchaser's price of good c from source s purchased by households; V3PUR_S(c) is the total cost of good c from both sources paid by households. V3PUR_S(c) is calculated as:

$$V3PUR\_S(c) = \sum_{s \in SRC} V3PUR(c,s), \qquad c \in COM.$$

The cost-share weighted Divisia index of the source-specific commodity prices for households, p3_s(c), is rewritten as:

$$p3\_s(c) = RS3(c,"dom")*p3(c,"imp") - RS3(c,"imp")*p3(c,"dom"), \qquad c \in COM. \quad (3.100)$$

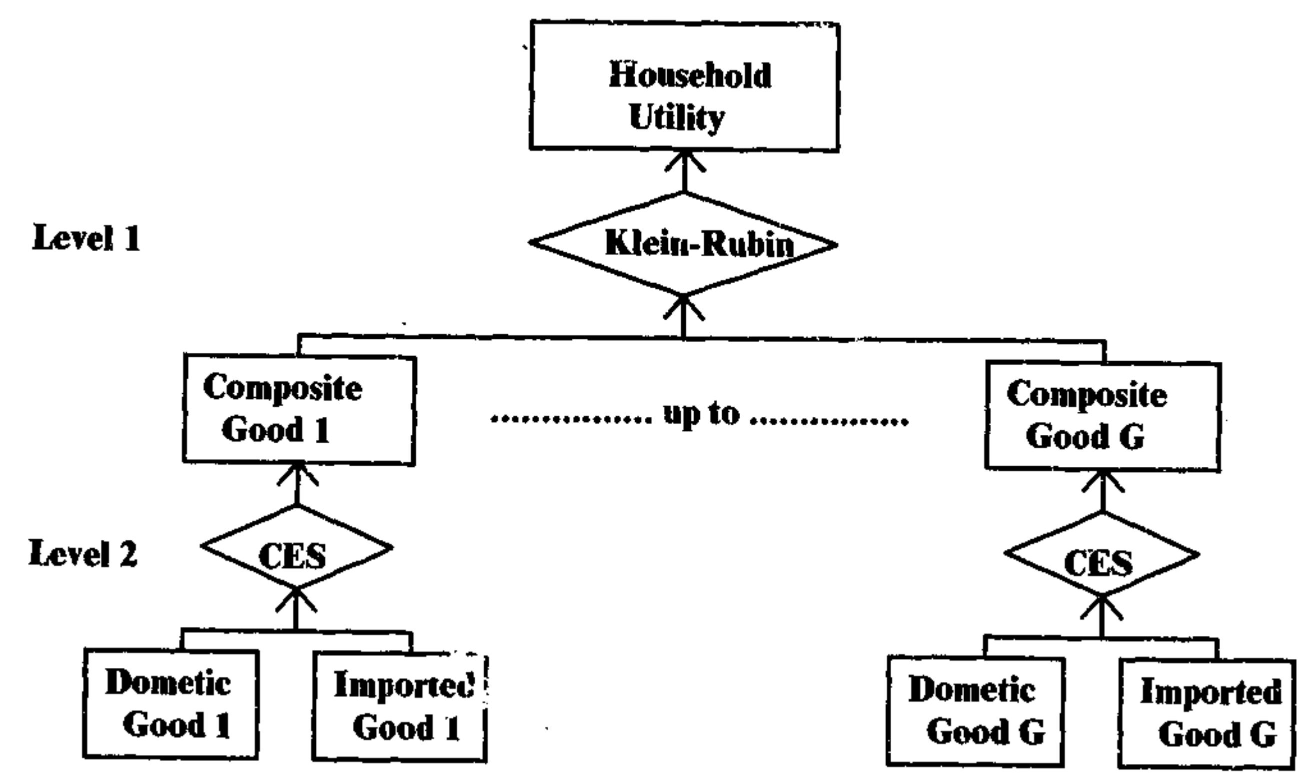


Figure 3.4 Structure of household demands

3.5.4 *Export demands*

In modelling foreign demand for Taiwan-made products, we classify commodities into three mutually exclusive categories: (a) *traditional* exports: commodities with large export shares in their total supplies; (b) *non-traditional* exports: commodities which are less overseas oriented; and (c) margin services for international trade.

For traditional exports, we specify downward-sloping demand schedules: the export demands are related inversely to the market prices in foreign currency (see also Figure 3.5). This can be expressed algebraically as follows.

$$X4(c) = F4Q(c)*F4Q\_C*F4Q\_TRAD*\left[\frac{P4(c)}{PHI*F4P(c)*F4P\_C}\right]^{EXP\_ELAST(c)}, \quad c\in TRADEXP, \quad (3.101)$$

where X4(c) is the export demand for good c; P4(c) is the f.o.b. (purchaser's) price of good c in local currency; PHI is the nominal exchange rate (local to foreign currency); EXP_ELAST(c), of negative value, is the constant elasticity of foreign demand for good c; F4P(c) and F4Q(c) are variables to account, respectively, for shifts of price (vertical) and quantity (horizontal) in the export demand schedule for good c; F4Q_C, F4Q_TRAD, and F4P_C function analogously as the shift variables just alluded, except that F4Q_C and F4P_C are effective on all exports and F4Q_TRAD is effective on all traditional exports.

We linearise Equation 3.101 as follows.

$$x4(c) - f4q(c) - f4q\_c - f4q\_trad = EXP\_ELAST(c)*[p4(c) - phi - f4p(c) - f4p\_c], \quad c\in TRADEXP. \quad (3.102)$$

We can interpret F4P(c) as the world price of good c. Increases in the f.o.b. price of good c relative to the world price will cause contractions in foreign demand for good c.

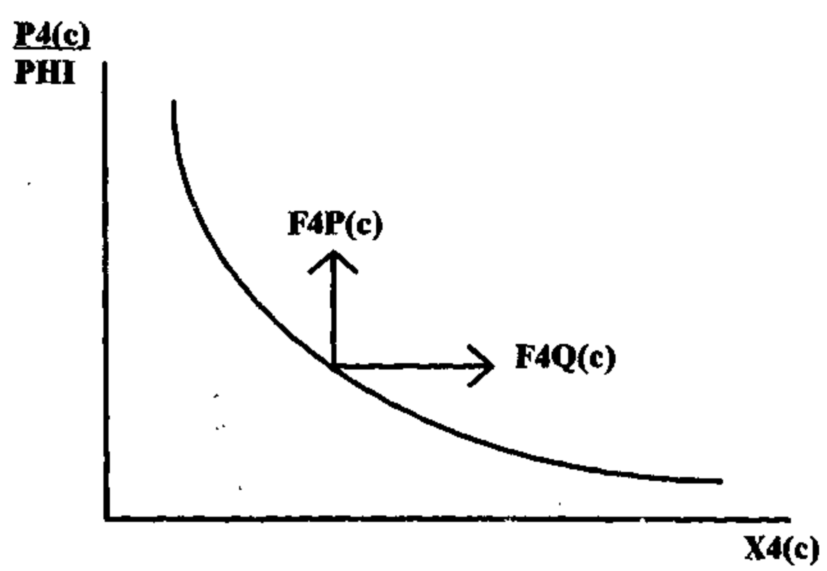


Figure 3.5 The demand schedule for traditional exports

For non-traditional exports, we assume that demands for individual non-traditional exports respond inversely to their average price in foreign currency. Algebraically, this relationship can be expressed as follows.

$$X4(c) = F4Q(c)*F4Q\_C*F4Q\_NTRAD*\left[\frac{P4\_NTRAD}{PHI*F4P\_NTRAD*F4P\_C}\right]^{EXP\_ELAST\_NT}, \quad c\in OTHEREXP, \quad (3.103)$$

$$\sum_{c\in OTHEREXP} P4(c)*X4(c) = P4\_NTRAD*X4\_NTRAD, \quad (3.104)$$

where X4_NTRAD is the demand for aggregate non-traditional exports; P4_NTRAD is average f.o.b. (purchaser's) price of non-traditional exports in local currency; EXP_ELAST_NT, of negative value, is the constant foreign elasticity of demand for the aggregate non-traditional exports; F4P_NTRAD and F4Q_NTRAD are shift variables to account, respectively, for shifts of price (vertical) and quantity (horizontal) in the demand schedule for the aggregate non-traditional export.

The equations below are the linearised versions of Equations 3.103 and 3.104.

$$x4(c) - f4q(c) = x4\_ntrad, \quad c\in OTHEREXP; \quad (3.105)$$

$$x4\_ntrad - f4q\_ntrad - f4q\_c = EXP\_ELAST\_NT*[p4\_ntrad - phi - f4p\_ntrad - f4p\_c], \quad (3.106)$$

$$p4\_ntrad = \sum_{c\in OTHEREXP}\left(\frac{V4PUR(c)}{V4OTHEREXP}\right)*p4(c), \quad (3.107)$$

where V4PUR(c) is the f.o.b. value of export good c; V4OTHEREXP is calculated as:

$$V4OTHEREXP = \sum_{c\in OTHEREXP} V4PUR(c).$$

For the last category—trade-related margin exports—we assume that the export volume of the margin services move with the total volume of exports and imports:

$$X4(c) = F4Q(c)*TRADEVOL, \quad c\in MAREXP; \quad (3.108)$$

$$TRADEVOL = V4TOT + V0CIF\_C, \quad (3.109)$$

where V4TOT is the total export earnings; V0CIF_C is the total value of imports, excluding tariffs; TRADEVOL is the total volume of international trade.

The linearised demand equations for trade-related margin exports are shown below.

$$x4(c) - f4q(c) = trdvol, \quad c\in MAREXP; \quad (3.110)$$

$$trdvol = \frac{V4TOT}{TRADEVOL}*x4tot + \frac{V0CIF\_C}{TRADEVOL}*x0cif\_c, \quad (3.111)$$

where x4tot and x0cif_c denote, respectively, percentage changes in export and import volume.

3.5.5 Government demands

There is no formal theory about government demand in TAIGEM. Generally, we assume that government demands for domestically-produced and imported goods move in line with real aggregate household consumption. However, some shift variables are introduced for flexibility. Thus, we write:

x5(c,s) = f5(c,s) + f5tot, c∈COM, s∈SRC; (3.112)

f5tot = x3tot + f5tot2, (3.113)

where x5(c,s) is the percentage change in government demand for good c from source s; x3tot is the percentage change in real aggregate household consumption; f5(c,s) is the shift in government demand for good c from source s; and f5tot2 functions analogously to f5(c,s) except that it is effective on all goods.

3.5.6 Inventory demands

We specify two arbitrary rules for inventory demands as follows.

$$\text{Rule A:}\quad 100*\left(\frac{\Delta X6(c,s)}{X6(c,s)}\right) = x0com(c), \qquad c\in COM. \quad (3.114)$$

In Rule A, we assume that inventory demands for both domestically-produced and imported good c, X6(c,s), move in line with the total supply of domestically-produced good c, X0COM(c). As inventory demands may be either positive or negative, we use the ordinary change variable, delx6(c,s), for X6(c,s) in the TABLO code. The linearised version of Equation 3.114 is[33]:

100*LEVP0(c,s)*delx6(c,s)= V6BAS(c,s)*x0com(c) + 100*fx6(c,s),
c∈COM, s∈SRC. (3.115)

LEVP0(c,s) is the current basic price of good c from source s and is equivalent to P0(c,s). We specify for LEVP0(c,s) an arbitrary initial value of one[34]. Variable, fx6(c,s), in ordinary change form, allows for shifts in inventory demand for source-specific good c.

Alternatively, we may assume inventory demand for good c from source s is subject to exogenous changes. Ordinary change variables, fx6B_c and fx6B(c,s) denote, respectively, shifts in inventory demands for all commodities and for source-specific good c. In TABLO code, this rule is written as:

[33] By defining V6BAS(c,s) = LEVP0(c,s)*X6(c,s), we can derive Equation 3.115 with the addition of the ordinary-change shift variable, fx6(c,s). That is,

$$100*\Delta X6(c,s) = \left(\frac{V6BAS(c,s)}{LEVP0(c,s)}\right)*x0com(c) + 100*fx6(c,s).$$

[34] As we define delx6(c,s) as an ordinary change variable, we need to specify the unit of measurement for the quantities of inventories. With LEVP0(c,s) set to one, we define the unit of measurement for inventories as base-period-dollars-worth. In multi-step computation, we update LEVP0(c,s) with the percentage change of P0(c,s).

Rule B:

100*LEVP0(c,s)*delx6(c,s)= 100*[ABS(V6BAS(c,s))*fx6B_c + fx6B(c,s)],
c∈COM, s∈SRC, (3.116)

where the expression, ABS(·), indicates the absolute value of the arguments; V6BAS(c,s) is the inventory value of good c from source s, which may be positive or negative.

To use rule A for simulations, we specify fx6(c,s) exogenous and fx6B(c,s) endogenous. To use rule B, we specify fx6B(c,s) exogenous and fx6(c,s) endogenous.

3.5.7 Demands for margin services

Margin services (e.g., Retail, wholesale, and transportation services.) facilitate the delivery of goods from producers factories to users. We assume that demands for margin services are proportional to demands for commodities, the delivery of which the margin services are associated with. Technological variables are introduced to accommodate technological improvements in the usage of margin services. Algebraically this can be expressed as follows.

X1MAR(c,s,i,m) = A1MAR(c,s,i,m)*X1(c,s,i),
c∈COM, s∈SRC, i∈IND, m∈MAR. (3.117)

X2MAR(c,s,i,m) = A2MAR(c,s,i,m)*X2(c,s,i),
c∈COM, s∈SRC, i∈IND, m∈MAR. (3.118)

X3MAR(c,s,m) = A3MAR(c,s,m)*X3(c,s),
c∈COM, s∈SRC, i∈IND, m∈MAR. (3.119)

X4MAR(c,m) = A4MAR(c,m)*X4(c),
c∈COM, s∈SRC, i∈IND, m∈MAR. (3.120)

X5MAR(c,s,m) = A5MAR(c,s,m)*X5(c,s),
c∈COM, s∈SRC, i∈IND, m∈MAR. (3.121)

where X1MAR(c,s,i,m) is the demand of industry i for margin service m to deliver intermediate input good c from source s, X1(c,s,i); X2MAR(c,s,i,m) is the demand of industry i for margin service m to deliver its capital-creating input good c from source s, X2(c,s,i); X3MAR(c,s,m) is the demand of household for margin service m to deliver good c from source s, X3(c,s,i); X4MAR(c,m) is the demand for margin service m to deliver export good c, X4(c); X5MAR(c,s,m) is the demand of government for margin service m to deliver good c from source s, X5(c,s); A1MAR(c,s,i,m), A2MAR(c,s,i,m), A3MAR(c,s,m), A4MAR(c,m), and A5MAR(c,s,m) are technological coefficients for margins usage of the corresponding users. Reductions in these coefficients indicate technical improvements in margin-using efficiency.

The linearised equations of margin demand are presented below.

$$x1mar(c,s,i,m) = x1(c,s,i) + a1mar(c,s,i,m), \quad c\in COM,\ s\in SRC,\ i\in IND,\ m\in MAR. \quad (3.122)$$

$$x2mar(c,s,i,m) = x2(c,s,i) + a2mar(c,s,i,m), \quad c\in COM,\ s\in SRC,\ i\in IND,\ m\in MAR. \quad (3.123)$$

$$x3mar(c,s,m) = x3(c,s) + a3mar(c,s,m), \quad c\in COM,\ s\in SRC,\ i\in IND,\ m\in MAR. \quad (3.124)$$

$$x4mar(c,m) = x4(c) + a4mar(c,m), \quad c\in COM,\ s\in SRC,\ i\in IND,\ m\in MAR. \quad (3.125)$$

$$x5mar(c,s,m) = x5(c,s) + a5mar(c,s,m), \quad c\in COM,\ s\in SRC,\ i\in IND,\ m\in MAR. \quad (3.126)$$

3.5.8 Price systems

In setting up the price systems for all markets, we impose the "zero-pure-profits" condition for all economic activities, including current production, capital creation, importing, and exporting.

"Zero-pure-profits" condition for domestic producers

We assume that total revenue of industry i is equal to the total cost of inputs. The cost-revenue equality relationship can be expressed algebraically as follows[35].

(A) For the 'ELECGEN' industries,

$$\sum_{c\in COM} P0COM(c)*Q1(c,i) = P1TOT(i)*X1TOT(i)$$
$$= \sum_{c\in COM} P1\_S(c,i)*X1\_S(c,i) + P1PRIM(i)*X1PRIM(i) + P1OCT(i)*X1OCT(i). \quad i\in ELECGEN. \quad (3.127)$$

The linearisation of the first two parts of the above equation, together with Equation 3.61, produces the relationship, in percentage change form, between the average output price received by industry i and its average input cost, P1TOT(i). This is Equation 3.62[36] in subsection 3.5.1(B).

The linearisation of the above equation, together with Equations 3.45 to 3.47, gives rise to Equation 3.128 as shown below. Equation 3.128 defines the percentage change in the average input cost, P1TOT(i), as a cost-share-weighted average of percentage changes in the input prices with allowance for technological change.

[35] Variable notations have been introduced in earlier sections.

[36] Equation 3.62 applies to all industries.

$$p1tot(i) - a1tot(i) = \sum_{c\in COM}\left(\frac{V1PUR\_S(c,i)}{V1TOT(i)}\right)*[p1\_s(c,i) + a1\_s(c,i)] + \left(\frac{V1PRIM(i)}{V1TOT(i)}\right)*[p1prim(i) + a1prim(i) + a1prim\_i] + \left(\frac{V1OCT(i)}{V1TOT(i)}\right)*[p1oct(i) + a1oct(i)], \quad i\in ELECGEN. \quad (3.128)$$

(B) For the "EUS" industry,

$$\sum_{c\in COM} P0COM(c)*Q1(c,i) = P1TOT(i)*X1TOT(i) =$$
$$\sum_{c\in NONELECCOM} P1\_S(c,i)*X1\_S(c,i) + PRAWELEC*XRAWELEC + P1PRIM(i)*X1PRIM(i) + P1OCT(i)*X1OCT(i), \quad i = \text{"EUS"}. \quad (3.129)$$

The linearisation of the above equation, together with Equations 3.50 to 3.53, gives rise to:

$$p1tot(i) - a1tot(i) = \sum_{c\in NONELECCOM}\left(\frac{V1PUR\_S(c,i)}{V1TOT(i)}\right)*[p1\_s(c,i) + a1\_s(c,i)] + \left(\frac{VRAWELE}{V1TOT(i)}\right)*[pRawElec + aelec] + \left(\frac{V1PRIM(i)}{V1TOT(i)}\right)*[p1prim(i) + a1prim(i) + a1prim\_i] + \left(\frac{V1OCT(i)}{V1TOT(i)}\right)*[p1oct(i) + a1oct(i)], \quad i = \text{"EUS"}. \quad (3.130)$$

(C) For the 'ORDINARY' industries,

$$\sum_{c\in COM} P0COM(c)*Q1(c,i) = P1TOT(i)*X1TOT(i) =$$
$$\sum_{c\in NONENERCOM} \{P1\_S(c,i)*X1\_S(c,i)\} + P1ENERPRIM(i)*X1ENERPRIM(i) + P1OCT(i)*X1OCT(i), \quad i\in ORDINARY. \quad (3.131)$$

The linearisation of the above equation, together with Equations 3.56 to 3.58, gives rise to:

$$p1tot(i) - a1tot(i) = \sum_{c\in NONENERCOM}\left(\frac{V1PUR\_S(c,i)}{V1TOT(i)}\right)*[p1\_s(c,i) + a1\_s(c,i)] + \left(\frac{V1ENERPRIM(i)}{V1TOT(i)}\right)*[p1enerprim + a1enerprim] + \left(\frac{V1OCT(i)}{V1TOT(i)}\right)*[p1oct(i) + a1oct(i)], \quad i\in ORDINARY. \quad (3.132)$$

With analogous algebraic manipulations, we can easily derive the linearised forms of the "zero-pure-profits" conditions for the rest of the economic activities. We simply present the levels forms of them as follows.

"Zero-pure-profits" condition for destination of sales

The total revenue from local sales and exports of good c should be equal to the total supply of domestic production of good c. Thus,

$$P0DOM(c)*X0DOM(c) + PE(c)*X4(c) = P0COM(c)*X0COM(c), \qquad c\in COM \quad (3.133)$$

where P0DOM(c) and PE(c) are local currency basic prices of good c for local sales and exports; X0DOM(c) and X4(c) are, respectively, supplies of good c for local sales and exports; P0COM(c) is the basic price of domestically-produced good c. X0COM(c) is the total supply of good c from all domestic producers.

The "zero-pure-profits" condition for capital formation

The value of new capital created for use in industry i should be equal to the total cost of the inputs needed. Thus,

$$P2TOT(i)*X2TOT(i) = \sum_{c\in COM} \sum_{s\in SRC} P2(c,s,i)*X2(c,s,i), \qquad i\in IND, \quad (3.134)$$

where P2TOT(i) is the asset price of a unit of capital good of industry i; X2TOT(i) is the amount of fixed capital created for use in industry i; P2(c,s,i) and X2(c,s,i) are, respectively, the price and quantity of good c from source s used as an input to create capital for industry i.

Basic values of imports

The basic values of imports are defined as their duties-inclusive c.i.f. local currency prices.

$$P0IMP(c) = PF0CIF(c)*PHI*T0IMP(c), \qquad c\in COM, \quad (3.135)$$

where PF0CIF(c) is the foreign currency c.i.f. price of imported good c, PHI is the nominal exchange rate (local to foreign currency); T0IMP(c) is one plus the *ad valorem* rate of tariff on imported good c.

F.o.b. export prices

The local currency price (f.o.b.) of exported good c is equal to the sum of the local currency basic value, ad valorem sales taxes and margins charges for this commodity. Thus,

$$X4(c)*P4(c) = X4(c)*PE(c)*T4(c) + \sum_{m\in MAR} X4MAR(c,m)*P0DOM(m), \qquad c\in COM, \quad (3.136)$$

where P4(c) and X4(c) are, respectively, the f.o.b. local currency export price and quantity of good c; PE(c) is the local currency basic price of export good c; T4(c) is

one plus the ad valorem sales tax rate for export good c; X4MAR(c,m) is the usage of margin commodity m to deliver good c to the port of exit.

Purchasers' price for producers

We recognise, for different users, the purchases' prices (in levels) of commodities as the sum of four exclusive constituents: (a) basic values, (b) sales taxes; (c) carbon dioxide taxes; and (d) margins. We temporarily ignore in this section the carbon dioxide taxes, which we introduce in detail in Section 3.5.11.

Basic values of domestic goods are the prices received by producers; basic values of imported goods are the prices received by importers, which includes import duties. All users and suppliers (domestic producers and importers) of good c face the same basic value. Sales tax rates on commodities vary across users. Margins prices are charged at basic value for all users. Equations (in levels) of purchasers' prices for all users are set out below.

The input cost, valued at purchasers' price, of good c from source s for industry i is equal to the sum of the basic value, ad valorem sales taxes and margins charges for this commodity. Algebraically,

$$X1(c,s,i)*P1(c,s,i) = X1(c,s,i)*P0(c,s)*T1(c,s,i) + \sum_{m\in MAR} X1MAR(c,s,i,m)*P0DOM(m), \qquad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.137)$$

where P1(c,s,i) and X1(c,s,i) are, respectively, the purchasers' price and quantity of good c from source s used as an input to production of industry i; P0(c,s) is the basic price of good c from source s; T1(c,s,i) is one plus the ad valorem sales tax rate for X1(c,s,i); and X1MAR(c,s,i,m) is the usage of margin type m attached to the flow of good c from source s to industry i. Note that P0(c,s) is equivalent to P0DOM(c) when s = "dom"; and to P0IMP(c) when s = "imp".

Purchasers' price for capital creators

The purchasers' cost of good c from source s used for capital creation in industry i is equal to the sum of the basic value, ad valorem sales taxes and margins charges for this commodity. Algebraically,

$$X2(c,s,i)*P2(c,s,i) = X2(c,s,i)*P0(c,s)*T2(c,s,i) + \sum_{m\in MAR} X2MAR(c,s,i,m)*P0DOM(m), \qquad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.138)$$

where P2(c,s,i) and X2(c,s,i) are, respectively, the purchasers' price and quantity of good c from source s used as an input to capital creation in industry i; T2(c,s,i) is one plus the ad valorem sales tax rate for X2(c,s,i); and X2MAR(c,s,i,m) is the usage of margin type m attached to the flow of good c from source s to industry i for capital formation.

Purchasers' price for households

Household expenditure on good c from source s valued at purchasers' prices is equal to the sum of the basic value, ad valorem sales taxes and margins charges for this commodity:

$$X3(c,s)*P3(c,s) = X3(c,s)*P0(c,s)*T3(c,s) + \sum_{m\in MAR} X3MAR(c,s,m)*P0DOM(m), \quad c\in COM,\ s\in SRC, \quad (3.139)$$

where P3(c,s) and X3(c,s) are, respectively, the purchasers' price and quantity of good c from source s demanded by households; T3(c,s) is one plus the ad valorem sales tax rate for X3(c,s); and X3MAR(c,s,m) is the margins usage for delivering X3(c,s).

Purchasers' price for government

Government consumption of good c from source s valued at purchasers' prices is equal to the sum of the basic value, ad valorem sales taxes and margins charges for this commodity.

$$X5(c,s)*P5(c,s) = X5(c,s)*P0(c,s)*T5(c,s) + \sum_{m\in MAR} X5MAR(c,s,m)*P0DOM(m), \quad c\in COM,\ s\in SRC, \quad (3.140)$$

where P5(c,s) and X5(c,s) are, respectively, the purchasers' price and quantity of good c from source s demanded by the government; T5(c,s) is one plus the *ad valorem* sales tax rate for X5(c,s); and X5MAR(c,s,m) is the margins usage for delivering X5(c,s).

Prices of inventories

There is only one price—the basic price—recognised for goods as inventory. This is because inventories are not subject to sales taxes, and there are no margin services required for inventories.

3.5.9 Market-clearing equations

We set out below in levels form the market-clearing equations as implied in our linearised model. They assure that demand equals supply for domestically produced commodities and for primary factors of production (capital, labour and land).

3.5.9(A) Demand equals supply for domestically produced commodities

The total demand for domestically produced commodity c in local and overseas markets should equal the total domestic supply of c. Thus, we write:

$$P0COM(c)*X0COM(c) = [P0DOM(c)*X0DOM(c)] + [PE(c)*X4(c)], \quad c\in COM, \quad (3.141)$$

where

$$P0COM(c)*X0COM(c) = P0COM(c)*\left(\sum_{i\in IND} Q1(c,i)\right), \quad c\in COM. \quad (3.142)$$

The total domestic demand for domestically produced commodity c, [P0DOM(c)*X0DOM(c)], is explained separately for non-margins commodities and for margins commodities.

Demand for non-margin commodities

The total demand for domestically produced non-margin commodities comprises the demand for domestically produced non-margin commodities as: (a) intermediate inputs for current production; (b) inputs for capital creation; (c) inputs to household consumption; (d) inputs to government consumption; and (e) inventories. Algebraically,

$$P0DOM(n)*X0DOM(n) = \sum_{i\in IND} P0DOM(n)*X1(n,"dom",i) + \sum_{i\in IND} P0DOM(n)*X2(n,"dom",i) + P0DOM(n)*X3(n,"dom") + P0DOM(n)*X5(n,"dom") + P0DOM(n)*X6(n,"dom"), \quad n\in NONMAR. \quad (3.143)$$

Demand for margin commodities

Commodities classified as margins are used for two purposes: as intermediate inputs; and as margins on the delivery of goods from producers' sites to purchasers. The former part of the total demand for domestically produced margin commodities is defined analogously to that for domestically produced non-margin commodities. The latter part of the total demand for domestically produced margin commodities consists of the demand for domestically produced margin commodities to deliver (a) intermediate inputs for current production; (b) inputs for capital creation; (c) goods to households; (d) export goods to the port; and (e) goods to the government. The sum of these two parts is given below:

$$\begin{aligned}
&\text{P0DOM(m)*X0DOM(m)} = \sum_{i\in IND} \text{P0DOM(m)*X1(m,"dom",i)} + \\
&\sum_{i\in IND} \text{P0DOM(m)*X2(m,"dom",i)} + \text{P0DOM(m)*X3(m,"dom",i)} + \\
&\text{P0DOM(m)*X5(m,"dom")} + \text{P0DOM(m)*X6(m,"dom")} + \\
&\sum_{c\in COM}\sum_{s\in SRC}\sum_{i\in IND} \text{P0DOM(m)*X1MAR(c,s,i,m)} + \\
&\sum_{c\in COM}\sum_{s\in SRC}\sum_{i\in IND} \text{P0DOM(m)*X2MAR(c,s,i,m)} + \\
&\sum_{c\in COM}\sum_{s\in SRC} \text{P0DOM(m)*X3MAR(c,s,m)} + \sum_{c\in COM} \text{P0DOM(m)*X4MAR(c,m)} \\
&+ \\
&\sum_{c\in COM}\sum_{s\in SRC} \text{P0DOM(m)*X5MAR(c,s,m)}, \qquad m\in MAR. \quad (3.144)
\end{aligned}$$

3.5.9(B) *Demand equals supply for imports*

The total demand for imported commodities comprises the demand for imported commodities as: (a) intermediate inputs for current production; (b) inputs for capital creation; (c) inputs to household consumption; (d) inputs to government consumption; and (e) inventories. This should equal to the total supply of imported commodities, as indicated in the left-hand side of the equation below. Note that there is no re-export of imported goods in TAIGEM.

$$\begin{aligned}
&\text{P0IMP(c)*X0IMP(c)} = \\
&\sum_{i\in IND} \text{P0IMP(c)*X1(c,"imp",i)} + \sum_{i\in IND} \text{P0IMP(c)*X2(c,"imp",i)} + \\
&\text{P0IMP(c)*X3(c,"imp")} + \text{P0IMP(c)*X5(c,"imp")} + \\
&\text{P0IMP(c)*X6(c,"imp")}, \qquad c\in COM. \quad (3.145)
\end{aligned}$$

3.5.9(C) *Market-clearing for labour of each occupation*

The total demand for occupation-specific labour by all industries should equal total supply. Thus,

$$\text{P1LAB\_I(o)*X1LAB\_I(o)} = \sum_{i\in IND} \text{P1LAB(i,o)*X1LAB(i,o)}, \qquad o\in OCC. \quad (3.146)$$

3.5.9(D) *Market-clearing for capital*

The demand for industry-specific capital should equal supply. Thus,

$$\text{P1CAP(i)*X1CAP(i)} = \text{GROR(i)*CAPSTOK(i)}, \qquad i\in IND, \quad (3.147)$$

where

$$\text{GROR(i)} = \left(\frac{\text{P1CAP(i)}}{\text{P2TOT(i)}}\right), \qquad i\in IND, \quad (3.148)$$

and,

$$\text{CAPSTOK(i)} = \text{P2TOT(i)*CURCAP(i)}, \qquad i\in IND. \quad (3.149)$$

GROR(i) is the gross rate of return for industry i; CURCAP(i) is the number of units of capital available for use in industry i; and CAPSTOK(i) is the asset value of capital stock of industry i, which is accumulated from investment (capital creation) of previous years. Note that CURCAP(i) is equivalent to X1CAP(i).

3.5.9(E) *Market-clearing for land*

Analogous to capital, land is assumed to be industry-specific. The demand for industry-specific land, X1LND(i), is subject to the supply of it, which is exogenously determined.

3.5.10 *Macroeconomic indexes and miscellaneous equations*

Various macroeconomic indices are introduced in the model to summarise the corresponding microeconomic components. We introduce below some major macroeconomic relations in levels, which have linearised counterparts in the model.

GDP from income and expenditure sides

Nominal GDP from income side and expenditure side are both calculated and they should agree to each other. From the expenditure side:

$$\begin{aligned}
\text{V0GDPEXP} = {} & \text{V3TOT} + \text{V2TOT_I} + \text{V5TOT} + \text{V6TOT} + \\
& (\text{V4TOT} - \text{V0CIF_C}), \qquad (3.150)
\end{aligned}$$

where V0GDPEXP is nominal GDP from expenditure side; V3TOT is aggregate household expenditure; V2TOT_I is aggregate investment; V5TOT is aggregate government consumption; V6TOT is the total value of inventories; V4TOT is total export earnings; and V0CIF_C is total import costs, exclusive of duties.

From the income side:

$$\begin{aligned}
\text{V0GDPINC} = {} & \text{V1LND_I} + \text{VLAB_IO} + \text{V1CAP_I} + \text{V1OCT_I} + \\
& \{ \text{V1TAX_CSI} + \text{V2TAX_CSI} + \text{V3TAX_CS} + \text{V4TAX_C} + \\
& \text{V5TAX_C} + \text{V0TAR_C} \}, \qquad (3.151)
\end{aligned}$$

where V0GDPINC is nominal GDP from income side; V1LND_I, V1LAB_IO, and V1CAP_I are total factor incomes from land, labour and capital, respectively;

V1TAX_CSI, V2TAX_CSI, V3TAX_CS, V4TAX_C, and V5TAX_C are, respectively, total revenues of commodity taxes on intermediate inputs, capital-creating inputs, consumption goods, exports, and goods demanded by government. V0TAR_C is total tariff revenue.

Other macroeconomic indexes

We also define in the model other macroeconomic indexes, including the CPI (consumer price index), GDP deflator, the ratio of trade balance to nominal GDP, terms of trade, the real exchange rate, and average real wage, indexed to CPI. Aggregate employment and aggregate capital stock in base-period value units are also included in the model.

Indexing and other equations

In the model we allow nominal wages, P1LAB(i,o), and the unit price of "other cost", P1OCT(i), to be indexed to the CPI. Shift variables are attached to the indexing equations to facilitate alternative model closures. With no emphasis on the income source of households, we specify that aggregate household expenditure (V3TOT) moves in line with (i.e., is indexed to) nominal GDP.

3.5.11 CO_2-related equations

3.5.11(A) Taxes on CO_2 emissions

Taxes on CO_2 emissions are levied on all emitting activities, including current production, capital formation, household and government consumption and export. The equations for CO_2 tax calculations are presented below in levels form.

Our treatment of CO_2 taxes is designed to allow:

(1) CO_2 taxes on each use of CO_2-containing goods to be proportional to the CO_2 emitted.

(2) CO_2 taxes to be indexed to some economy-wide price index such as the GDP price index.

(3) integration with the framework for other TAIGEM *ad valorem* commodity taxes.

CO_2 tax on polluting goods as intermediate inputs

The first equation defined the CO_2 tax base as the product of the quantity of CO_2 emissions and a general price index. Thus,

$$\text{TAXBASE1(c,s,i)} = [\text{SPINDEX*CO2(c,s,i)}], \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.152)$$

where CO2(c,s,i) is the amount of CO_2 emitted from good c from source s used by industry i as an intermediate input; and SPINDEX is the price index for the taxes on CO_2 emissions, which is set at one in the first year of recursive dynamic simulations and is assumed to move with the GDP deflator, P0GDPEXP[37].

This amount of CO_2-tax payment (TAXBASE(c,s,i)*ST1(c,s,i), where SPINDEX*ST1(c,s,i) is the specific tax rate on a unit of CO_2) is added to the input cost at purchasers' price of good c from source s for industry i. Hence, Equation 3.137 is rewritten as:

$$\text{X1(c,s,i)*P1(c,s,i)} = \text{X1(c,s,i)*P0(c,s)*T1(c,s,i)} + \text{TAXBASE1(c,s,i)*ST1(c,s,i)} + \sum_{m\in MAR} \text{X1MAR(c,s,i,m)*P0DOM(m)}, \quad c\in COM,\ s\in SRC,\ i\in IND. \quad (3.137a)$$

We define the coefficient V1STX(c,s,i) in Table 3.4 as the product of TAXBASE1(c,s,i) and ST1(c,s,i). In our data base, V1STX(c,s,i) is null as no CO_2 tax was imposed in 1994. Once a CO_2 tax is levied, V1STX(c,s,i) will be updated[38] and thus production costs rise. The update statement for V1STX(c,s,i) is as follows:

$$\text{(CHANGE) V1STX(c,s,i)} = 0.01\text{*V1STX(c,s,i)*[x1(c,s,i) + spindex]} + \text{TAXBASE1(c,s,i)*dels1(c,s,i)}, \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.153)$$

where the expression, (CHANGE), declares that the right-hand side of the above equation calculates the variation in the left-hand side coefficient, V1STX(c,s,i).

We derive the RHS of Equation 3.153 as follows.

$$\text{V1STX(c,s,i)} = \text{TAXBASE1(c,s,i)*ST1(c,s,i)}.$$

Thus,

$$\begin{aligned}\Delta\text{V1STX(c,s,i)} &= \text{TAXBASE1(c,s,i)*}\Delta\text{ST1(c,s,i)} + \text{ST1(c,s,i)*}\Delta\text{TAXBASE1(c,s,i)}\\ &= \text{TAXBASE1(c,s,i)*dels1(c,s,i)} + \text{ST1(c,s,i)*TAXBASE1(c,s,i)*taxbase1(c,s,i)/100}\\ &= \text{TAXBASE1(c,s,i)*dels1(c,s,i)} + \text{V1STX(c,s,i)*taxbase1(c,s,i)/100}\end{aligned} \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.154)$$

where

[37] In other words, ST1 is technically an *ad valorem* tax with base TAXBASE1. TAXBASE1 is defined (updated by spindex and x1) in such a way that ST1 is in effect a specific tax on CO_2.

[38] As described in Footnote 4, coefficients are updated in the multi-step Johansen computation by the stepwise percentage changes in their corresponding price and quantity.

$$\text{taxbase1}(c,s,i) = \text{spindex} + \text{x1}(c,s,i), \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.155)$$

which is the linearised version of Equation 3.152, on the assumption that emissions are proportional to usage, X1(c,s,i). That is,

$$\text{TAXBASE1}(c,s,i) = \text{SPINDEX}*\text{CO2}(c,s,i) = \text{SPINDEX}*\text{EC}(c,s,i)*\text{X1}(c,s,i), \quad c\in COM,\ s\in SRC,\ i\in IND, \quad (3.152a)$$

where EC(c,s,i) is the constant CO_2 emissions coefficient per tonne of X1(c,s,i).

Analogous to the case of intermediate inputs, CO_2 taxes collected from investors, households, government and export are calculated as follows.

CO_2 tax on polluting goods as capital-creating inputs

$$\text{TAXBASE2}(c,s,i)*\text{ST2}(c,s,i) = \text{SPINDEX}*\left(\frac{\text{V2BAS}(c,s,i)}{\sum_{i\in IND}\text{V2BAS}(c,s,i)}\right)*\text{CO2}(c,s,\textit{"Invest"})*\text{ST2}(c,s,i)$$

$$c\in COM,\ s\in SRC,\ i\in IND. \quad (3.156)$$

As we only have the commodity-by-source data of CO_2 emissions from capital formation, CO2(c,s,*"Invest"*), we use the industry shares, $\left(\frac{\text{V2BAS}(c,s,i)}{\sum_{i\in IND}\text{V2BAS}(c,s,i)}\right)$, to prorate the CO_2 emissions from capital goods among industries.

CO_2 tax on polluting goods for household consumption

$$\text{TAXBASE3}(c,s)*\text{ST3}(c,s) = \text{SPINDEX}*\text{CO2}(c,s,\textit{"HouseH"})*\text{ST3}(c,s), \quad c\in COM,\ s\in SRC. \quad (3.157)$$

CO_2 tax on polluting goods for government consumption

$$\text{TAXBASE5}(c,s)*\text{ST5}(c,s) = \text{SPINDEX}*\text{CO2}(c,s,\textit{"GovGE"})*\text{ST5}(c,s) \quad c\in COM,\ s\in SRC. \quad (3.158)$$

Analogous to the case of intermediate inputs, we incorporate these tax payments on CO_2 emissions as part of the input costs at purchasers' prices. Hence, Equations 3.138, 3.139, 3.140, and 3.136 are rearranged as follows.

$$\text{X2}(c,s,i)*\text{P2}(c,s,i) = \text{X2}(c,s,i)*\text{P0}(c,s)*\text{T2}(c,s,i) + \text{TAXBASE2}(c,s,i)*\text{ST2}(c,s,i) + \sum_{m\in MAR}\text{X2MAR}(c,s,i,m)*\text{P0DOM}(m), \quad c\in COM,\ s\in SRC,\ i\in IND. \ (3.138a)$$

$$\text{X3}(c,s)*\text{P3}(c,s) = \text{X3}(c,s)*\text{P0}(c,s)*\text{T3}(c,s) + \text{TAXBASE3}(c,s)*\text{ST3}(c,s) + \sum_{m\in MAR}\text{X3MAR}(c,s,m)*\text{P0DOM}(m), \quad c\in COM,\ s\in SRC. \ (3.139a)$$

$$\text{X5}(c,s)*\text{P5}(c,s) = \text{X5}(c,s)*\text{P0}(c,s)*\text{T5}(c,s) + \text{TAXBASE5}(c,s)*\text{ST5}(c,s) + \sum_{m\in MAR}\text{X5MAR}(c,s,m)*\text{P0DOM}(m), \quad c\in COM,\ s\in SRC. \ (3.140a)$$

$$\text{X4}(c)*\text{P4}(c) = \text{X4}(c)*\text{PE}(c)*\text{T4}(c) + \text{TAXBASE4}(c)*\text{ST4}(c) + \sum_{m\in MAR}\text{X4MAR}(c,m)*\text{P0DOM}(m), \quad c\in COM. \ (3.136a)$$

The derivation procedure for the update statements for V2STX(c,s,i), V3STX(c,s), V4STX(c) and V5STX(c,s) is the same as that for V1STX(c,s,i).

3.5.11(B) Reporting variables for CO_2 emissions

We calculate the economy-wide CO_2 emissions, CO2TOT, as the sum of emissions from the polluting commodities of all sources used by all local users:

$$\text{CO2TOT} = \sum_{c\in BADCOM}\sum_{s\in SRC}\sum_{u\in LOCALUSERS}\text{CO2}(c,s,u). \quad (3.159)$$

The linearised version of Equation 3.159 is as follow.

$$\text{totco2} = \sum_{c\in BADCOM}\sum_{s\in SRC}\left\{\sum_{i\in IND}\left(\frac{\text{CO2}(c,s,i)}{\text{CO2TOT}}\right)*\text{x1}(c,s,i) + \left(\frac{\text{CO2}(c,s,\text{"Invest"})}{\text{CO2TOT}}\right)*\text{x2\_i}(c,s) + \left(\frac{\text{CO2}(c,s,\text{"HouseH"})}{\text{CO2TOT}}\right)*\text{x3}(c,s) + \left(\frac{\text{CO2}(c,s,\text{"GovGE"})}{\text{CO2TOT}}\right)*\text{x5}(c,s)\right\}, \quad (3.160)$$

where totco2 is the percentage change in the economy-wide CO_2 emissions; and the corresponding percentage change variables of CO_2 emissions by users are the quantity ones, x's, due to the assumption that CO_2 emissions are proportional to usage.

We also calculate as follows contributions to total CO_2 emissions by individual use of polluting commodities.

$$\text{contco2}(c,s,u) = \left(\frac{\text{CO2}(c,s,u)}{\text{BASECO2TOT}}\right)*\text{x1}(c,s,u), \quad c\in BADCOM,\ s\in SRC,\ u\in IND;$$

$$\text{contco2}(c,s,\text{"Invest"}) = \left(\frac{\text{CO2}(c,s,\text{"Invest"})}{\text{BASECO2TOT}}\right)*\text{x2\_i}(c,s), \quad c\in BADCOM,\ s\in SRC;$$

$$\text{contco2}(c,s,\text{"HouseH"}) = \left(\frac{\text{CO2}(c,s,\text{"HouseH"})}{\text{BASECO2TOT}}\right)*\text{x3}(c,s), \quad c\in BADCOM,\ s\in SRC;$$

$$\text{contco2}(c,s,\text{"GovGE"}) = \left(\frac{\text{CO2}(c,s,\text{"GovGE"})}{\text{BASECO2TOT}}\right)*\text{x5}(c,s), \quad c\in BADCOM,\ s\in SRC, \quad (3.161)$$

where contco2(c,s,u) is an ordinary change variable defined over all local polluters (for all u∈LOCALUSERS, including industries, investors, households, and government); referring to their contributions to the economy-wide CO_2 emissions change due to the use of good c from source s by user u; and BASECO2TOT[39] is the pre-shock amount of economy-wide CO_2 emissions.

3.6 Investment allocation mechanism for comparative static simulations

In TAIGEM, we have two mechanisms of investment allocation across industries. We introduce in this section the one for use in comparative static simulations. The other, for use in recursive dynamic simulations, is introduced in Section 3.9.

For comparative static simulations, TAIGEM adopts the Dixon, Parmenter, Sutton, and Vincent (1982), hereafter DPSV, theory of investment allocation across industries. DPSV assumes that the aggregate level of investment is determined outside the model. The model endogenously determines the allocation of aggregate investment across industries.

We divide investors into two groups, labelled EXOGINV and ENDOGINV. Investors in the EXOGINV group are subject to government regulation. Investors classified in the ENDOGINV group decide their investment plans following the rule to be introduced below.

Investment decision of ENDOGINV industries

ENDOGINV investors suppose that an increase in the capital of industry i will lead to a decline in its rate of return. This can be expressed algebraically as follows.

$$R1CAP^{E}(i) = R1CAP^{0}(i) * \left(\frac{X2TOT(i)}{CURCAP(i)}\right)^{-BETA(i)}, \quad i \in ENDOGINV. \quad (3.162)$$

BETA(i) is a positive parameter, the inverse of which indicates the investment elasticity. $R1CAP^{0}(i)$ and $R1CAP^{E}(i)$ are, respectively, the current and expected net rates of return on fixed capital in industry i. CURCAP(i) is the current level of capital stock in industry i. X2TOT(i) is the number of units of fixed capital to be created for industry i, which will be added to CURCAP(i) of the next period[40, 41].

[39] For computational accuracy, BASECO2TOT is defined as the pre-shock levels of total CO_2 emissions. For detailed explanation of this technical point see Appendix 4.

[40] We assume that capital has gestation lag of one period in yielding services. Thus, investment does not expand the production capacity of current period. Yet, it contributes to expenditure-side GDP of the current period.

[41] We do not put the capital accumulation formulae explicitly in the comparative static mode of TAIGEM. This is because we only focus on the one-period, short-run or long-run, effects in comparative static analyses. We do not give attention to capital stocks available for use in the next period.

R1CAP(i) is defined as:

$$R1CAP(i) = \left(\frac{P1CAP(i)}{P2TOT(i)}\right) - DPRC(i), \quad i \in IND, \quad (3.163)$$

where P1CAP(i) and P2TOT(i) are, respectively, the rental to and the unit asset price of industry-specific capital; and DPRC(i) is the constant rate of depreciation for industry-specific capital.

The allocation of the aggregate ENDOGINV investment expenditure across industries follows the rule that all industries invest to the point where their expected net rates of return are equal. Based on this assumption, we can rewrite Equation 3.162 as:

$$FINV(i) * \left(\frac{R1CAP^{0}(i)}{OMEGA}\right)^{(1/BETA(i))} = \frac{X2TOT(i)}{CURCAP(i)}, \quad i \in ENDOGINV; (3.162a)$$

where OMEGA is the economy-wide rate of return observed by all industries; and the shift variable FINV(i) can be used to allow for exogenous shifts in investment of industry i.

By this rule, industries that enjoy higher net rate of return relative to other industries will attract more investment, and vice versa. Figure 3.6 illustrates the determination of investment for ENDOGINV industries. A positive effect of the exogenous shock pushes up the rate-of-return schedule of industry K. With its current level of capital stock, industry K thus enjoys a higher rate of return relative to other industries. This will attract more investment influx to industry K. That is, its investment/capital ratio will move from A to A'. However, investors are rather cautious in keeping a sensible rate of return, as suggested in Equation 3.162. Eventually, the realised rate of return for industry K will restore to the economy-wide rate, OMEGA. Analogously, a negative shock will reduce the investment/capital ratio from A to, say, A″.

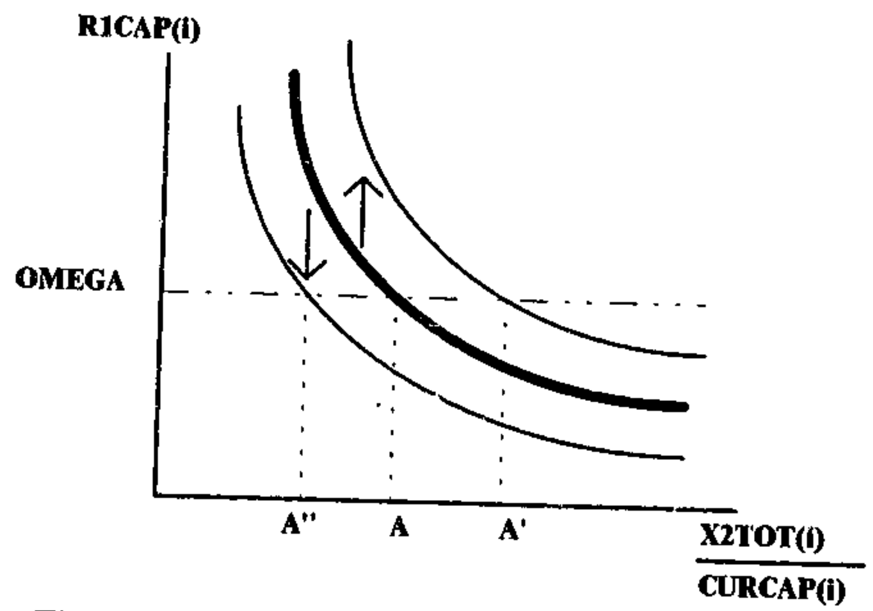


Figure 3.6 The expected rate-of-return schedule

Investment decision of EXOGINV industries

The EXOGINV investors make their investment plans following the real aggregate investment for ENDOGINV industries, which we refer as private investment. The equations are set out as follows.

$$X2TOT(i) = FINV(i)*\left(\frac{V2TOT\_ENDOGINV}{P2TOT\_ENDOGINV}\right)^{ETA(i)}, \ i \in EXOGINV; \quad (3.164)$$

$$V2TOT\_ENDOGINV = \sum_{i \in ENDOGINV} P2TOT(i)*X2TOT(i), \quad (3.165)$$

where V2TOT_ENDOGINV is aggregate "endogenous" private investment; P2TOT_ENDOGINV is the capital-goods price index defined over ENDOGINV investors; and the parameter, ETA(i), is normally set to one.

Environment settings for investment planning

The conventional DPSV short-run closure sets aggregate investment exogenous while the economy-wide rate of return, OMEGA, is endogenously determined so as to retain the given level of aggregate investment. For long-run simulations, net rates of return, R1CAP(i), and OMEGA are both fixed, while industry capital stocks and aggregate investment adjust to restore rates of return to their initial equilibrium levels.

3.7 Differences between comparative static and recursive dynamic simulations

In either comparative static or recursive dynamic simulations with TAIGEM, we are analysing economic issues in the following manner: relative to the state where it would otherwise be, how far does the economy deviate in a certain period of time due to the introduction of some policy? The model's equation system depicts the whole economy for some period of time.

In doing comparative static simulations, we do not explicitly specify the time span in the model's equations. We may interpret a simulation as a short-run analysis by fixing wage rates and industry capital stocks, or as a long-run analysis by letting industries face fixed labour supply and letting capital stocks to adjust to restore (initial) equilibrium rates of return. The time length is rather vague under such closure assumptions. Short run may refer to two or three year's time and long run may refer to seven to ten years or longer. The numerical results of a comparative static simulation gauge the deviation of the economy away from its *ceteris paribus* equilibrium due to the policy introduced. We are not concerned about the time path

of adjustment from the current (initial) equilibrium toward a new equilibrium at the end of the simulation period.

In year-on-year recursive dynamic simulations, timing is made explicit by adding into the model capital accumulation formulae, details of which are explained in Section 3.8. Policy analysis is conducted by running two series of year-on-year recursive simulations: the base-case series and the policy series. The base-case simulations produce a path that forecasts the future course of the economy *without* the policy change under consideration. We refer to this path as the business-as-usual (BAU) forecasting path. The policy simulations produce a path that predicts the future course of the economy *with* the policy change under consideration. We refer to this path as the perturbed forecasting path. We estimate the policy impact by examining the deviation of the perturbed forecasting path from the BAU forecasting path.

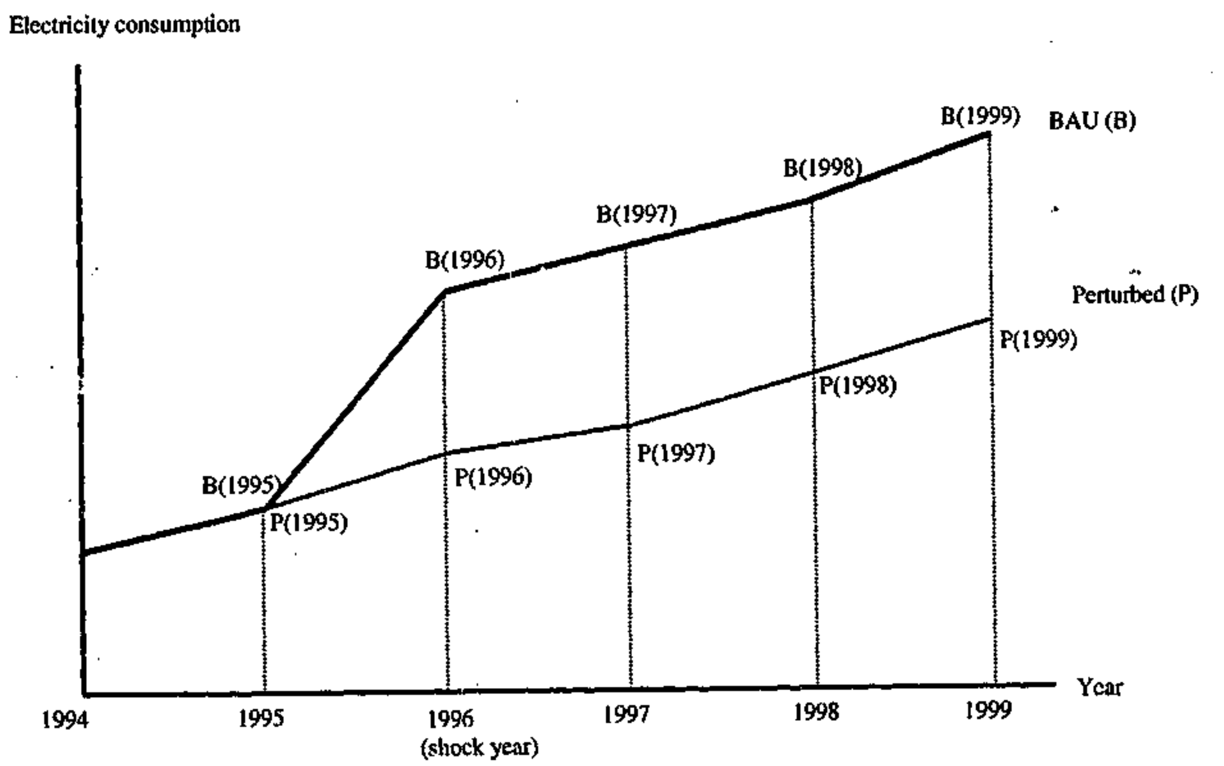
For either series of dynamic simulations, each year shows the short-run (or one-year) adjustment, as industry capital stocks are predetermined via the capital accumulation formulae (see Section 3.8).

After producing the two paths of economic growth under the BAU and the perturbed scenarios[42], we are able to calculate the comparative static results for each specific year (in the short or long run). Figure 3.7 illustrates the cumulative percentage growth of electricity consumption in the BAU and the Perturbed simulations, with the policy shock introduced in 1996. The following formula (Equation 3.166) illustrates how we calculate the policy deviation of some model variable away from control in some year of the forecast period, D(t).

[42] The difference between the two scenarios exactly reveals the policy shocks implemented in each year of the simulation period.

$$D(1994+T)=\left[\frac{\prod_{k=1}^{T}\left(1+\frac{p(k)}{100}\right)}{\prod_{k=1}^{T}\left(1+\frac{b(k)}{100}\right)}-1\right]*100, \qquad (3.166)^{43}$$

where b(k) and p(k) are year-on-year growth rates of electricity consumption in year k. D(1994 + T) measures the gap between the BAU and the Perturbed scenarios in year (1994 + T).



* B(t) and P(t) denote levels of electricity consumption in the BAU and the perturbed simulations.

Figure 3.7 Calculating policy deviation from control for some year

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43 The derivation of Equation 3.166 is as follows.

$$D(1994+T)=\left[\frac{P(1994+T)}{B(1994+T)}-1\right]*100=\left[\frac{P(1994)*\left(1+\frac{p(1)}{100}\right)*\left(1+\frac{p(2)}{100}\right)*\dots*\left(1+\frac{p(T)}{100}\right)}{B(1994)*\left(1+\frac{b(1)}{100}\right)*\left(1+\frac{b(2)}{100}\right)*\dots*\left(1+\frac{b(T)}{100}\right)}-1\right]*100$$

$$=\left[\frac{\left(1+\frac{p(1)}{100}\right)*\left(1+\frac{p(2)}{100}\right)*\dots*\left(1+\frac{p(T)}{100}\right)}{\left(1+\frac{b(1)}{100}\right)*\left(1+\frac{b(2)}{100}\right)*\dots*\left(1+\frac{b(T)}{100}\right)}-1\right]*100, \text{ with } P(1994)=B(1994)$$

$$=\left[\frac{\prod_{k=1}^{T}\left(1+\frac{p(k)}{100}\right)}{\prod_{k=1}^{T}\left(1+\frac{b(k)}{100}\right)}-1\right]*100.$$

B(t) and P(t) denote levels of electricity consumption, as seen in Figure 3.7.

We use Figure 3.8 to illustrate the difference in calculating the numerical results between a comparative static (panel A) and a recursive dynamic (panel B) simulation. Both panels of Figure 3.8 shows the growth paths of some variable, e.g., electricity consumption. Point A is electricity consumption in the base year (year 0). Point B marks the level to which electricity consumption would grow in T years in the absence of some policy change, e.g., the introduction of energy-saving technology. Point C marks the level that electricity consumption would attain T years after the introduction of energy-saving technology, *ceteris paribus*. Points B' and C' on the vertical axis mirror points B and C.

In simulating the policy impact, we are to investigate the distance between points C and B, which measures the deviation of the electricity consumption away from control. By adopting the Johansen solution method, our model produces numerical results in percentage change form. In this example, the percentage change in the electricity consumption is calculated as $100*\left(\frac{C-B}{B}\right)$. That is, the electricity consumption would fall by $100*\left|\frac{C-B}{B}\right|$ % in year T due to the improvement of energy efficiency, *ceteris paribus*.

In comparative static simulations, we simply calculate the percentage-change results as $100*\left(\frac{C-A}{A}\right)$ (see panel A). We use point A of year 0 to approximate the business-as-usual position (point B) of year T. This is because we do not account for the adjustment process in comparative static simulations and therefore point B is not available. We assume that the business-as-usual economic context in year T is similar to that in year 0.

In recursive dynamic simulations, we are able to calculate the percentage changes as $100*\left(\frac{C-B}{B}\right)$, with point B produced in the BAU forecasting simulation and point C produced in the perturbed forecasting simulation (see panel B). Points B and C, respectively, reveal the accumulation results of annual business-as-usual and perturbed (by the policy shock) growth from year 0 to year T. Points B and C in panel B account for the adjustment in the preceding years, which is ignored in comparative static simulations. The availability of paths AB and AC—the BAU and the perturbed paths, respectively—in recursive dynamic simulations enhances the estimation of policy impacts.

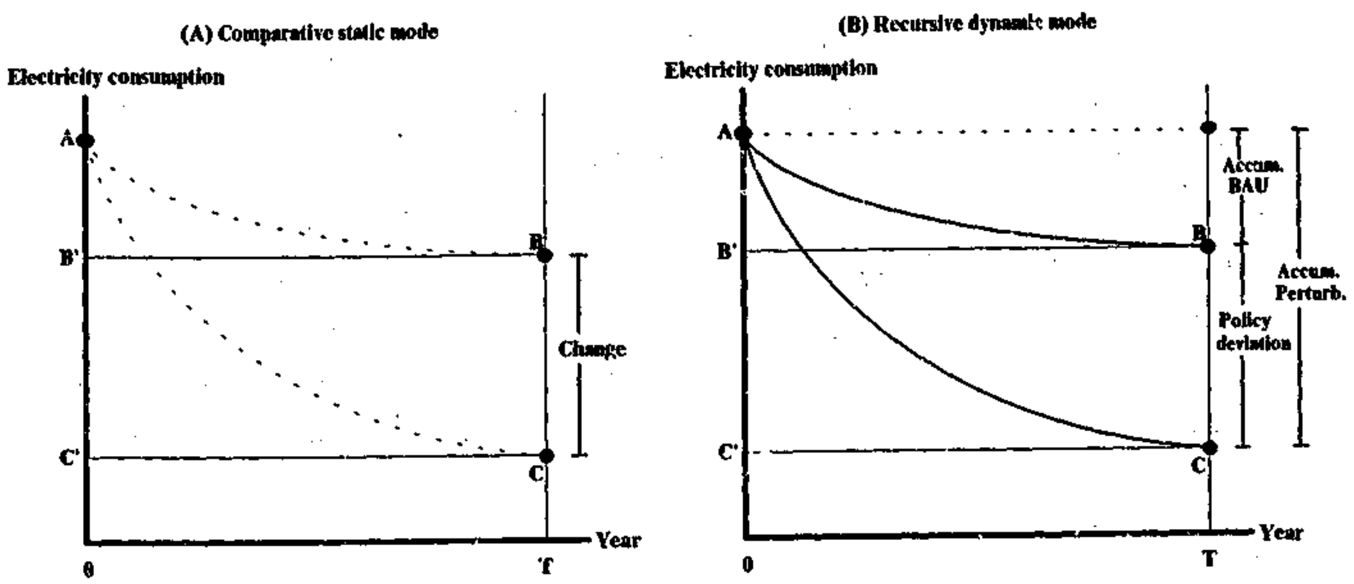

Figure 3.8 Differences in the calculation of numerical results between comparative static and recursive dynamic simulations

In a comparative static simulation, the economy reaches a new equilibrium within the short or long run. In recursive dynamic simulations, the economy reaches a new equilibrium every year. Each year of the simulation is equivalent to a one-period short-run comparative static simulation. The time series of single-year solutions are linked together via the capital accumulation formulae (see Equation 3.167), which transfer capital stocks from year to year. In short, the BAU path consists of a time series of economic equilibria, as does the perturbed forecasting path.

Another difference between comparative static and recursive dynamic applications is that dynamic models require far more information about changes in exogenous variables. For comparative static simulations of the policy impact, we need a base-period database to calibrate the model for the initial equilibrium solution (i.e., point A), and the value of the policy shock—e.g., energy efficiency improvement—which moves the economy to the state of point C. For recursive dynamic simulations, we need more data in addition to the base-period database and the policy shock value. For the BAU forecasting in recursive dynamic simulations, we need to incorporate all available information about the future course[44] of the economy to produce a sensible and accurate control path. The perturbed forecasting is conducted with a policy shock based on the BAU forecasting path.

To run BAU simulations, we need to collect all available per annum growth rates of economic variables. We specify as exogenous those variables whose annual

[44] We collect economic forecasts produced by specialists of forecasting and the statistics bureau (DGBAS). Examples are growth rates of import and export volumes, foreign prices, terms of trade, private consumption, aggregate investment. Moreover, we postulate the future changes of technology and tastes by reference to empirical studies of their historical trend.

growth rates are available. We also need to postulate their farther time-paths. In producing the BAU forecasting path, we first use the base-period, say 1994, database to calibrate the model to the initial equilibrium (point A). Then, we shock the exogenous variables by their growth rates of the year 1995. This produces the 1995 growth rates of the endogenous variables. The model also updates the 1994 database with the 1995 growth rates of all variables to characterise the equilibrium for 1995. We use the updated database of 1995 to calibrate for the initial equilibrium of 1996. We shock the exogenous[45] variables by their growth rates of 1996. The 1996 growth rates of the endogenous variables are solved and the 1995 database is updated to represent the economic equilibrium of 1996. The complete BAU path is produced via applying the same procedure in each annual run:

(1) calibrating the model for the initial equilibrium of that year with the database of the year before;
(2) shocking exogenous variables by the growth rates for that year;
(3) solving for the growth rates of endogenous variables for that year; and
(4) updating the (initial) database with the annual growth rates of all variables to represent the economy (in equilibrium) of that year.

The perturbed forecasting path is produced in the similar way to the above described, except that we impose the policy shock in addition to the annual growth of other exogenous variables. For example, we want to simulate the effects of a carbon tax imposed in 2002. As there are no policy shocks before 2002, we use the updated database of 2001 to calibrate for the initial equilibrium for 2002. That is, the economy remains in the same state as in the BAU case for years 1995 to 2001. Then we shock the carbon tax variables by the intended rates. The model solves for the endogenous variables and updates the initial database with the growth rates of all variables. We apply the same procedure in the subsequent year runs to complete the perturbed forecast. The imposition of carbon tax in 2002 affects the economic structure of 2002 and makes the economy deviate from its BAU state since then. We compare the BAU and the perturbed paths to analyse the impact of the carbon tax.

3.8 Physical capital accumulation for recursive dynamic simulations

For dynamic simulations, we introduce capital accumulation formulae by which industry net capital stock and investment of this period are transferred to the next period. We assume that capital goods (investment) acquired in this year will not

[45] The selection of exogenous variables for each year run is subject to the availability of growth data. With the Johansen solution approach, the change of closure is rather easy.

provide services until the start of next year. Accordingly, capital accumulation formula for industry i can be written as:

$$K_i(t+1) = [1 - D_i]*K_i(t) + I_i(t), \quad i \in IND \quad (3.167)$$

where

$K_i(t)$ is the quantity of capital available for use in industry i during year t;

$I_i(t)$ is the quantity of new capital created for industry i during year t; and

D_i is the rate of depreciation in industry i, treated as a constant.

Equation 3.167 produces the time paths of industry capital stocks with given values of capital stocks at the start of the forecasting period and investment in the subsequent years determined via the mechanism described in Section 3.9.

We rearrange Equation 3.167 as:

$$K_i(t+1) - K_i(t) = - D_i*K_i(t) + I_i(t).$$

Or, shifting t back a year:

$$\Delta K_i = K_i(t) - K_i(t-1) = - D_i*K_i(t-1) + I_i(t-1). \quad (3.167a)$$

To implement Equation 3.167a in our linearised model, we express ΔK_i in terms of the percentage-change variable of industry capital stock, k_i, as follows:

$$0.01*K_i(t-1)*k_i(t) = \Delta K_i = - D_i*K_i(t-1) + I_i(t-1). \quad (3.167b)$$

Figure 3.9 illustrates the interpretation for k_i and the transfer of capital stocks from year to year. In our base-year database (serving as the initial solution to the model for the year 1 simulation), we have the data of rates of depreciation, D_i, the quantities of opening capital stocks, i.e., $K_i(0)$, and investment, $I_i(0)$[46]. $K_i(1)$ is determined by Equation 3.167. In year 1 simulation, Equation 3.167b calculates $k_i(1)$, which measures the growth of the current-period (or opening) capital stock for year 1. $inv_i(1)$ is determined via the investment mechanism. After the computation of year 1, the model updates $K_i(0)$ up to $K_i(1)$ by $k_i(1)$, and $I_i(0)$ up to $I_i(1)$ by $inv_i(1)$. In the year 2 simulation, the updated database from the year 1 simulation serves as the initial solution to the model. Again, with D_i, $K_i(1)$ and $I_i(1)$ known, $K_i(2)$ is therefore determined. $k_i(2)$ is calculated in the year 2 simulation. $inv_i(2)$ is determined via the investment mechanism. The model updates $K_i(1)$ up to $K_i(2)$ by $k_i(2)$, and $I_i(1)$ up to $I_i(2)$ by $inv_i(2)$ after the year 2 computation. The same procedure applies for the subsequent years of the dynamic simulation. Since $K_i(t)$ is predetermined in every year, the entire forecast is like a series of linked short-run simulations.

[46] In calibrating the model to the initial solution (data), we choose as the unit of measurement for goods, one dollar's worth (at pervious year prices), rather than natural units (e.g., litres). That is, one unit of each good is worth one dollar at last year's prices. Thus, we can easily take the quantities from the initial data.

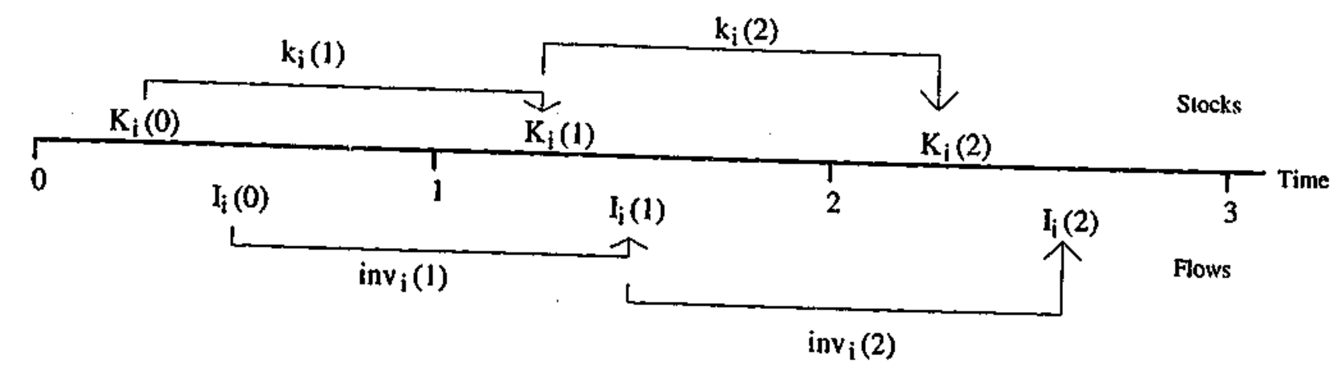

Figure 3.9 Physical capital accumulation

In GEMPACK's TABLO language, Equation 3.167b is written as:

$$0.01*QCAPSTOK(i)*x1cap(i) = CAPADD(i)*delUnity + faccum(i). \quad (3.168)$$

QCAPSTOK(i) corresponds to $K_i(t-1)$ in Equation 3.167b. x1cap(i) corresponds to $k_i(t)$ in Equation 3.167b. delUnity is an ordinary change variable, which is always set exogenous and shocked at 1.0 when running dynamic simulations. The shift variable, faccum(i), is also in ordinary change form and is set exogenous (endogenous) to turn on (off) this equation: on for dynamic simulations and off for comparative static simulations where we do not require the explicit relationship between investment and capital stock. CAPADD(i) is the net addition to the capital stock, i.e., $\Delta K(i)$ in Equation 3.167b. In TABLO language, it is expressed as:

$$CAPADD(i) = - DPRC(i)*CAPSTOK^{ini}(i) + V2TOT^{ini}(i), \quad (3.169)$$

$CAPSTOK^{ini}(i)$ corresponds to $K_i(t-1)$ in Equation 3.167b. $V2TOT^{ini}(i)$ corresponds to $I_i(t-1)$ in Equation 3.167b. DPRC(i) is the rate of depreciation, corresponding to D_i.

The TABLO statement of Equation 3.168 ensures that in the multi-step computation of year 1, say, the final value of $K_i(1)$ obtained via the stepwise update by $k_i(1)$ is the same as the value of $K_i(1)$ calculated straightforwardly via the capital accumulation formulae (Equation 3.167). $CAPSTOK^{ini}(i)$ and $V2TOT^{ini}(i)$ are held constant through the computation of each annual simulation, as is CAPADD(i). With faccum(i) exogenously set at zero and delUnity at 1.0, the RHS of Equation 3.168 gives the amount which the LHS must produce after the multi-step computation. QCAPSTOK(i) is initially evaluated at $K_i(t-1)$ and afterwards is updated stepwise by x1cap(i). Though both $CAPSTOK^{ini}(i)$ and QCAPSTOK(i) correspond to $K_i(t-1)$, only the latter is updated during the multi-step computation.

3.9 Investment allocation mechanism for recursive dynamic simulations

The investment allocation mechanism used in recursive dynamic simulations has a similar flavour as the one used in comparative static simulations, but is more elaborate. In comparative static simulations, we assume that industries attract investment as long as they have higher rates of return relative to the economy-wide average rate of return. In dynamic simulations, we assume that gross growth rate of capital stock for industry i, $\frac{I_i(t)}{K_i(t)}$, is positively related to its expected gross rate of return (GROR, henceforth) for next year, $E_i(t)$, with a finite slope:

$$\frac{I_i(t)}{K_i(t)} = F[E_i(t)], \quad \text{where } F_E > 0.$$

We specify the equilibrium ratio of $\frac{I_i(t)}{K_i(t)}$ as a logistic function of GROR for year t+1:

$$\frac{I_i(t)}{K_i(t)} = Q_i(t)*G_i(t)*\left(\frac{M_i(t)^{\alpha_i}}{Q_i(t) - 1 + M_i(t)^{\alpha_i}}\right), \qquad (3.170)$$

where α_i is the investment elasticity of industry i, constant for all years; we specify a value of 2.0 for all industries;

$G_i(t)$ is the trend capital growth of industry i, the value of which can be observed from historical data and is normally greater than the rate of depreciation;

$Q_i(t)$ defined as the ratio of maximum ($W_i(t)$) to trend capital growth of industry i, i.e., $Q_i(t) = \frac{W_i(t)}{G_i(t)}$, we specify a value of 3.0 for all industries;

$M_i(t)$ is defined as the ratio of expected ROR to the normal GROR ($S_i(t)$) of industry i, i.e., $M_i(t) = \frac{E_i(t)}{S_i(t)}$, the value of $S_i(t)$ can be observed from historical data and is normally greater than the rate of depreciation. When $E_i(t) = S_i(t)$, then $\frac{I_i(t)}{K_i(t)} = G_i(t)$, that is, $G_i(t) = F[S_i(t)]$.

Equation 3.170 says that industry i will increase its investment/capital ratio relative to its trend level of capital growth when its expected GROR is above its long-run or normal level.

We assume that investors form expectations about next period's rates of return (GROR's) by reference to past expectations for and actual GROR's:

$$E_i(t) = (1 - \Theta)*E_i(t\text{-}1) + \Theta*R_i(t), \quad 0 < \Theta < 1. \qquad (3.171)$$

$E_i(t)$ is the expected GROR holding in year t for year t+1; $E_i(t\text{-}1)$ is the expected ROR holding in year t-1 for year t; $R_i(t)$ is the realised GROR in year t. With this partial adjustment mechanism, expected GROR's converge to actual GROR's in the long run.

Equations 3.170 and 3.171 are linearised and rewritten in TABLO language as follow.

$$\text{x2tot(i) - x1cap(i) = gtrend(i) +}$$
$$\text{ALPHA(i)}*\left(1.0 - \frac{\text{GROSSGRO(i)}}{\text{GROMAX(i)}}\right)*[\text{gretxp(i) - rnorm(i)}]. \qquad (3.170a)$$

$$\text{0.01*GRETEXP(i)*gretexp(i) =}$$
$$\text{0.33* \{[GROSSRET0(i) - GRETEXP0(i)]*delUnity +}$$
$$\text{\{0.01*GROSSRET(i)*[p1cap(i) - p2tot(i)]\}\}}. \qquad (3.171a)$$

The mapping of the two sets of variable notations used in Equations 3.170 v.s. 3.170a and 3.171 v.s. 3.171a is shown in Table 3.9.

Table 3.9 The mapping of variable notations used in Equations 3.170 and 3.171 v.s. Equations 3.170a and 3.171a

Variables in Eq's 3.170 and 3.171	TABLO-syntax counterparts in Eq's 3.170a and 3.171a		Formula	Description
	% change variables	Coefficients (levels)		
$I_i(t)$	x2tot(i)			Units of investment in industry i
$K_i(t)$	x1cap(i)			Units of capital stock in industry i
$\frac{I_i(t)}{K_i(t)}$		GROSSGRO(i)	$= \frac{\text{V2TOT(i)}}{\text{CAPSTOK(i)}}$	Investment/capital ratio
$S_i(t)$	rnorm(i)	RNORMAL(i)		Normal gross rate of return (GROR) of industry i
$Q_i(t)$		QRATIO(i)		The ratio of maximum to trend investment/capital of industry i
$G_i(t)$	gtrend(i)	GROTREND(i)		The trend investment/capital ratio of industry i
$W_i(t)$		GROMAX(i)	= QRATIO(i)*GROTREND(i)	Maximum investment/capital ratio of industry i
$E_i(t)$	gretexp(i); delgretexp(i) (CHANGE)	GRETEXP(i)	$= \text{RNORMAL(i)}*\left(\frac{\text{QRATIO(i) - 1}}{\frac{\text{GROMAX(i)}}{\text{GROSSGRO(i)}} - 1}\right)^{\frac{1}{\text{ALPHA(i)}}}$	Expected GROR of industry i
$E_i(t\text{-}1)$		GRETEXP0(i)	$= \text{GRETEXP}^{ini}\text{(i)}$	Initial (last year's) expected GROR of industry i
$R_i(t)$	delgret(i) (CHANGE)	GROSSRET(i)	$= \frac{\text{V1CAP(i)}}{\text{V2TOT(i)}}$	Actual GROR of industry i, i.e., $\frac{\text{P1CAP(i)}}{\text{P2TOT(i)}}$
$R_i(t\text{-}1)$		GROSSRET0(i)	$= \text{GROSSRET}^{ini}\text{(i)}$	Initial (last year's) actual GROR of industry i
$M_i(t)$	mratio(i)			The ratio of expected to normal GROR of industry i
α_i		ALPHA(i)		Investment elasticity of industry i

To derive Equation 3.170a, we first re-arrange Equation 3.170 as follows and drop indexes i and t for clarity.

$$Q*\left(\frac{I}{K}\right) - \left(\frac{I}{K}\right) + \left(\frac{I}{K}\right)*M^{\alpha} = Q*G*M^{\alpha},$$

Then we linearise the above equation and obtain the following equation, with lower case denoting percentage changes:

$$Q*\left(\frac{I}{K}\right)*(inv - k) - \left(\frac{I}{K}\right)*(inv - k) + \left(\frac{I}{K}\right)*M^{\alpha}*(inv - k) + \alpha*M^{\alpha}*\left(\frac{I}{K}\right)*m$$
$$= Q*G*\alpha*M^{\alpha}*m + Q*M^{\alpha}*G*g.$$

Rearranging the above equation gives:

$$[Q - 1 + M^{\alpha}]*\left(\frac{I}{K}\right)*(inv - k) = \alpha*M^{\alpha}*\{Q*G*m - \left(\frac{I}{K}\right)*m\} + Q*M^{\alpha}*G*g,$$
$$= \alpha*M^{\alpha}*\{W - \left(\frac{I}{K}\right)\}*m + M^{\alpha}*W*g.$$

As $W*M^{\alpha} = Q*G*M^{\alpha} = [Q - 1 + M^{\alpha})*\left(\frac{I}{K}\right)$, we derive the following equation, which is consistent with Equation 3.170a:

$$inv - k = \frac{\alpha*M^{\alpha}*\{W - \left(\frac{I}{K}\right)\}*m}{W*M^{\alpha}} + \frac{M^{\alpha}*W*g}{W*M^{\alpha}},$$
$$= g + \alpha*\{1 - \left(\frac{I/K}{W}\right)\}*[e - s], \text{ with } m = e - s.$$

We can add slack variables, finv2(i) and finv2_i, in Equation 3.170a:

$$x2tot(i) - x1cap(i) + finv2(i) + finv2\_i = gtrend(i) +$$
$$ALPHA(i)*\left(1.0 - \frac{GROSSGRO(i)}{GROMAX(i)}\right)*[gretxp(i) - rnorm(i)].i \in IND.(3.170b)$$

finv2(i) and finv2_i only appear in this equation.

To derive for Equation 3.171a, we first re-arrange Equation 3.171 as follows and drop index i for clarity.

$$E(t) = (1 - \Theta)*E(t-1) + \Theta*R(t).$$
$$\Delta E = E(t) - E(t-1) = \Theta*[R(t) - E(t-1)]$$
$$= \Theta*\{[R(t-1) + \Delta R] - E(t-1)\}.$$
$$0.01*E(t)*e = 0.01*E(t)*[m + s]$$
$$= \Theta*\{[R(t-1) - E(t-1)] + 0.01*R(t)*r\}.$$

Setting $\Theta = 0.33$, the above equation is consistent with Equation 3.171a. An homotopy variable, delUnity, is incorporated in Equation 3.171a for technical reasons. It is an ordinary change variable, the value of which is set to 1.0 for year-to-year simulations.

3.10 Labour supply and real wage adjustment for recursive dynamic simulations

In the static mode of TAIGEM, there is no explicit function to determine labour supply. Consequently, in comparative static simulations we normally assume either that the average real wage or the aggregate employment is exogenous. For recursive dynamic simulations, we specify as follows an upward-sloping labour supply schedule for year t:

$$\left(\frac{L(t)}{N}\right)^{\gamma} = W(t), \qquad (3.172)$$

where γ is the elasticity of wage with respect to employment[47]; L denotes actual employment; W denotes the real wage; and N denotes the trend employment level—the level of employment corresponding to NAIRU (Non Accelerating Inflation Rate of Unemployment). Equation 3.172 says that the real wage will rise by γ% if employment in year t rises above the trend level by 1%. The labour supply schedule continually shifts upwards as long as actual employment outgrows the trend level. On the demand side, employment would fall if real wage rises. Therefore, in the long run employment adjusts towards the trend level.

We re-write Equation 3.172 as follows:

$$\left(\frac{W(t)}{W(t-1)} - 1\right) = \gamma*\left(\frac{L(t)}{N} - 1\right),$$
$$= \gamma*\left(\frac{L(t) - L(t-1) - (N - L(t-1))}{N}\right),$$
$$= \gamma*\left(\frac{L(t-1)}{N} - 1\right) + \gamma*\left(\frac{L(t) - L(t-1)}{N}\right), \qquad (3.172a)$$

Defining

$$delwagerate = \left(\frac{W(t)}{W(t-1)} - 1\right), \quad delempratio = \left(\frac{L(t) - L(t-1)}{N}\right),$$
$$EMPRAT0 = \frac{L(t-1)}{N}, \quad \text{and} \quad \gamma = ELASTWAGE,$$

Equation 3.172a becomes:

$$delwagerate = ELASTWAGE*\{[EMPRAT0 - 1] + delempratio\}.$$

In GEMPACK's TABLO language, we rearrange the above equation as follows:

[47] We set a value of 0.25 for γ. For stability, the value of $(1/\gamma)$ should be greater than the labour demand elasticity. In the short run, labour demand elasticity in TAIGEM is 0.9.

$$delwagerate = ELASTWAGE*\{[EMPRAT0 - 1]*delUnity + delempratio\} + delfwage, \quad (3.172b)$$

where delUnity is an ordinary change variable, the value of which is set at 1.0[48]; delfwage is a shifter variable, set as exogenous to activate Equation 3.172b, and vice versa. The value of EMPRAT0 is arbitrarily set to 1.0 for 1994 (the base year), and the end-of-period actual/trend employment ratio, EMPRAT, is updated by delempratio of 1994. The EMPRAT0 of 1995 is set to the updated EMPRAT of 1994, and the end-of-period EMPRAT of 1995 is updated by delempratio of 1995. The same procedure applies for the subsequent years.

We link delwagerate to the percentage-change variable of real wage, W(t), as follows:

$$\begin{aligned} delwagerate &= 0.01*WAGERATE*realwage \quad (3.173) \\ &= 0.01*WAGERATE*[p1lab\_io - p3tot]. \end{aligned}$$

realwage measures percentage changes in the real wage, W(t), which is defined as the CPI-indexed average wage, $\frac{P1LAB\_IO}{P3TOT}$. As delwagerate is in ordinary change and realwage is in percentage change, the update rule of GEMPACK requires incorporating coefficient WAGERATE in Equation 3.173 to ensure that both sides of the equation equate each other in the multi-step computation. WAGERATE is updated stepwise by delwagerate in each annual run but it is re-based to 1.0 in each year.

We also link delempratio to the percentage-change variable of the actual/trend employment ratio, $\left(\frac{L(t)}{N}\right)$, as follows:

$$delempratio = 0.01*EMPRAT*[employ\_i - emptrend]. \quad (3.174)$$

employ_i measures the percentage change in aggregate employment, L(t); and emptrend measures the percentage change in the trend employment level—the growth rate of labour force. Analogously, coefficient EMPRAT in Equation 3.174 is incorporated to ensure that both sides of the equation equate each other in the multi-step computation. EMPRAT is updated stepwise by delempratio in each annual run.

3.11 Closures for comparative static and recursive dynamic simulations

A model's closure is the choice of which variables are exogenous, and which endogenous. We introduce the general rule of closure setting in Section 3.11.1 for comparative static simulations and in Section 3.11.2 for recursive dynamic simulations.

48 delUnity is incorporated in Equation 3.172b for technical reasons required by GEMPACK.

3.11.1 Closures for comparative static simulations

For comparative static simulations with TAIGEM, we set as exogenous tax rates, technology and consumer preferences as these variables are not explained in our model. These are naturally exogenous variables in most conventional CGE models. Like the ORANI model, the static mode of TAIGEM does not incorporate equations to determine endogenously all the components of GDP—aggregate private consumption (C), aggregate investment (I), and government consumption (G), export (X) and import (M)—or labour supply and the absolute price level. Therefore, we need to set some of these exogenous in comparative static simulations:

(a) either domestic absorption (C + I + G) or the balance of trade (X - M) must be exogenous;

(b) either the real wage or aggregate employment must be exogenous;

(c) either a domestic price level (CPI or GDP deflator) or the exchange rate must be set as numeraire.

Conventionally, capital stocks are assumed fixed in the short run and flexible in the long run; real wages are rigid in the short run and adjustable in the long run. That is, in the long run real wages adjust to the policy shock under consideration and employment is not affected. In the short run real wages are unaffected by the shock and employment adjusts.

For comparative static simulations, we do not implement an explicit capital supply function. For short-run simulations we normally fix aggregate investment and capital stocks, and for long-run simulations we fix rates of return.

3.11.2 Closures for recursive dynamic simulations

3.11.2(A) *Closures for the BAU forecasting simulations*

For BAU forecasting simulations, we put into the model all available and reliable forecasts from specialists of forecasting so as to produce a accurate and sensible business-as-usual growth path of the economy. Typical examples of these forecasts are macroeconomic forecasts—e.g., components of GDP—and government announcement of future changes in taxes or some policy targets. Quite often the available forecasts are for variables that are naturally endogenous in conventional CGE closures. To accommodate these forecasts in our forecasting simulations, we need to swap them with other naturally exogenous variables. For example, we may need to endogenise overall factor productivity once all components of GDP on the expenditure and income sides are exogenized. If we obtained forecasts of both export prices and volumes, we need to endogenise shifter variables so as to locate the export demand schedule consistent with these forecasts.

In the BAU forecasting simulations, rates of change in consumer preferences and industry-specific technology are normally exogenous and set to their historically average values. Policy instrument variables—e.g., tax rates—are exogenous in forecasting and their values are set according to government announcement.

3.11.2(B) Closures for the perturbed forecasting simulations

The perturbed forecasting simulations produce a path that shows the deviation of the economy away from its BAU path. More specifically, the perturbed forecasting path is produced as the result of the policy shock under consideration in addition to the growth in the BAU state.

Closures for perturbed forecasting simulations are quite similar to those for comparative static simulations. We set naturally endogenous variables endogenous, e.g., C, I, and G, so that they respond to the policy change under consideration. Correspondingly, naturally exogenous variables, such as the shifter of foreign demand curves, are exogenous. We shock them by the percentage changes computed in the associated BAU forecasting simulation—that is, we assume that the export demand schedules shift by the same percentage amounts in both BAU and perturbed simulations.

In the perturbed simulations, we first reproduce the BAU forecasting path using the perturbed closure without putting in the policy shock under consideration. This is to ensure that in the absence of the policy shock all of the exogenous variables in the perturbed closure have the same percentage changes as they have in the associated BAU forecasting simulations. Then we simulate again with the perturbed closure and shock in addition the policy variable of interest. That is, among the exogenous variables in the perturbed closure, only the policy variables to be shocked have different values from the associated BAU forecasting solution. This process is to avoid computation errors due to path dependence. The perturbed forecasting simulation thus produces deviations from the corresponding BAU forecasting solutions in response to the policy change under consideration.

We list in Appendix 2 the three sets of frequently used closures for simulations with TAIGEM—short- and long-run comparative static simulations, and recursive dynamic simulations.

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CHAPTER 4
Innovations in TAIGEM for Energy-using Consumer Durables: the Case of Motor Vehicles

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4.1 Introduction

We extend the TAIGEM model to tackle several problems in modelling the demand for privately-owned motor vehicles in CGE models. First, most models inappropriately treat cars and gasoline as substitutes, rather than complements, in household demand. This can produce odd results. For example, households buy less gasoline but more cars when gas prices rise—even though, in reality, motor vehicles require gasoline to provide transport services. Most conventional CGE models display this quirky behaviour, which arises from the use of additive demand systems, such as the Linear Expenditure System (LES). But additivity is inappropriate for complementary commodities. In fact, the marginal utility of cars is closely related to petrol use.

Second, conventional CGE models fail to address the durable nature of privately owned motor vehicles. Households enjoy a long-lasting stream of transport services their cars provide. Yet, input-output accounts—the main data source for most CGE models—mention only newly-acquired cars and treat them as perishables in household consumption (Inter-Secretariat Working Group on National Accounts, 1993, sec. 9.40). In reality, households can still consume some transport services from their existing car stock even though they do not buy any new cars in some period. This leads to under estimation of the economy's true consumption.

Starting from standard TAIGEM, we create a dummy industry which produces transport services from gasoline and privately-owned motor vehicles. This approach has been used in input-output accounting to deal with owner-occupied dwellings[1]. The new industry—named Private Transport Services (hereafter, PTS)—uses motor vehicles as capital and gasoline as an intermediate input to produce transport services for households. We impute capital rentals for existing cars. Current car purchases are treated as additions to the capital stock of this industry. Consequently, households get utility from transport services yielded by their cars and gasoline. Moreover, household demand for gasoline is related to the whole stock of cars—both newly-acquired and existing. We specify a proper production structure for the PTS industry to ensure that cars and motor fuels are complementary in producing transport services. We specify a substitution elasticity of 0.2 between car capital and gasoline to account for price-induced fuel conservation. Vehicle license fees are also included in PTS production costs.

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1 In most Input-Output accounting systems, owner-occupied dwellings are treated as capital goods and have imputed rentals.

Car capital for the PTS industry has two special features. First, a car can be used immediately after purchase, while other industries in TAIGEM take one year to install capital. Second, cars with newer technology take time to filter into the stock: technological changes do not affect pre-existing cars. We identify embodied technical change via the "vintage capital" approach, splitting the PTS industry into 11 sub-industries according to car age. We model the transport services produced by the different vintages as good, but not perfect, substitutes.

The new treatment allows better modelling of household demand for new cars. Assuming newer cars use less fuel, vehicle management policies that reduce the average service life of cars (such as heavier taxes on gas-guzzling cars) will also help abate greenhouse gas emissions.

In this chapter, we describe the set-up of the dummy industry and our first-stage innovation for private transport services. Section 4.2 is a brief comparison between the standard and modified TAIGEMs, focussing on the treatment of demands for privately-owned motor vehicles. In Section 4.3 we describe how we changed the database for the new industry. In Section 4.4 we introduce its production structure. We run two illustrative comparative static simulations of a gasoline tax increase with both the standard and the new version of TAIGEM. We discuss the simulation results in Section 4.5. Our second-stage innovation considers the "embodied technical change" via the vintage distinction of cars. This is introduced in the next chapter.

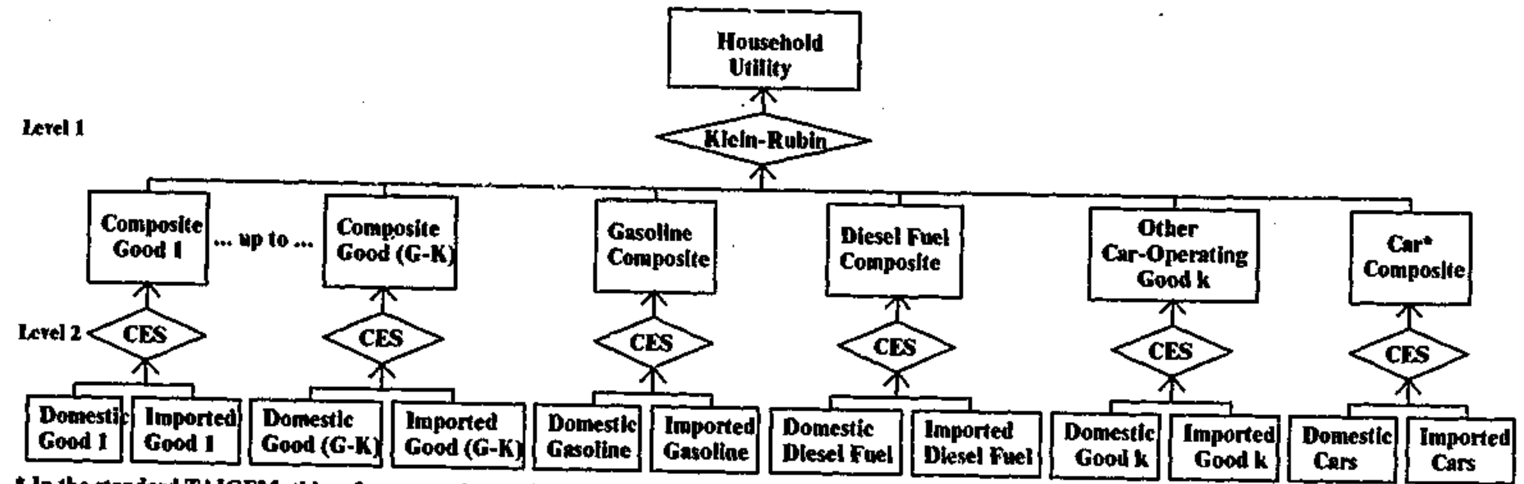
4.2 Household demands for cars and gasoline in the standard and the new version of TAIGEM

We show in Figures 4.1(A) and 4.1(B) the differences in household demands for cars and gasoline between the standard and the new version of TAIGEM. For brevity, we use the term "STD" for the standard TAIGEM model, as introduced in Chapter 3, and use the "DURA" for the version of TAIGEM with the new industry—the Private Transport Services (PTS) industry. Hereafter we refer to the two model versions as STD and DURA.

In Figure 4.1(A), version STD specifies an LES (Linear Expenditure System) for household demand. All goods are substitutes. Consequently, households buy less gasoline but more cars as gasoline prices rise. Moreover, version STD counts in only newly-acquired cars and treats them as perishable goods. In Figure 4.1(B), version DURA still uses the LES for household demands. Households consume Private Transport Services[2] (PTS), instead of motor fuels (gasoline and diesel fuel), other

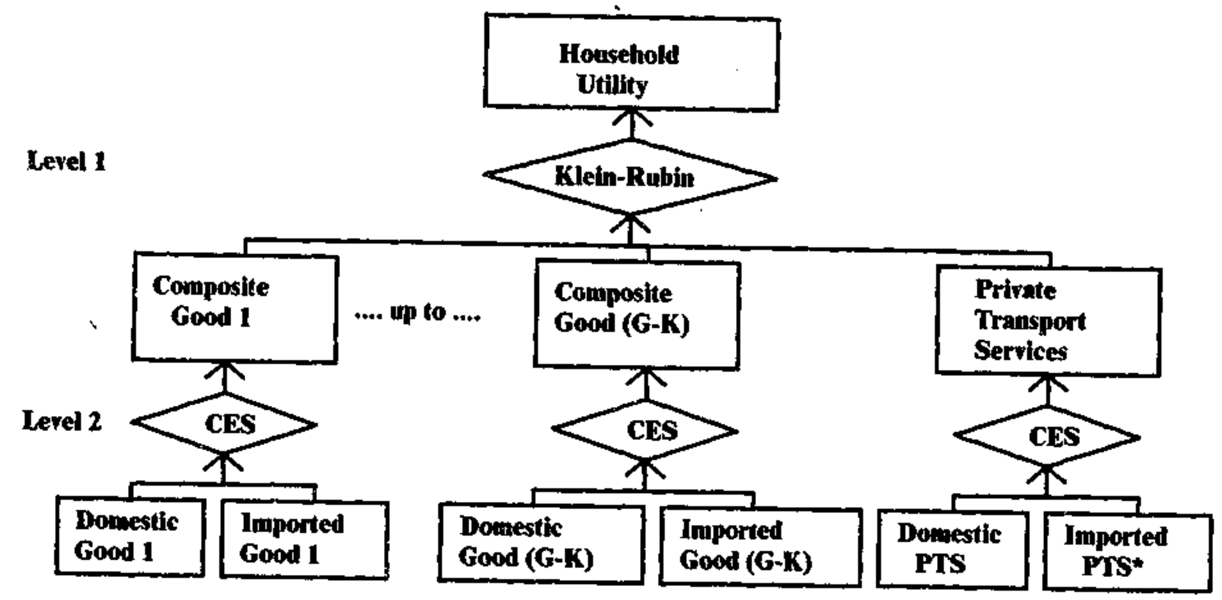
[2] There is no import competitor for Private Transport Services.

car-operating goods and newly-acquired cars. The PTS is made of the above-mentioned goods plus a stock of pre-existing cars. However, the original TAIGEM assumes that only producers use capital while households are defined as simply consumers of final goods. Households do not perform production. Hence, we set up a dummy industry—the PTS industry, to assume the production of private transport services for households. We introduce the production structure of the PTS industry in section 4.4.



* In the standard TAIGEM, this refers to newly acquired cars only.

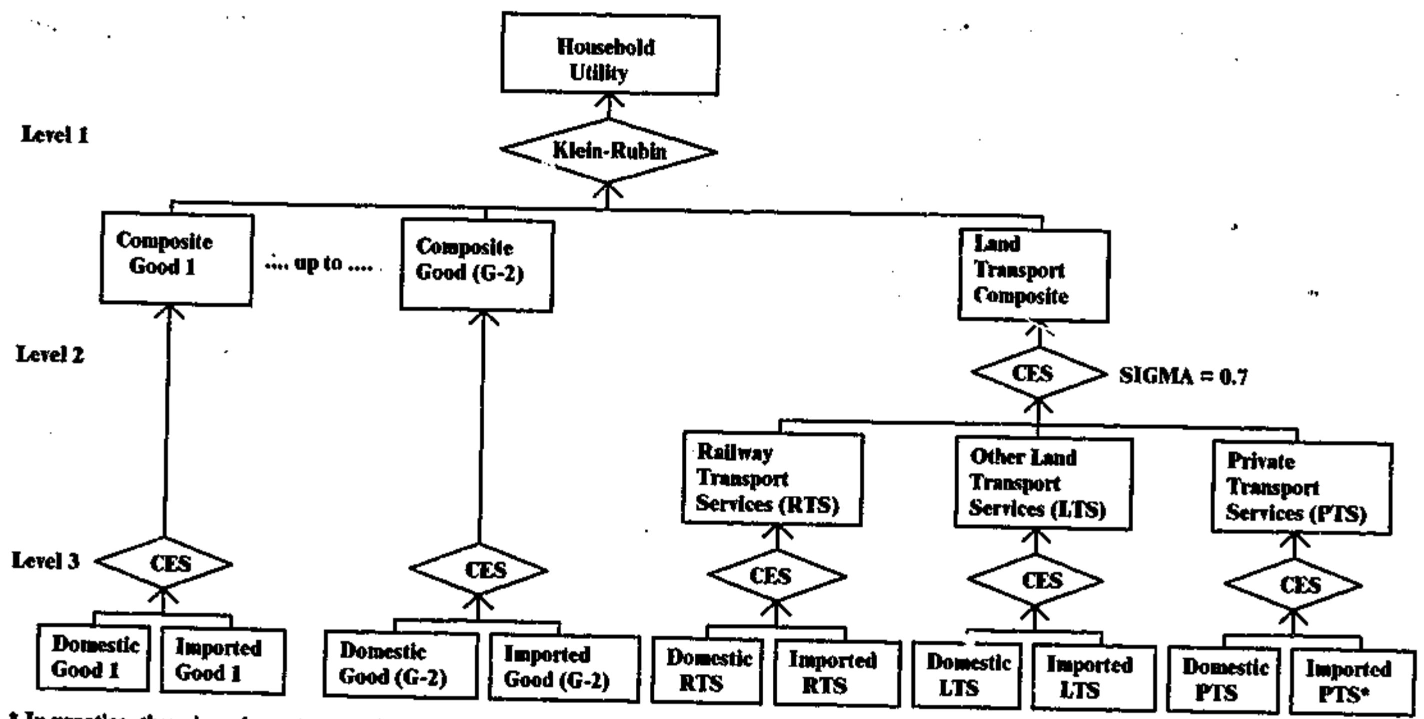
Figure 4.1(A) The nesting system for household demand in version STD



* In practice, there is no import competitor for Private Transport Services.

Figure 4.1(B) The nesting system for household demand in version DURA

In setting up PTS, we form an "land transport" bundle in the household demand system. Figure 4.2 shows the nested household demand system with the "land transport" bundle. We specify a substitution elasticity of 0.7 between Railway Transport Services (RTS), Other Land Transport Services (LTS)—buses and taxis—, and PTS. This addition to the nesting system recognises the special possibilities of substituting between private (cars) and public (bus or rail) transport.



* In practice, there is no import competitor for Private Transport Services.

Figure 4.2 Forming a "land transport" bundle in the nested household demand in version DURA

4.3 Adding the PTS industry to the database

In this section we describe how we reallocated household expenditure on car-related goods to form the cost column of the PTS industry.

In the original database, as shown in Figure 4.3, we add two columns—for PTS production costs and for investment—and a row for PTS sales. (see also the shaded row and column in the figure) We move household expenditure on motor vehicles to become the investment of the PTS industry. Household purchases of gasoline and other car-operating goods (e.g., tyres and lubricants) now become intermediate inputs of the PTS industry. The associated margins and taxes are also moved to the corresponding entries in the database. We impute rentals for the privately owned

motor vehicles[3]. Sales of PTS are equal to its total input cost including these rentals. The PTS industry produces a single product and hence this value also appears on the diagonal of the MAKE matrix. The PTS is supplied to households exclusively. There are no margins required for delivering PTS. No commodity nor specific taxes are imposed on it. Moreover, it faces no import competition. Two characteristics in the cost structure of the PTS industry are:

- Gasoline is the essential intermediate input, representing 30% of the total cost of the PTS industry;
- It uses only capital as a primary factor, and the capital rental takes up 47% of the total cost.

			Absorption Matrix							
			Producers		Investors		Household	Export	Gov't	Change in inventories
		Size	I	'PTS'	I	'PTS'	1	1	1	1
Basic flows		C×S								
		"Gasoline"×S		26046 1028			0 0			
		"MV"×S				98697 73733	0 0			
		"PTS"×S	0 0	0 0	0 0	0 0	232204 0	0	0 0	0 0
Margin		C×S×M								n/a
		"PTS"×S×M	0	0	0	0	0	0	0	n/a
Taxes		C×S								n/a
		"PTS"×S	0	0	0	0	0	0	0	n/a
Labour		O		0						
Capital		1		90087						
Land		1		0						
"Other costs"		1		0						
FCT		"PTS"		22653						
VLT		"PTS"		19503						
Total costs		I		232204						

C = Number of commodities
I = Number of industries
S = 2; domestic, imported
O = Number of occupation types
M = Number of commodities used as margins

Figure 4.3 Adding the PTS industry to the TAIGEM database

3 Statistics published by the Directorate-General of Budget, Accounting and Statistics (DGBAS) indicated value of private cars was NT$900872 million; we used a discount rate of 10% to impute the value of car services.

In Table 4.1 we summarise the differences in the household demand columns of versions STD and DURA. After the modification, households do not consume gasoline, diesel fuel, lubricants and vehicles services (e.g. repair and maintenance). Households do not buy motor vehicles in version DURA. Other car-operating expenses are partially apportioned to the PTS industry as input costs. The prorating ratios are taken from the 1994 Survey of Household Income and Expenditure[4].

As we take into account the capital services of old cars, GDP is altered. Table 4.2 shows the differences on both sides of GDP between the two versions. On the income side, modification increases GDP by the amount of the capital rentals of the PTS industry. On the expenditure side of GDP, aggregate investment increases by the amount that used to be household purchases of cars. Aggregate consumption decreases by 136466 million dollars, which is the difference between the investment (newly acquired cars) and the capital rentals of the PTS industry.

Table 4.1 Effect of the database change on household expenditure

Unit: $NTD million, at purchaser's prices

Commodities	Original	After change
Gasoline	**57249**	**0**
Diesel Fuel	**321**	**0**
Lubricants	**1447**	**0**
Rubber Products	10351	3024
Hand Tools	1144	1122
House Electronic products	63626	63486
Light Equipment	5253	4970
Video and Radio	58642	57707
Motor Vehicles	**226554**	**0**
Insurance	65869	59869
Vehicle Services	**26236**	**0**

4 The Survey of Household Income and Expenditure classifies household expenditure into 12 categories. Transportation and communication is one category among them. We take as the prorating ratios the expenditure shares of the commodity used for transportation purpose.

Table 4.2 Induced differences in both sides of GDP

Unit: $NTD million

Components of GDP	Original (A)	After change (B)	Difference (C) = (B) - (A)
GDP from income side	6426113	6516200	**132243**
Land	227241	227241	0
Labour	3699243	3699243	0
Capital rental	1941430	2031517	**90087**
Other costs	294354	294354	0
Indirect Taxes	263845	306001	**42156**
GDP from expenditure side	6426113	6516200	**132243**
Consumption	3765697	3671386	-94311
Investment	1508450	1735004	226554
Government	977116	977116	0
Inventory changes	68510	68510	0
Exports	2776824	2776824	0
Imports	-2670484	-2670484	0

In addition to household expenses on private transport needs, we also take into account taxes on privately owned cars. Two taxes are levied on car usage by households:

(a) the fuel consumption tax[5] (FCT), an annual tax on car ownership, used to fund maintenance, construction, and management of highways, and

(b) vehicle license fees[6] (VLF), another annual tax on car ownership.

Our database, based on the conventional Input-Output (I-O) accounts, does not include these fees in the household demand column[7]. The I-O accounts deal only with household expenditure on goods and service but not deal with other outlays such as taxes and transfer payments[8]. The vehicle license tax and the fuel consumption tax

5 The rates of the fuel consumption tax are different for motor vehicles fuelled by gasoline and diesel fuel.

6 The rates of the vehicle license tax (VLT) vary according to types—passenger car or light truck, and the piston displacement of cars. Passenger cars are more heavily taxed than light trucks. The larger the piston displacement, the higher the VLT rate. The VLT rate does not discriminate between vintages of cars.

7 Commodity taxes have been counted for in the household consumption column.

8 Together with National Income (NI) Accounting, Input-Output (I-O) Accounting is a branch of National Economic Accounting. I-O accounts present in detail commodity flows to industries as productive inputs and to final demanders for consumption. The NI accounts present in a more comprehensive way values and compositions of national products and the distribution of national income from production. Household taxes and transfer payments to the government.(e.g., income tax, indirect taxes apart from commodity tax) are displayed in NI but not in I-O.

are regarded as household transfers to the government in the national income (NI) accounts. Nevertheless, the Survey of Household Income and Expenditure, a part of the national income (NI) accounting, does not reveal the individual entries of the FCT and VLF. We deduce these tax payments from transportation data. The FCT revenue is 22653 million and the VLF revenue is 19503 million in 1994. We incorporate the FCT and the VLF revenues in the "other costs" of the PTS industry[9].

We observe that there are two types of privately owned motor vehicles: (a) passenger cars, and (b) light trucks. In Taiwan, nearly all passenger cars are fuelled by gasoline, while light trucks use either gasoline or diesel fuel. Light trucks have a lower rate of vehicle license tax than passenger cars. The fuel consumption tax on gasoline-fuelled trucks is higher than on diesel trucks. The number of privately owned light trucks is small relative to passenger cars. Statistics (MOTC, 1995) show that passenger cars constitute 86% of privately owned vehicles in 1994. We deduce from the survey data that gasoline-fuelled cars take up approximately 95% of the year 1994 stock of privately owned vehicles. Yet, in our model we do not distinguish types of vehicles. Further, we assume that gasoline and diesel fuel are used in fixed proportion to all vehicles (see also section 4.4).

4.4 The production structure of the PTS industry

The production structure of the PTS industry is analogous to that of the non-electricity industries ('ORDINARY' industries, as seen in Figure 3.2(C). The commodity-source nest at level 2 in Figure 4.4 shows that each of the composite goods, including gasoline, diesel fuel and cars, is a cost-minimising CES aggregation of that good from domestic and imported sources. We assume that the PTS industry uses gasoline and diesel fuel in fixed proportions. This is shown as the fuel-composite nest at level 1b. The PTS industry uses only cars as capital. However, new cars yield services directly (for other industries, investment goods take one year to install). The capital-composite nest at level 1b indicates that the car capital stock is a direct addition of all cars (whether pre-existing or newly-acquired). We allow for substitution between fuel and car capital. This is to reflect either autonomous or price-induced fuel saving. Fuel savings can be achieved by planning and consolidating trips, avoiding congested roads, driving slowly and at an even pace, and removing unnecessary weight from the vehicle. The fuel-car composite nest at level 1a of Figure 4.4 shows the cost-minimising CES aggregation of fuel composite and

9 For other industries, vehicle license tax and fuel consumption tax have been included in their "other costs".

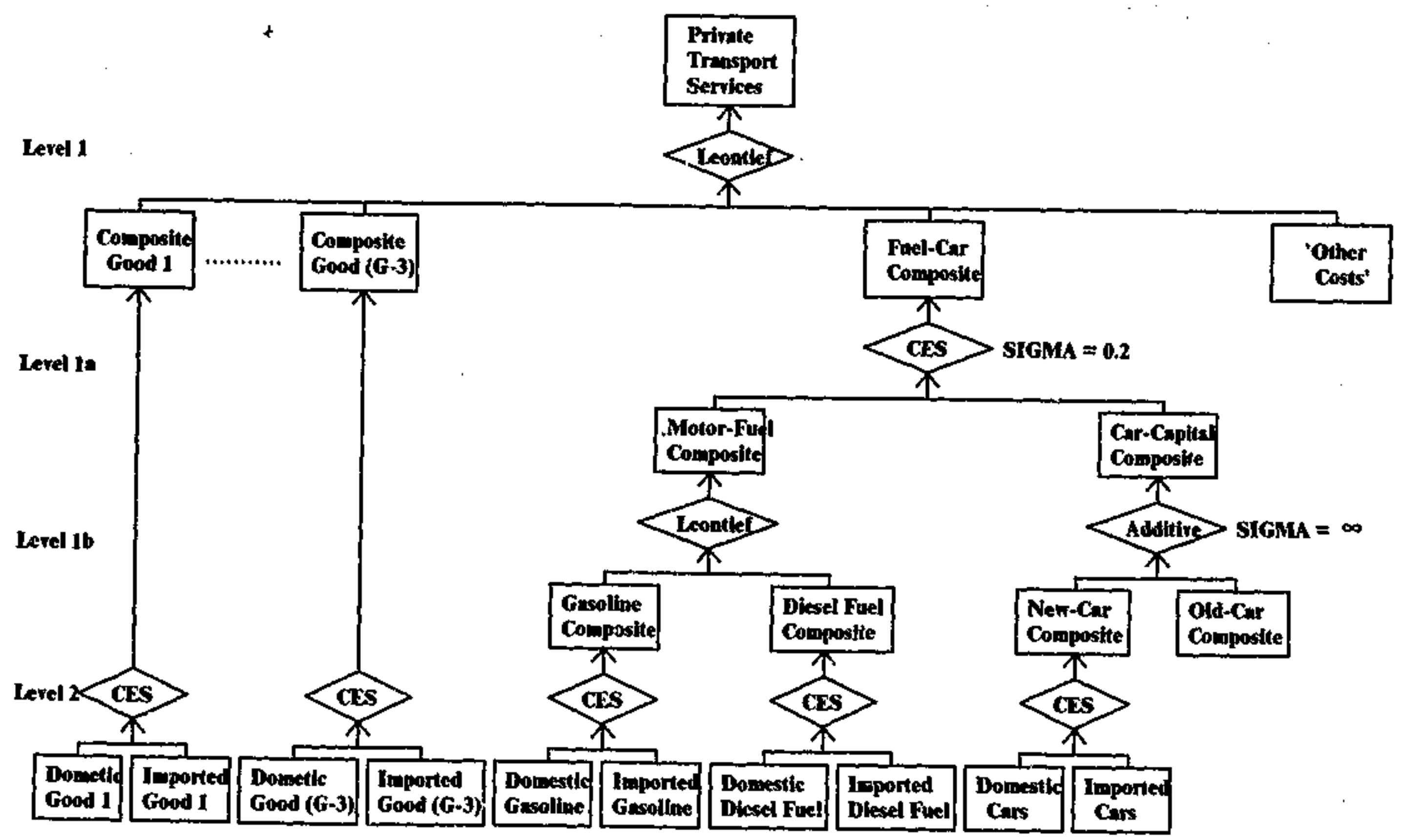
car stock. The activity nest at level 1 indicates that the PTS industry uses the following in fixed proportions:

(i) fuel-car composite,

(ii) intermediate input composites: tyres, repair and maintenance, car insurance, and

(iii) "other costs" tickets.

Although not shown in Figure 4.4, two annual per-car taxes are also included in PTS costs—fuel consumption tax (FCT) and vehicle license tax (VLT). We distinguish FCT and VLT as separate entries of the PTS industry for simulation purpose. Note that FCT and VLT are different from "other costs" tickets. In TAIGEM, we assume that an industry demands "other costs" tickets in fixed proportion to its activity levels. FCT and VLT are fees charged on car ownership. Hence, they are related to car capital.



* There is no import competitor for Private Transport Services.

Figure 4.4 The production structure of the PTS industry in version DURA

We introduce below the linearised equations derived from the production structure of the PTS industry. Notations for variables and coefficients, and ranges of sets are listed in Table 4.3.

Demands for source-specific intermediate inputs, X1(c,s,"PTS"), including motor fuels

(see also source nests at Level 2 of Figure 4.4)

$$x1(c,s,\text{"PTS"}) = x1\_s(c,\text{"PTS"}) + RS1(c,s,\text{"PTS"})*\{twistsrc(c) + twistsrc\_c - SIGMA1(c)*[p1(c,\text{"dom"},\text{"PTS"}) - p1(c,\text{"imp"},\text{"PTS"})]\}, \quad c\in COM,\ s\in SRC, \qquad (4.1)$$

$$p1\_s(c,\text{"PTS"}) = RS1(c,\text{"dom"},\text{"PTS"})*p1(c,\text{"imp"},\text{"PTS"}) - RS1(c,\text{"imp"},\text{"PTS"})*p1(c,\text{"dom"},\text{"PTS"}), \quad c\in COM, \qquad (4.2)$$

where

$$RS1(c,\text{"dom"},\text{"PTS"}) = \left(\frac{V1PUR(c,\text{"imp"},\text{"PTS"})}{V1PUR\_S(c,\text{"PTS"})}\right), \text{ and}$$

$$RS1(c,\text{"imp"},\text{"PTS"}) = RS1(c,\text{"dom"},\text{"PTS"}) - 1 = -\left(\frac{V1PUR(c,\text{"dom"},\text{"PTS"})}{V1PUR\_S(c,\text{"PTS"})}\right), \quad c\in COM.$$

Equation 4.1 is the percentage change form of the CES demand function. It indicates imperfect substitution between domestically produced and imported commodities (x1(c,s,"PTS")) as intermediate inputs. Equation 4.2 states the cost-share weighted Divisia index of the source-specific commodity prices, p1(c,s,"PTS").

Demand for the motor-fuel composite, X1_S(f)

(see also the motor-fuel composite nest at Level 1b of Figure 4.4)

$$x1\_s(f) - [a1\_s(f) + a1mvpetrol\_f] = x1mvpetrol\_f, \quad f\in MVPETROL, \qquad (4.3)$$

$$p1mvpetrol\_f - a1mvpetrol\_f = \sum_{f\in MVPETROL} S1MVPETROL(f)*[p1\_s(f,\text{"PTS"}) + a1\_s(f,\text{"PTS"})], \qquad (4.4)$$

where

$$S1MVPETROL(f) = \frac{V1PUR\_S(f,\text{"PTS"})}{\sum_{f\in MVPETROL} V1PUR\_S(f,\text{"PTS"})}.$$

Equation 4.3 indicates that gasoline and diesel fuel are purchased in fixed proportion. This is an arbitrary assumption as our model does not distinguish between vehicles according to fuel. Equation 4.4 states the cost-share (S1MVPETROL(f)) weighted Divisia index of the prices of source-composite motor fuels, p1_s(f,"PTS"), and the corresponding technical changes, a1_s(f,"PTS").

Table 4.3 Variables, coefficients and sets used in the demand equations of the PTS industry

	Description	Index and range
Sets		
COM	refers to all commodities.	c
SRC	refers to two sources: domestic and imported.	s
MVPETROL	refers to motor fuels—Gasoline and Diesel Fuel.	f
NONMVPETROL	= COM - MVPETROL.	c
Variables (percentage change unless otherwise indicated)		
x1(c,s,"PTS")	Demand by industry i for good c from source s as an intermediate input	c∈COM
p1(c,s,"PTS")	Purchaser's price of source-specific intermediate input c paid by industry i	s∈SRC
x1_s(c,"PTS")	Demand by industry i for source-composite good c as an intermediate input	c∈COM
a1_s(c,"PTS")	Input-saving technical change of industry i in using source-composite intermediate input c	c∈COM
p1_s(c,"PTS")	Purchaser's price of source-composite intermediate input c paid by industry i	c∈COM
x1mvpetrol_f	Demand by the PTS industry for the motor-fuel composite	
a1mvpetrol_f	Input-saving technical change of the PTS industry in using the motor-fuel composite	
p1mvpetrol_f	Purchaser's price of the motor-fuel composite paid by the PTS industry	
x1carcap	total car capital available for use in the current period	
x1cap("PTS")	Capital stock of the PTS industry	
p1cap	Average rental price of cars, both pre-existing and newly-acquired	
x1carcapOLD	Stock of pre-existing cars	
x1carcapNEW	Stock of newly-acquired cars	
x2tot("PTS")	Investment of the PTS industry—cars	
delUnity	An ordinary change variable, always shocked by 1.0 in year-on-year simulations	
faccumPTS	Shifter to turn on and off the capital accumulation equation of the PTS industry	
x1fulprimPTS	Demand of the PTS industry for the fuel-car composite	
a1fulprimPTS	Input-saving technical change of the PTS industry in using the fuel-car composite	
p1fulprimPTS	Cost-share weighted average of p1mvpetrol_f and p1carcap	
x1tot(i)	Output of the PTS industry	i = "PTS"
a1tot(i)	Total factor-saving technical change of the PTS industry	i = "PTS"

....continued

Table 4.3 (continued)

	Description	Index and range
xloct(i)	Demand of the PTS industry for "other costs"	i = "PTS"
aloct(i)	Input-saving technical change of the PTS industry in using "other costs"	i = "PTS"
Coefficients		
SIGMA1(c)	Armington substitution elasticity between domestic and imported good c	$c \in COM$
V1PUR(c,s,"PTS")	Value, at purchaser's price, of source-specific intermediate input c used by the PTS industry	$c \in COM$ $s \in SRC$
V1PUR_S(c,"PTS")	$= \sum_{s \in SRC} V1PUR(c,s,"PTS")$.	$c \in COM$
SIGMA1FUPRIM	Elasticity of substitution between the motor-fuel composite and car capital, which is set at 0.2.	
CARCAPNEW	Value of newly-acquired cars, which equals V2TOT("PTS").	
CARCAPOLD	Value of pre-existing cars	
CARCAPTOT	= CARCAPNEW + CARCAPOLD.	
QCARCAPOLD	Capital stock of the PTS industry valued at last year's prices	
DPRC(i)	Depreciation rate	
CAPADDOLDCAR	Net addition to the capital stock of the PTS industry	

The demand for the car-capital composite, X1CARCAP

(see also the car-capital composite nest at Level 1b of Figure 4.4)

To derive demand for the car-capital composite, X1CARCAP, we first use simplified notation to introduce the capital accumulation of the PTS industry, followed by the TABLO presentation. We assume that new cars yield services immediately after purchases. This makes the capital accumulation formula of the PTS industry differ from that of other industries. New cars are added to the stock available for use in the current period, say, year t. That is,

$$K^{TOT}(t) = K^{OLD}(t) + K^{NEW}(t), \qquad (4.5)$$

where $K^{OLD}(t)$ denotes old cars in use during year t, $K^{NEW}(t)$ denotes cars bought in year t, and $K^{TOT}(t)$ is the total car stock available for use during year t. Note that they are in quantity units. We assume that old cars and new cars are homogenous.

From Equation 4.5,

$$\Delta K^{TOT} = \Delta K^{OLD} + \Delta K^{NEW}. \qquad (4.6)$$

ΔK^{OLD} is defined as the difference in old-car stock between years t and t-1, that is,

$$\Delta K^{OLD} = K^{OLD}(t) - K^{OLD}(t\text{-}1).$$

ΔK^{OLD} is pre-determined with the value of $K^{OLD}(t\text{-}1)$ known and $K^{OLD}(t)$ calculated from the depreciated car stock of year t-1:

$$K^{OLD}(t) = K^{TOT}(t\text{-}1)*(1 - D), \qquad (4.7)$$

where D is the depreciation rate. Equation 4.7 can be re-written as

$$K^{OLD}(t) = [K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)]*(1 - D). \qquad (4.7a)$$

Equation 4.7a reflects the "no gestation lag" assumption. We also assume new cars are purchased at the beginning of the year, and hence we take a full-year depreciation of new cars, analogous to old cars. We re-arrange Equation 4.7a as

$$\Delta K^{OLD} = K^{OLD}(t) - K^{OLD}(t\text{-}1)$$
$$= - D*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D). \qquad (4.8)$$

From Equation 4.8, we derive the percentage change in the old-car capital, k^{OLD}:

$$0.01*K^{OLD}*k^{OLD} = \Delta K^{OLD} = - D*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D). \qquad (4.9)$$

The percentage-change in the new-car capital, k^{NEW}, is calculated from the following equation:

$$0.01*K^{NEW}*k^{NEW} = \Delta K^{NEW} = K^{NEW}(t) - K^{NEW}(t\text{-}1). \qquad (4.10)$$

We re-write Equation 4.6 in terms of percentage-change variables:

$$K^{TOT}*k^{TOT} = K^{OLD}*k^{OLD} + K^{NEW}*k^{NEW}, \qquad (4.11)$$

This equation determines k^{TOT}.

Figure 4.5 illustrates how the percentage-change variables of old- and new-car stock are calculated. k^{OLD} measures the annual growth of old cars, i.e., from $K^{OLD}(t\text{-}1)$ to $K^{OLD}(t)$. k^{NEW} measures the annual growth of newly-acquired cars, i.e., from $K^{NEW}(t\text{-}1)$ to $K^{NEW}(t)$. k^{TOT} measures the annual growth of the total car capital of the PTS industry, K^{TOT}.

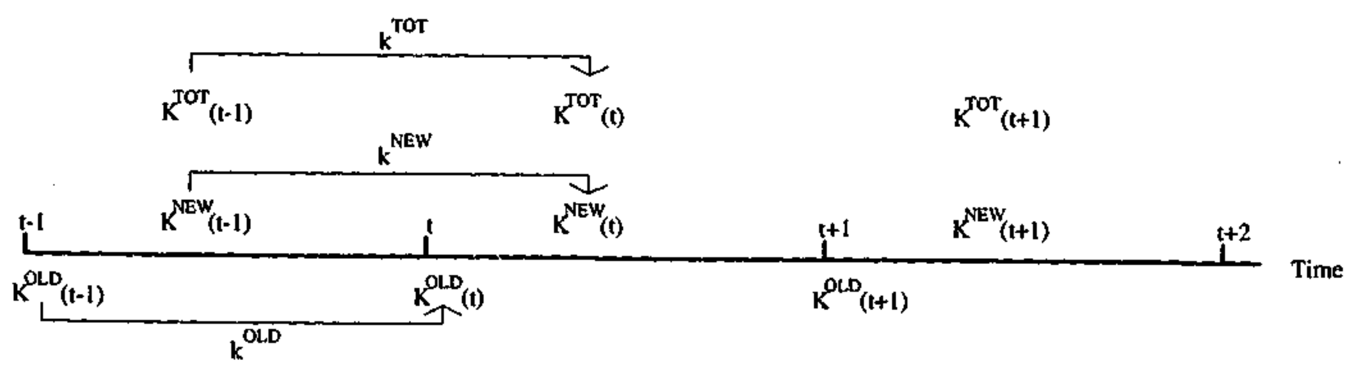


Figure 4.5 Capital accumulation in the PTS industry, without gestation lag

Table 4.4 Mapping the simplified notation to coefficients and variables used in the TABLO code for the capital accumulation formula

Coefficients/variable name		Definition
Simplified	in TABLO	
$K^{OLD}(t)$	QCARCAPOLD	Capital stock of old cars in use in year t, valued at prices of year t-1
$K^{OLD}(t-1)$	$CARCAPOLD^{ini}$	Capital stock of old cars in use in year t-1, valued at prices of year t-1
$K^{NEW}(t)$	QCARCAPNEW; X2TOT	Capital stock of new cars bought in year t, valued at prices of year t-1
$K^{NEW}(t-1)$	$CARCAPNEW^{ini}$; $V2TOT^{ini}$	Capital stock of new cars bought in year t-1, valued at prices of year t-1
$K^{TOT}(t)$	QCARCAPTOT	Entire capital stock of the PTS industry, valued at last year's prices
ΔK^{OLD}	CAPADDOLDCAR	New addition to old-car stock
D	DPRC("PTS")	Depreciation rate for capital stock of the PTS industry
D^{OLD}	DPRCOLD	Depreciation rate for old cars
D^{NEW}	DPRCNEW	Depreciation rate for new cars
k^{OLD}	x1carcapOLD	Percentage change in the old-car stock
k^{NEW}	x1carcapNEW	Percentage change in the new-car stock
k^{TOT}	x1carcap	Percentage change in the whole stock of cars

We incorporate Equations 4.9 to 4.11 in the TABLO code of TAIGEM. Table 4.4 shows the mapping from simplified notation to the coefficients and variables used in the TABLO code.

Equations 4.12 and 4.13 together are the TABLO presentation of Equation 4.9.

0.01*QCARCAPOLD*x1carcapOLD =
CAPADDOLDCAR*delUnity + faccumPTS. (4.12)

x1carcapOLD, equivalent to k^{OLD}, denotes the annual growth of old cars. QCARCAPOLD, equivalent to $K^{OLD}(t)$, is the old-car capital stock in use during the current year, valued at last year's prices. In a multi-step computation, QCARCAPOLD is updated by the percentage-change quantity variable, x1carcapOLD, but not adjusted to changes in asset prices. delUnity is an ordinary change variable, which is always set exogenous and shocked at 1.0 when running year-on-year (dynamic) simulations. The shift variable, faccumPTS, is set exogenous to turn on this equation and endogenous to turn off the equation. CAPADDOLDCAR is the net addition to the capital stock of old cars, which is equivalent to ΔK^{OLD} in Equation 4.8. CAPADDOLDCAR is evaluated with the initial values of its constituents but not updated in a multi-step computation. In TABLO, it is written as:

CAPADDOLDCAR = - DPRC("PTS")*$CARCAPOLD^{ini}$ +
[1 - DPRC("PTS")]*$V2TOT^{ini}$("PTS"), (4.13)

$CARCAPOLD^{ini}$, equivalent to $K^{OLD}(t-1)$ in Equation 4.8, is the stock of old cars at the start of last year, and $V2TOT^{ini}$("PTS"), equivalent to $K^{NEW}(t-1)$ in Equation 4.8, is the new-car acquisition in last year. Equations 4.5 to 4.11 need quantity units. We chose last period dollar's worth. Hence, $CARCAPOLD^{ini}$ and $V2TOT^{ini}$("PTS") are in quantity units—equivalent to $K^{OLD}(t-1)$ and $K^{NEW}(t-1)$, respectively. That is, both sides of Equation 4.12 are in quantity units, as derived in Equation 4.9.

The percentage-change variable in the TABLO code for k^{NEW} in Equation 4.10 is x1carcapNEW, which refers to investment (new-car acquisition) of the PTS industry, x2tot("PTS"). We use the following equation to link x1carcapNEW to x2tot("PTS"):

x1carcapNEW = x2tot("PTS"). (4.14)

Equation 4.15 below presents Equation 4.11 in TABLO language.

QCARCAPTOT*x1carcap =
QCARCAPOLD*x1carcapOLD + QCARCAPNEW*x1carcapNEW (4.15)

QCARCAPTOT, QCARCAPOLD, QCARCAPNEW, and x1carcap are equivalent to K^{TOT}, K^{OLD}, K^{NEW}, and k^{TOT}, respectively. In a multi-step computation, QCARCAPNEW is updated with its corresponding percentage-change quantity varialbes, x1carcapNEW. QCARCAPTOT is calculated as the sum of QCARCAPOLD and QCARCAPNEW at each step of a multi-step computation. We use the following notational equation to link x1carcap to the common variable notation for industry capital—x1cap(i).

x1carcap = x1cap("PTS"). (4.16)

As Wykoff (1970) points out, cars depreciate faster in the first year than in subsequent years: nearly two times faster in the post-war (1950-1968) USA context. To accommodate this argument, we extend Equation 4.7a and hence Equation 4.9 to accommodate different depreciation rates for old and new cars. Equations for new cars (k^{NEW}; x1carcapNEW) and the whole car stock (k^{TOT}; x1carcap) remain unchanged. We modify Equation 4.7a as follows.

$$K^{OLD}(t) = K^{OLD}(t-1)*(1 - D^{OLD}) + K^{NEW}(t-1)*(1 - D^{NEW}), \qquad (4.17)$$

where D^{OLD} and D^{NEW} are depreciation rates for old and new cars respectively. By reference to Wykoff (1970), we set D^{OLD} equal to 12% per annum and D^{NEW} equal to 25%. Note that we still assume services of old and new cars are homogenous, though their depreciation rates differ. Accordingly Equation 4.8 is modified as:

$$\Delta K^{OLD} = K^{OLD}(t) - K^{OLD}(t\text{-}1) = - D^{OLD}*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D^{NEW}), \quad (4.18)$$

Equation 4.9 then becomes:

$$0.01*K^{OLD}*k^{OLD} = \Delta K^{OLD} = - D^{OLD}*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D^{NEW}). \quad (4.19)$$

Following Equation 4.19, Equation 4.13 becomes:

$$\text{CAPADDOLDCAR} = - \text{DPRCOLD*CARCAPOLD}^{ini} + [1 - \text{DPRCNEW}]*\text{V2TOT}^{ini}(\text{"PTS"}), \quad (4.20)$$

where DPRCOLD and DPRCNEW correspond to D^{OLD} and D^{NEW}, respectively. Equation 4.12 remains the same. Table 4.5 summarises the two sets of car capital accumulation equations: same and differing depreciation rates for old and new cars.

Table 4.5 Tally of capital accumulation associated equations: differing depreciation rates for old and new cars

Eq. No.	Equations for capital accumulation with same depreciation rates	Eq. No.	Equations for capital accumulation with differing depreciation rates
(4.8)	$\Delta K^{OLD} = - D*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D)$	(4.18)	$\Delta K^{OLD} = - D^{OLD}*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D^{NEW})$
(4.9)	$0.01*K^{OLD}*k^{OLD} = \Delta K^{OLD} = - D*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D)$	(4.19)	$0.01*K^{OLD}*k^{OLD} = \Delta K^{OLD} = - D^{OLD}*K^{OLD}(t\text{-}1) + K^{NEW}(t\text{-}1)*(1 - D^{NEW})$
(4.10)	$0.01*K^{NEW}*k^{NEW} = \Delta K^{NEW} = K^{NEW}(t) - K^{NEW}(t\text{-}1)$		the same as in the left
(4.11)	$K^{TOT}*k^{TOT} = K^{OLD}*k^{OLD} + K^{NEW}*k^{NEW}$,		the same as in the left
(4.12)	0.01*QCARCAPOLD*x1carcapOLD = CAPADDOLDCAR*delUnity + faccumPTS.		the same as in the left
(4.13)	CAPADDOLDCAR = - DPRC("PTS")*CARCAPOLD^{ini} + [1 - DPRC("PTS")]*V2TOT^{ini}("PTS")	(4.20)	CAPADDOLDCAR = - DPRCOLD*CARCAPOLD^{ini} + [1 - DPRCNEW]*V2TOT^{ini}("PTS"),
(4.14)	x1carcapNEW = x2tot("PTS").		the same as in the left
(4.15)	QCARCAPTOT*x1carcap = QCARCAPOLD*x1carcapOLD + QCARCAPNEW*x1carcapNEW		the same as in the left

The demand for the fuel-car composite

(see also the fuel-car composite nest at Level 1a of Figure 4.4)

$$\text{x1mvpetrol\_f} - \text{a1mvpetrol\_f} = \text{x1fulprimPTS} - \text{SIGMA1FUPRIM}*[\text{p1mvpetrol\_f} + \text{a1mvpetrol\_f} - \text{p1fulprimPTS}] \quad (4.21)$$

$$\text{x1cap("PTS")} - \text{a1cap("PTS")} = \text{x1fulprimPTS} - \text{SIGMA1FUPRIM}*[\text{p1cap("PTS")} + \text{a1cap("PTS")} - \text{p1fulprimPTS}] \quad (4.22)$$

Equations 4.21 and 4.22 indicate imperfect substitution between the motor fuel composite (x1mvpetrol_f) and car capital. p1fulprimPTS is the cost-share weighted average of the price of the motor-fuel composite (p1mvpetrol_f) and the rental price of the PTS industry's total car capital (p1cap("PTS")).

Demands for all inputs

(see also Level 1 of Figure 4.4)

$$\text{x1fulprimPTS} - [\text{a1fulprimPTS} + \text{a1tot("PTS")}] = \text{x1tot("PTS")}. \quad (4.23)$$

$$\text{x1\_s(c,"PTS")} - [\text{a1\_s(c,"PTS")} + \text{a1tot("PTS")}] = \text{x1tot("PTS")}, \quad c \in \text{NONMVPETROL}. \quad (4.24)$$

$$\text{x1oct(i)} - [\text{a1oct(i)} + \text{a1tot(i)}] = \text{x1tot(i)}, \quad i = \text{"PTS"}. \quad (4.25)$$

Equations 4.23 to 4.25 show that the fuel-car composite, other intermediate inputs (such as tyres) and "other costs" are used in fixed proportion to the output of PTS.

Demands for FCT and VLT

$$\text{x1vltPTS} = \text{x1carcap}, \quad (4.26)$$

$$\text{x1fctPTS} = \text{x1carcap}, \quad (4.27)$$

$$\text{p1vltPTS} = \text{p3tot} + \text{f1vlt}, \quad (4.28)$$

$$\text{p1fctPTS} = \text{p3tot} + \text{f1fct}, \quad (4.29)$$

Equations 4.26 and 4.27 indicates that vehicle license fee (x1vlt) and fuel consumption fee (x1fct) move with the total car capital of the PTS industry (x1carcap). The rates of the fees are adjusted to the CPI, as indicated in Equations 4.28 and 4.29. f1vlt and f1fct are shifters. They can be used to increase the rates of the charges on car ownership.

4.5 Illustrative comparative static simulations: a gasoline tax increase

We discuss the results of the illustrative comparative static simulations of a gasoline tax increase with both versions STD and DURA. A 15% *ad valorem* tax is imposed on all purchases of CO_2-emitting petroleum goods[10], except exports. The effects in the two versions are compared so as to demonstrate the suitability of our treatment for the energy-using consumer durables.

Section 4.5.1 states the assumptions underlying the simulation. Section 4.5.2 contains a qualitative analysis common to both versions STD and DURA. Expected qualitative differences between the two sets of results are discussed in section 4.5.3. Quantitative results from the two long-run simulations appear in Tables 4.8 to 4.19. They are discussed in section 4.5.4.

4.5.1 Assumptions underlying both simulations

The simulations were conducted with a typical long-run comparative static closure. The key assumptions in this closure are as follows:

- Industry-specific rates of return are assumed fixed and capital stocks are free to adjust.
- Aggregate employment is not affected by the imposition of the petroleum tax; instead the real wage adjusts.
- The ratio of the balance of trade to nominal GDP is constant.
- In each industry investment moves in proportion to the capital stock.
- Aggregate government consumption moves in line with aggregate real private consumption.
- The total of (private + government) consumption is regarded as residual in the GDP identity.
- Foreign prices of imports are fixed (small country assumption).
- The number of households is not explained in our model, so it is set exogenous.
- The nominal exchange rate is the numeraire.
- Production technology and consumer tastes are assumed not to be affected by the imposition of the petroleum tax.

In the long-run comparative static simulations, we obscure the durable nature of cars by the assumption that investment (new car purchases) of the PTS industry moves with its capital stock (of cars). Dynamic simulations make distinct the durable nature of cars via the capital accumulation equations in a sequence of short-run (year-on-year) simulations.

[10] The taxed CO_2-emitting petroleum goods include gasoline, diesel fuel, aviation fuel, fuel oils, kerosene, refined gas and other refined petroleum products.

4.5.2 Qualitative analysis

Before we compare the numerical results of the two versions, we analyse qualitatively how the economic agents will respond to the imposition of the petroleum tax.

Macroeconomic aspects

In the closure, we assume that the real wage rate adjusts so as to keep employment unaffected by the imposition of the tax. We also assume fixed rates of return. In this simulation, we do not assume tax-revenue neutrality—there is no other tax rebate or subsidy to recycle the revenue from the petroleum tax. The increase in the petroleum tax tends to raise production costs and hence the market prices of commodities (including capital goods). Producers are able to transfer **part** of the tax burden to purchasers, depending on their demand elasticities. The remaining tax burden falls on profits in the short run. In the long run, rates of return must be restored to their original levels which is assumed in the closure. Rates of return are defined as the ratios of capital rental prices to investment prices. As investment prices rise, capital rental prices also rise, which is accomplished via the reduction of capital/labour ratios. For these ratios to rise, wages must fall relative to rentals. Capital shrinks as aggregate employment is assumed fixed in this illustrative simulation. As a result, GDP from income side falls.

On the expenditure side, the trade balance moves towards deficit[11] as the ratio of the trade balance to GDP is assumed fixed. The movement in aggregate consumption (private plus government) is then determined residually from the GDP identity. We use the algebra below based on simplified model equations to illustrate this argument.

From the expenditure side the percentage change in real GDP, gdp, is computed as follows:

$$gdp = S_C*ac + S_I*ai + S_B*tb, \tag{4.30}$$

where ac, ai and tb are the percentage changes in real aggregate consumption, investment and the balance of trade, and S_C, S_I and S_B are the shares of the expenditure categories in GDP.

From the income side the percentage change in real GDP can be written as the weighted sum of percentage changes in economy-wide primary factor inputs, that is

[11] According to our data base, there is a trade-balance surplus. In this case, as GDP decreases, the trade surplus decreases, i.e., the trade balance will move towards deficit. If on the other hand there were a deficit in the data, a decrease in GDP would generate a decrease in the deficit, i.e., the trade balance would move towards surplus.

$$gdp = S_K*ak + S_L*al + S_N*an \quad (4.31)$$

where ak, al and an are the percentage changes in the aggregate capital, labour and land, and S_K, S_L and S_N are the shares of the primary factors in real GDP.

According to the closure, al and an are equal to zero; and gdp = tb[12]. As S_B is rather small, $1/(1 - S_B)$ approximates to unity[13]. We then obtain the following equation:

$$ac \cong \frac{1}{S_C}*[S_K*ak - S_I*ai]. \quad (4.32)$$

Equation 4.32 indicates that the direction of the movement in aggregate consumption depends on the relative contributions[14] of aggregate capital and aggregate investment to GDP. As we assume that for each industry investment moves with its capital stock, the percentage change in aggregate investment differs from that in aggregate capital stock in their composition. We explain this statement as follows. Based on the closure assumption, the percentage changes in industry investment, inv(i), and capital stock, kap(i), are equal for all industries:

$$inv(i) = kap(i), \qquad i \in IND. \quad (4.33)$$

The percentage change in aggregate investment is the share-weighted average of percentage changes in investment of all industries:

$$ai = \sum_{i \in IND} W_i^I * inv(i), \quad (4.34)$$

where W_i^I is the investment share of industry i in the aggregate investment. The percentage change in aggregate capital stock is the share-weighted average of percentage changes in capital stocks of all industries:

$$ak = \sum_{i \in IND} W_i^K * kap(i), \quad (4.35)$$

where W_i^K is the capital share of industry i in the aggregate capital stock. Though inv(i) = kap(i), the percentage changes in aggregate investment, ai, still differs from aggregate capital stock, ak, due to the difference between W_i^I and W_i^K for all i. If most of the industries with $W_i^I > W_i^K$ contracted, we would expect aggregate investment, ai, to fall more than aggregate capital, ak. The direction of movement of aggregate consumption, ac, (see Equation 4.32) depends on the signs of ai and ak,

[12] Strictly speaking, they are set equal in nominal (rather than real) terms. We ignore the terms of trade effect.

[13] In our data base, $S_B = 0.02$. $1/(1 - S_B) = 1.02$.

[14] Hereafter, contribution of some specific variable denotes the share weighted percentage change in that variable.

coupled with the difference between S_K and S_I. From the data base we know that S_K is bigger than S_I[15] in both versions.

In summary, we expect to see the macro-economy perform in the following way:

- Aggregate capital stock shrinks to counteract downward pressure on rates of return;
- Aggregate employment is fixed, so wages must fall so that capital/labour ratios can fall;
- Real GDP falls;
- The balance of trade declines accordingly; and
- The movement of aggregate consumption (private plus government) depends on the relative magnitudes of the movements in aggregate investment and aggregate capital stock.

Responses of economic agents

The decrease in the wage/rental ratio tends to favour labour-intensive industries. Relatively, commodities produced by capital-intensive industries lose their attractiveness in the market. This leads to output reductions for capital-intensive industries and increases for labour-intensive industries. Industries adjust their factor employment accordingly. The aggregate capital/labour ratio declines. As aggregate employment is assumed fixed in this simulation, aggregate capital stock must be scaled down. This is consistent with the macroeconomic aspects stated above.

4.5.3 Differences between the two versions of TAIGEM

While the qualitative analysis stated above holds for both versions, we expect to see differences in the magnitudes between the two versions of TAIGEM. As we add a new dummy PTS industry in version DURA, the industry structure shows differences between the two versions of TAIGEM. For example, we expect to see that the aggregate capital stock in version DURA shrinks more than in version STD. The underlying justification is that the newly established dummy PTS industry in version DURA is extremely capital-intensive, and also petrol-intensive. The petroleum tax pushes up its production cost and thus output price. The market demand hence decreases. This industry then reduces its activity level and thus capital stock. As this industry occupies a rather big share in aggregate capital stock, aggregate capital

[15] In version STD, the share of aggregate capital in GDP is 30.21% and that of aggregate investment is 23.47%. In version DURA, the share of aggregate capital in GDP is 31.18% and that of aggregate investment is 26.63%.

stock in version DURA will decrease more than in version STD. Hence, we expect to see the dummy PTS industry's behaviour explains much of the difference in the results between the two versions.

Secondly, we expect to see version DURA remedy the divergence of households' demand for gasoline and motor vehicles in the standard TAIGEM. In version STD we specify a Linear Expenditure System for household demand. All commodities are substitutes for each other. Via the substitution effect, we expect to see households increase their purchase of motor vehicles in response to the price increase of gasoline. But in reality gasoline and motor vehicles are complements. In version DURA, less private transport is demanded as the petroleum tax on its most important input, gasoline, pushes up its cost and thus its output price. Households hence substitute away from private transport services. As we specify a Leontief production function for the PTS industry, it will decrease the usage of gasoline and decrease its capital stock, which is solely composed of motor vehicles. Due to the closure assumption, the investment of the PTS industry follows the adjustment of its desired capital stock. Therefore, we expect to see consistency in household-induced demand for gasoline and motor vehicles. That is the aim of establishing the dummy PTS industry to remedy the inconsistency in household demand for gasoline and motor vehicles. We will analyse this quantitatively in the next section.

The Oil Refinery industry's product mix depends on the responses of its customers. In version STD households the most important gasoline purchaser, will reduce purchases of gasoline, while PTS in version DURA is less elastic in its demand for gasoline. Oil-fired power-generating industries will suffer a cost disadvantage, and shrink. Their demands affect the Oil Refinery industry's production decision.

4.5.4 *Quantitative Results*

Part of the ORANI tradition is to provide detailed explanations of results, based on model equations and database shares. Following that tradition, we next investigate the quantitative results to verify the qualitative analysis stated above and to resolve the issues that are indeterminate in the qualitative analysis. We will also compare the magnitudes of the impact on economic variables between the two versions.

We first point out in section 4.5.4(A) how version DURA remedies the contradiction in households' demand for gasoline and motor vehicles in the standard TAIGEM. Impacts on Oil Refinery industry in the two versions are also compared in section 4.5.4(B). The impact on the macroeconomic aspects is reported in section 4.5.4(C).

4.5.4(A) Households' v.s. PTS' demand for gasoline and motor vehicles

As mentioned in section 4.5.3, demands for gasoline and motor vehicles should be correlated. As shown in Table 4.6, in the original model the petroleum tax discourages households' consumption of gasoline and diesel fuel (-4.99% and -3.63% respectively), while they purchase more motor vehicles (increasing by 0.23%). On the other hand, in version DURA PTS reduces its consumption of gasoline as car stocks shrink. This is more realistic.

Table 4.6 Household and PTS demands for gasoline and motor vehicles

(%)	STD / Household demand for	DURA / PTS demand for
Gasoline	-4.99	-1.31
Diesel Fuel	-3.63	-1.31
Lubricants	-1.22	-1.31
Motor Vehicles / Capital stock	**0.23**	**-1.31**

4.5.4(B) Differences in the impact on the Oil Refinery industry

The same 15% *ad valorem* tax was imposed on all petroleum products. Nevertheless, in both versions the basic (i.e., pre-tax) price of Fuel Oils decreases while the basic prices of other petroleum products increase (see Table 4.7). This is because the demand for Fuel Oils is much more elastic than for other petroleum products. Note that the main customers of Fuel Oils are oil-fired power industries. The petroleum tax prompts the End Use Suppliers to substitute away from these technologies. This reflects the more elastic market demand for Fuel Oils. On the other hand, the demanders of other petroleum products have less scope for substitution. Therefore, the petroleum tax will reduce the basic price of Fuel Oils while pushing up the basic prices of other petroleum products.

In comparison, the basic price of gasoline rises more in version DURA. As PTS is the major customer of gasoline[16], its Leontief production function makes the market demand for gasoline less elastic[17] in version DURA than in the original STD model.

[16] Households in version STD, thus PTS in version DURA, consumes 45% of the total sales of gasoline

[17] In version STD, households have a Linear Expenditure System for demand; in version DURA, PTS has to purchase a fixed amount of car-fuel composite while we allow slight substitution (0.2) between motor fuels and car capital.

Table 4.7 The impact on the Oil Refinery industry

	Output of commodities		Basic prices of commodities	
Versions	STD	DURA	STD	DURA
Commodities	(%)	(%)	(%)	(%)
Gasoline	-3.14	-1.16	2.12	4.22
Diesel fuel	-3.81	-3.21	0.37	-1.07
Aviation fuel	-0.55	-0.46	9.00	6.05
Fuel oils	-6.47	-5.58	-6.39	-7.00
Kerosene	-1.88	-1.38	5.44	3.65
Lubricants	-2.30	-1.70	4.32	2.81
Naphtha	-2.90	-2.09	2.73	1.80
Refinery gas	-2.21	-1.59	4.55	3.10
Asphalt	-1.68	-1.21	5.96	4.08
Refined petroleum N.E.C.	-2.03	-1.44	5.02	3.48

4.5.4(C) *Macroeconomic aspects*

In this section we check that for both versions the qualitative analysis of macroeconomic results is confirmed numerically. As the difference in industry structures between the two versions may account for the difference in the magnitudes of the macroeconomic variables, we will refer to the industrial details. Tables 4.8 to 4.19 assist in the comparison for the macroeconomic results.

GDP from income side

As shown in Table 4.8, the aggregate capital stock decreases by 0.06% in version STD and by 0.11% in version DURA. As a result, GDP falls by 0.07% in version STD, and by 0.08% in version DURA. The real wage falls by 0.55% in version STD and by 0.58% in version DURA. These falls in capital, GDP and wages conform with the qualitative analysis. Below we analyse the numerical differences between results from the two models.

Aggregate capital stock in version DURA decreases nearly twice as much as in version STD, while the wage/rental ratio in version STD declines slightly more than in version DURA[18]. We refer to the industry results to explain this difference. Table 4.9 compares data and results from the STD and DURA versions. The first two columns show the share of each industry in the aggregate capital stock. The second two columns show the percentage changes in industry capital stocks. The third pair of columns shows the contributions of industries to the aggregate capital stock,

[18] In percentage change form, the wage/rental ratio equals to the nominal wage minus the rental price of capital.

which are calculated by multiplying the industry shares—column (A) divided by 100—with the percentage changes in industry capital stocks—column (B). Summation of the contributions of all industries gives the percentage change in aggregate capital stock, as shown in Table 4.8.

Table 4.8 Macroeconomic results

	Versions	
Percentage changes of	STD	DURA
Average capital rental	0.05	0.05
Aggregate investment price index	0.05	0.05
Average nominal wage	-0.36	-0.34
Real wage	-0.55	-0.58
Aggregate capital stock	-0.06	-0.11
Aggregate employment*	0.00	0.00
Real GDP	-0.07	-0.08
Aggregate real private consumption	0.05	0.08
Aggregate real investment	-0.30	-0.41
Aggregate real government consumption	0.05	0.08
Export volume index	-0.20	-0.22
Import volume index, C.I.F. weights	-0.13	-0.15
Real devaluation	-0.15	-0.17
Terms of trade	0.08	0.07
GDP price index	0.15	0.17
CPI	0.20	0.24
Total nominal supernumerary household expenditure	0.30	0.39
Total CO_2 emissions	-1.09	-0.86
Aggregate indirect tax revenue	6.73	6.79
Tax revenue from production	17.72	19.80
Tax revenue from households	6.96	0.24
Tariff revenue	-0.08	-0.33
Tax revenue from exports	-0.21	-0.24

* marks exogenous variables.

Comparing the two versions in Table 4.9, industries apart from the additional PTS in version DURA have similar contributions in both versions to the changes of aggregate capital stock. The shares of these other industries in the aggregate capital stock diminish due to the addition of the extremely capital-intensive PTS industry. This weakens their contribution (in DURA) to the change in the aggregate stock, given the same percentage changes in industry stocks in both versions. Moreover, as the wage/rental ratio falls less in version DURA, industry-specific capital stocks shrink less than in version STD. On the whole, industries apart from PTS have slightly smaller contributions in both versions to the aggregate capital stock, though the pattern is similar.

Table 4.9 Significant contributions to the change in the aggregate capital stock

	Industry shares (A)		Percentage changes of industry capital stocks (B)		Industry contributions to the aggregate capital stock (C) = [(A)/100]*(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Industries	(%)	(%)	(%)	(%)	(%)	(%)
PTS	**n/a**	**4.44**	**n/a**	**-1.31**	**n/a**	**-0.058**
CombCy_Oil	0.18	0.17	-27.99	-26.07	-0.050	-0.045
Steam_Oil	0.14	0.13	-32.54	-30.39	-0.046	-0.041
Oil Refinery	0.54	0.51	-3.84	-2.69	-0.021	-0.014
Fisheries	1.30	1.25	-1.18	-1.08	-0.015	-0.014
Land Transport	1.45	1.38	-0.56	-0.51	-0.008	-0.007
GasTur_Oil	0.03	0.03	-18.19	-16.53	-0.006	-0.005
GasTur_Gas	0.00	0.00	9.89	9.21	0.000	0.000
EndUseElec	2.55	2.44	0.12	0.12	0.003	0.003
Steam_Gas	0.06	0.05	10.50	9.72	0.006	0.005
CombCy_Gas	0.08	0.08	10.89	10.10	0.009	0.008
Hydro	0.31	0.29	11.02	10.26	0.034	0.030
Nuclear	0.79	0.75	10.72	9.99	0.084	0.075
Steam_Coal	0.90	0.86	11.70	10.94	0.105	0.094
The rest	91.66	87.62			-0.154	-0.140
Total	100.00	100.00			-0.06	-0.11

The contraction of PTS' capital stock accounts for most of the difference. Individual industry supply curves in this long-run closure are very flat. The petroleum tax, which increases PTS costs, shifts this supply curve up. PTS' basic price increases by 3.09%. Demand for PTS, which is quite flat, falls. PTS reduces its output and capital stock accordingly by 1.31%. This contributes -0.06% to the change in aggregate capital stock (originally PTS hold 4.44% of the total). This is approximately the difference in the changes of aggregate capital stock between the two versions.

Among industries listed in these two tables, oil-fired power-generating industries—ComCy_Oil, Steam_Oil, and GasTur_Oil—Fisheries; and Land Transport industries are heavy users of the taxed petroleum goods. Suffering from the petroleum tax, their capital stocks contract. The three oil-fired power-generating

industries contract more sharply than others, because the End Use Supplier substitutes away from them. The petroleum tax makes oil-fired power relatively costly.

On the other hand, the model allows smaller substitution possibilities for the products of PTS, Fisheries and Land Transport industries. Their demands are less elastic than the End Use Supplier's demand for the oil-fired electricity. As a result, these industries' production and capital stocks do not contract as much as the oil-fired power industries.

As petroleum-using industries shrink, the Oil Refinery industry also suffers. Its activity level and thus its capital stock decline. In version STD its capital stock contracts more (by 3.84%) than in version DURA (by 2.69%). This is because the market demand for gasoline—Oil Refinery's most important product—is both less elastic and falls less in version DURA than in version STD. The demand elasticity difference was discussed in section 4.5.4(B).

GDP from expenditure side

Aggregate Investment

Aggregate investment decreases by 0.30% in version STD and by 0.41% in version DURA (see Table 4.8). We know from the income side of GDP that the aggregate capital stock contracts in both versions. But, capital contracts less than investment in aggregate.

Table 4.10 explores the difference in the decrease of the aggregate investment between the two versions. It distinguishes the PTS industry and the 3 sectors that in STD contributed most to the investment decline. Comparing the two versions in Table 4.10, the difference between the two versions in the contraction of aggregate investment comes largely from the newly established PTS industry (row 1, column (C)). Investment in the other three industries contracted less in DURA. The Oil Refinery industry reduces its investment less sharply (-2.69%) in version DURA, pulling down aggregate investment by 0.05%. The Public Administration Services (PAS henceforth) is closely related to government consumption. The output of PAS increases as government consumption increases (see Table 4.8). However, PAS reduces its capital stock and thus its investment, even though its output expands. This arises due to the declining real wage. The PAS industry is fairly labour-intensive: its cost share of labour is 58%, while capital is only of 6% in its total cost. The falling real wage prompts PAS to substitute away from capital, and hence its investment decreases. The decrease is smaller in version DURA than in version STD because aggregate private consumption and thus government consumption[19] increases more in DURA. We will discuss aggregate consumption later in this section.

Table 4.10 Significant contributions to the change in the aggregate investment

	Industry shares (A)		Percentage changes in industry investment (B)		Industry contributions to aggregate investment (C) = [(A)/100]*(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Industries	(%)	(%)	(%)	(%)	(%)	(%)
PTS	**n/a**	**13.06**	**n/a**	**-1.31**	**n/a**	**-0.172**
Oil Refinery	2.10	1.83	-3.84	-2.69	-0.081	-0.049
PAS	20.82	18.10	-0.15	-0.10	-0.031	-0.018
Land Transport	5.42	4.72	-0.56	-0.51	-0.030	-0.024
The rest	71.66	62.29			-0.153	-0.146
Total	100.00	100.00			-0.30	-0.41

As a heavy user of diesel fuel and gasoline, the Land Transport industry[20] suffers increased costs and reduced sales. It reduces its output, capital stock and thus investment. The substitution effect arising from reduced real wages also contributes to the contraction in the Land Transport industry's capital stock and investment since this industry is also labour-intensive[21]. However, Land Transport industry's investment decreases less in version DURA. Household demand for Land Transport accounts for this difference[22]. As shown in Table 4.8, aggregate private consumption increases more in version DURA. The reduction in household demand for Land Transport is hence relatively less. This then leads to smaller decreases in output and capital stock and hence in investment.

In summary, two forces prompt the Land Transport industry to reduce its capital stock and hence its investment: (1) the real wage decline directly induces reduction

[19] As mentioned in the qualitative analysis, the movement of aggregate private consumption depends on the relative contributions of aggregate capital and aggregate investment to GDP. We assume that government consumption moves with private consumption. A detailed discussion about the quantitative result for aggregate private consumption appears below.

[20] Diesel fuel contributes 12.05% and gasoline 7.62% to its total cost.

[21] The cost share of labour for the Land Transport industry is 44%, while capital is only 13% in its total cost.

[22] The household sector is the first-ranked direct-use customer of this industry, therefore household demand will have significant influence on this industry's production. Of Land Transport output, 52% goes to direct use (mostly by households, 31%) and 48% is used for margins purposes.

of its capital; and (2) the price rise of its output prompts household substitution away from Land Transport, which in turn reduces its production and hence in capital and investment. These two sorts of substitution effect are common in both versions, while the income effect of household consumption accounts for the difference between them.

The shares of industries apart from PTS are smaller in the DURA model[23]. This diminishes their contributions to the change in aggregate investment. Overall, PTS's adjustment in investment accounts for most of the difference in aggregate investment between the two versions.

Up to now, we have seen from the income side the contraction in the aggregate capital stock and hence the reduction in GDP in both versions. From the expenditure side, aggregate investment shows even sharper decreases than the aggregate capital stock. Next, we will discuss the impacts on the balance of trade and aggregate consumption.

Trade

As shown in Table 4.8, aggregate export volumes fall by 0.20% in version STD and by 0.22% in version DURA[24]; aggregate import volumes fall by 0.13% in version STD and by 0.15% in version DURA. Hence, the trade balance moves towards deficit[25] in both cases. The real exchange rate decreases by 0.15% in version STD and by 0.17% in version DURA.

Note that we assume that the balance of trade moves in line with GDP. Since GDP falls and there is a trade surplus in the data base (see footnote 11), the balance of trade moves towards deficit in both versions. Comparatively, the move toward deficit is bigger in version DURA than in version STD. So is the real appreciation. The rationale is as follows.

Assume first that there is no change in export for both versions. In the results, we observe that import decreases in both versions. Other things being equal, this will lead the trade balance to move towards surplus, which violates our closure specification. Therefore, we must have an appreciation. The appreciation lessens the competitiveness of exports in the world market and also drives up import volumes. In equilibrium, the appreciation results in decreases of both exports and imports,

[23] Note that we move households' current purchase of Motor Vehicles in version STD to the dummy PTS' investment in version DURA. This expands economy-wide investment, and hence the shares of the original industries (those other than the dummy PTS) become smaller.

[24] Note that we adopt the small country assumption that the foreign prices of imports are fixed. Hence the shrinkage of exports leads to improvement of the terms of trade.

[25] According to our data base, the initial balance of trade is in surplus.

eventually pushing the trade balance towards deficit. This is the common rationale for both versions. As to the comparison, we find a bigger move towards trade deficit and a bigger appreciation in version DURA. The bigger move towards deficit can be explained by the bigger fall in GDP. As to the bigger appreciation in version DURA, following the above rationale, the bigger decrease of imports requires a bigger appreciation to push the trade balance further towards deficit.

We now turn to discuss the bigger decrease of aggregate imports in version DURA. As shown in Table 4.11, for both versions, imports of Fuel Oils, Crude Oil and Diesel Fuel are discouraged and make significant negative contributions to aggregate imports. The sizes of these contributions do not vary much between versions.

Table 4.11 Significant contributions to the change in aggregate import volume

	Commodity shares (A)		Percentage changes in imports by commodity (B)		Commodity contributions to aggregate import volume (C) = [(A)/100]*(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Commodities	(%)	(%)	(%)	(%)	(%)	(%)
Fuel Oils	0.53	0.53	-22.66	-22.11	-0.12	-0.12
Crude Oil	2.62	2.62	-3.79	-2.63	-0.10	-0.07
Diesel Fuel	0.34	0.34	-12.08	-12.59	-0.04	-0.04
Motor Vehicles	**5.37**	**5.37**	**0.02**	**-0.93**	**0.00**	**-0.05**
The rest	91.14	91.14			0.13	0.12
Percentage change in aggregate import volume					-0.13	-0.16

Crude Oil is the raw material for the production of petroleum goods. The Oil Refinery industry relies on the imported Crude Oil. The petroleum tax discourages market demand for petroleum goods so that both domestic production and import volumes of Crude Oil decrease. In comparison, version STD has a bigger decrease. This is because of a bigger reduction in Oil Refinery output (from STD's more elastic demands for fuel, discussed in section 4.5.4(B)).

As discussed previously, prices of domestically-produced Fuel Oils and Diesel Fuel both decline; those goods become cheaper than their imported competitors. So, demand for imported oils decreases more. As well, the main customers—oil-fired power industries—shrink in the face of the petroleum tax. Hence, imports of Fuel Oils and Diesel Fuel decrease sharply.

Imports of Motor Vehicles differ between the two versions, wholly accounting for DURA's bigger import fall. As discussed previously, households in version STD

buy more motor vehicles (both domestic and imported), while PTS in version DURA reduces its investment in motor vehicles.

Imports of Motor Vehicles increase slightly (0.02%) in version STD, and make a slight positive contribution to aggregate import volume. This results from the substitution effect in household consumption. Households in version STD use much less gasoline when facing the petroleum tax. On the other hand, they buy more Motor Vehicles (domestically produced and imported). As shown in Table 4.12, among significant contributions to imports of motor vehicles, household purchases in version STD increase by 0.25% and contribute 0.13% to the total increase. Other users bought less Motor Vehicles.

Table 4.12 Significant contributions to the volume change of imported Motor Vehicles (MV) in STD

Imported MV as investment goods of industries.	Industry shares in total MV imports (A)	Percentage changes in industry demand for imported MV as investment goods (B)	Industry contributions to total imports of MV (C) = [(A)/100]*(B)
Oil Refinery	0.66	-3.82	-0.03
Land Transport	3.21	-0.54	-0.02
Fisheries	1.18	-1.16	-0.01
Current purchase by households	HH purchase share in the total import volume of MV (A)	Percentage changes in HH demand for imported MV as current consumption (B)	HH contribution to total imports of MV (C) = [(A)/100]*(B)
Households (HH)	49.32	0.25	0.13

Table 4.13 Significant contributions to the volume change of imported Motor Vehicles in DURA

Imported MV as intermediate inputs of industries:	Industry shares in total imports of MV (A)	Percentage changes in industry demand for imported MV as intermediate inputs (B)	Industry contributions to total imports of MV (C) = [(A)/100]*(B)
Motor Vehicles	24.05	-0.82	-0.20
Imported MV as investment goods of industries:	Industry shares in total imports of MV (A)	Percentage changes in industry demand for imported MV as investment goods (B)	Industry contributions to total imports of MV (C) = [(A)/100]*(B)
PTS	49.32	-1.27	-0.62
Oil Refinery	0.66	-2.64	-0.02
Land Transport	3.21	-0.46	-0.02
Fisheries	1.18	-1.03	-0.01

Conversely, imports of Motor Vehicles decrease by 0.93% in version DURA. Here, the PTS industry reduces its purchase of motor vehicles as investment goods. The petroleum tax imposed on its major intermediate input, gasoline, raises its production cost and thus its output price. The market demand hence declines. This prompts the PTS industry to reduce output and hence its capital stock, which in turn leads to the decrease in its investment. Note that the PTS industry purchases only motor vehicles as its investment goods. In Table 4.13, we see that the PTS industry buys 1.27% less imported motor vehicles, contributing -0.62% to the decrease in the import volume of motor vehicles. This contribution of -0.62% and the lack of the STD household contribution (-0.13%) explain 80% of the difference in aggregate vehicle imports.

Thus, increased gasoline prices have opposite effects on Motor Vehicle purchases in the two versions of the model. In both versions, higher gasoline prices reduce gasoline sales. In the standard version, where gasoline and motor vehicles are treated as substitutes, demand for vehicles rises. The modified version, which recognises the complementarity between gasoline and motor vehicles, predicts that motor vehicles sales will fall.

Aggregate Consumption

As seen in Table 4.8, aggregate private and government consumption[26] both increase, by 0.05% in version STD and by 0.08% in version DURA.

As we mentioned in the qualitative analysis, the movement of aggregate consumption (private plus government consumption) depends on the relative magnitudes of the contributions of aggregate capital and aggregate investment to GDP. Table 4.14 shows the relative magnitudes of the contributions of aggregate capital and investment in the two versions. In both versions, the contribution of aggregate investment to the decline of GDP is bigger that that of aggregate capital. As both aggregate investment and aggregate capital stock fall, aggregate consumption will decrease. The results in Table 4.14 support our qualitative analysis.

[26] Note that our closure forces government consumption to move in line with aggregate private consumption. The size of both is given by the trade balance constraint.

Table 4.14 Effects determining movement in aggregate consumption

	Versions	
(%)	STD	DURA
Share of aggregate capital in GDP (Sk/100)	30.21	31.18
Percentage change in aggregate capital (x1cap_i)	-0.06	-0.11
Contribution of aggregate capital to GDP ((A) = [Sk/100]*x1cap_i)	-0.02	-0.03
Share of aggregate investment in GDP (Si/100)	23.47	26.63
Percentage change in aggregate investment (x2tot_i)	-0.30	-0.41
Contribution of aggregate investment to GDP ((B) = [Si/100]*x2tot_i)	-0.07	-0.11
(C) = (A) - (B)	0.05	0.08
Share of aggregate consumption in GDP ([Sc + Sg]/100)	73.81	70.69
Percentage change in aggregate consumption (x3tot; x5tot)	0.05	0.08
Contribution of aggregate consumption to GDP ([[Sc + Sg]/100]*x3tot)	0.04	0.06

Aggregate consumption in version DURA increases more than in version STD. The percentage increases in aggregate capital and investment in version DURA are both bigger than in version STD. Furthermore, their shares of GDP in version DURA are also bigger than in version STD. On the other hand, the share of aggregate consumption in GDP in version DURA is relatively smaller[27]. Therefore, the increase of aggregate consumption in version DURA must be bigger than in version STD. In other words, the resources released from the contraction of investment are shifted to aggregate consumption. As the contraction of aggregate investment in version DURA is bigger, aggregate consumption increases more.

Price indexes

As a result of the imposition of the petroleum tax, the GDP price index rises in both versions, the rise being greater in DURA than in STD (see Table 4.8). Table 4.15 provides a decomposition of the increases in the index in both versions. Among the contributions, the rise in CPI is the major contributor in both versions. In version STD, CPI rises by 0.20%, with a positive contribution of 0.11% to the GDP price index. In version DURA, CPI rises by 0.24%, contributing 0.14% to the GDP price index. The difference in CPI accounts for the difference in GDP price index between the two versions.

[27] As we move household purchase of motor vehicles, which used to be regarded as current consumption, to the PTS dummy industry's investment, the share of aggregate private consumption in GDP decreases in version DURA and aggregate investment has a relatively larger share. The share of aggregate capital also increases because we add in the imputed rentals of the car stock.

Table 4.15 Significant contributions to the change in the GDP price index

	Shares (A)		Percentage changes in (B)		Contributions (C) = [(A)/100]*(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Price indexes for	(%)	(%)	(%)	(%)	(%)	(%)
Aggregate private consumption	58.60	55.70	0.20	0.24	0.11	0.14
Aggregate real investment	23.47	26.63	0.06	0.05	0.01	0.01
Government consumption	15.21	15.00	-0.10	-0.09	-0.01	-0.01
Inventories	1.07	1.05	0.02	0.02	0.00	0.00
Aggregate exports	43.21	42.61	0.08	0.07	0.03	0.03
Aggregate imports (C.I.F.)	41.56	40.98	0.00	0.00	0.00	0.00
Total	100.00	100.00			0.15	0.17

We go on to explore the source for the CPI rise. Table 4.16 lists significant contribution effects to CPI for both versions. Basically, commodities apart from gasoline and PTS show similar percentage changes in consumer prices. The price of gasoline rises sharply in version STD (8.62%, see Table 4.16), contributing 0.13% to the rise of CPI. In version DURA, the price rise in gasoline does not affect CPI directly in that households consume no gasoline. However, PTS made from gasoline, motor vehicles and other operating goods has a price rise of 3.09%. With a budget share of 5.24% in household expenditure, the price rise of PTS contributes 0.16% to the rise of CPI in version DURA. In other words, the price rise of gasoline is shifted indirectly to CPI through the price rise of the PTS.

Table 4.16 Significant contributions to the change in CPI

	Shares (A)		Percentage changes in (B)		Contributions (C) = [(A)/100] *(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Price indexes of	(%)	(%)	(%)	(%)	(%)	(%)
Gasoline	1.52	n/a	8.62	n/a	0.13	n/a
PTS	n/a	5.24	n/a	3.09	n/a	0.16
Land Transport	2.09	2.17	1.32	1.23	0.03	0.03
Gas	0.62	0.65	1.76	1.71	0.01	0.01
End Use Supplier	1.46	1.52	0.74	0.70	0.01	0.01
Air Transport	1.39	1.44	0.68	0.69	0.01	0.01

Table 4.17 Decomposition of the changes in purchasers' price of PTS in version DURA

	Cost shares (A)	Percentage changes in purchasers' price of (B)	Contributions (C) = [(A)/100]*(B)
	(%)	(%)	(%)
Gasoline	30.12	10.18	3.07
Diesel Fuel	0.17	6.27	0.01
Lubricants	0.76	1.67	0.01
Rubber Product	3.86	0.03	0.00
Hand Tools	0.01	0.05	0.00
Electric Appliances	0.07	-0.01	0.00
Light Equipment	0.15	0.00	0.00
Video and Radio	0.49	-0.00	0.00
Insurance	3.16	-0.13	-0.00
Vehicle Services	13.81	-0.03	-0.01
Primary Factors (Capital only)	47.40	0.01	0.00

Actually, the difference in CPI between both versions comes mainly from the distinction in the price changes of gasoline. The consumption share of gasoline by households (directly or indirectly) is similar in both versions. In version STD, households' budget share of gasoline is 1.52%. Note that in version DURA households' consumption of gasoline is moved to be one of PTS' intermediate inputs. Referencing the cost share of gasoline of the dummy PTS industry, we can calculate the *indirect* consumption share of gasoline by households in version DURA[28] via multiplying households' budget share of PTS by the dummy PTS industry's cost share of gasoline. The result is 1.58%[29]. In this way of calculation, the consumption shares of gasoline by households (directly and indirectly) are similar. So, it is the changes in the purchasers' price of gasoline for households in version STD and for PTS in version DURA that contribute to their difference in CPI. Table 4.16 indicates that the purchasers' price of gasoline for households increases by 8.62%, contributing a rise of 0.13% to CPI. Table 4.17 indicates that the purchaser price of gasoline for PTS increases by 10.18%, contributing 3.07% in the rise of its purchaser price. PTS' purchaser price in turn contributes a rise of 0.16%[30] to CPI.

[28] PTS is only provided for households in version DURA.

[29] Households' budget share of PTS is 5.24%, while PTS' cost share of gasoline is 30%. Hence, households' budget share of the indirect consumption of gasoline is 1.6%, similar to the budget share of the direct consumption of gasoline.

[30] We can approximate this contribution effect via multiplying households' indirect consumption share with the price change of gasoline: 1.6%*10.18% = 0.16%.

The changes in the purchaser price of gasoline differ between both versions because of the difference in substitution possibility. Demand for gasoline is less elastic in version DURA. Hence, in version DURA less reduction in gasoline demand contributes to a bigger price increase, while in version STD strong reduction in gasoline demand moderates the price increase.

In contrast to the general price rise induced by the petroleum tax, the government price index falls in both versions (see Table 4.15). This is not surprising since the government consumption is mainly composed of services from labour-intensive industries. Wages decline in both versions (see Table 4.8). We list in Table 4.18 the most significant contributions to government price index in the two versions.

Table 4.18 Significant contributions to the change in the government price index

	Shares (A)		Percentage changes in (B)		Contributions (C) = [(A)/100]*(B)	
Versions	STD	DURA	STD	DURA	STD	DURA
Price indexes of	(%)	(%)	(%)	(%)	(%)	(%)
Education Training Services	0.18	0.18	-0.27	-0.24	-0.05	-0.04
PAS	0.78	0.78	-0.06	-0.05	-0.04	-0.04
Social Welfare Services	0.02	0.02	-0.17	-0.14	-0.00	-0.00

CO_2 emissions

The petroleum tax causes CO_2 emissions to decrease by 1.09% in version STD and by 0.86% in version DURA. As can be seen in Table 4.19, the major source of difference in the CO_2 emissions between the two versions lies in the difference between household and PTS emissions. This is because the decrease in gasoline usage in version DURA is smaller.

The Steam_Coal, Steam_Gas and ComCy_Gas electricity-generators contribute significantly to overall CO_2 emissions growth, while CO_2 emissions from Steam_Oil, ComCy_Oil and Diesel reduce greatly and hence help curtail the economy-wide emission. We specified CES substitution between the 10 kinds of raw electricity for the electricity end-use supplier. Hence, demand for Steam_Oil and ComCy_Oil falls since their production costs are relatively higher than other raw electricity generating industries. Hence, CO_2 emissions from the production process in these two industries are largely reduced. On the other hand, Steam_Coal, Steam_Gas and CombCy_Gas are favoured due to their relative lower production costs. Hence, CO_2 emitted from these three industries increases.

Among the users listed in Table 4.19, households have a contribution of 0.23% to the reduction of total CO_2 emission in version STD, while in version DURA PTS only helps reduce the total CO_2 amount by 0.06%. This is the critical point that makes the distinction in the total CO_2 emission between the two versions.

Table 4.19 Significant contributions to the change in total CO_2 emissions

	Contributions to total CO_2 emissions	
Versions	STD	DURA
Households	**-0.23**	**n/a**
PTS	**n/a**	**-0.06**
Steam_Coal	2.77	2.59
Steam_Gas	0.14	0.13
CombCy_Gas	0.06	0.06
Diesel	-0.06	-0.06
CombCy_Oil	-1.12	-1.05
Steam_Oil	-2.30	-2.16
Oil Refinery	-0.11	-0.08

Tax revenue

The petroleum tax increases aggregate indirect tax revenue by around 6.7% in both versions. Among the sources of the tax revenue, tax revenue from production increases by 17.72% in version STD and 19.80% in version DURA. Tax revenue from households increase 6.96% in version STD, but only 0.24% in version DURA. Since we move parts of households' purchases of petroleum goods (those for transport purpose) to PTS in version DURA, households pay fewer taxes in version DURA. On the other hand, version DURA has a higher increase in aggregate tax revenue from production.

Tariff revenue in version STD decreases mainly because of the decrease in local demand for imported Fuel Oils, Diesel Fuel and Crude Oil. In version DURA, the decrease in imported Motor Vehicles makes tariff revenue fall further and hence causes the significant difference between two versions.

In this simulation, we do not impose the petroleum tax on exports. However, tax revenue from exports decreases in both versions. The improvement in terms of trade reduces Taiwanese exports in the world market, and hence tax revenue from exports decreases.

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CHAPTER 5
Ageing Gracefully: Identifying Vintages of Privately Owned Cars in TAIGEM

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5.1 Introduction

In this chapter, we introduce the second new version of TAIGEM—version TAIVINT. TAIVINT is created to account for the feature of "embodied technical change" in the car stock of the PTS industry set up in version DURA (introduced in Chapter 4). Cars with newer technologies (e.g., fuel-saving and low-emissions) take time to filter into the stock. Further, technological changes do not normally affect pre-existing cars. Like ORANI and MONASH, the standard TAIGEM only considers autonomous energy efficiency improvement (AEEI) and it is normally exogenous. As the standard TAIGEM does not distinguish vintages of capital, technological changes (i.e., shocks on the A variables) affect the whole stock of capital. This is not realistic.

In TAIVINT, we split the PTS industry into 11 sub-industries, each of which uses cars of the same age. These sub-industries produce vintage-specific private transport services (PTS) which we model as good, but not perfect, substitutes. Via this treatment, we identify the "embodied technical change". The scrapping of old cars and the additions of new and more fuel-efficient cars gradually change the fuel intensity of PTS production.

By introducing vintages, we allow the model to capture the following idea: assuming newer cars use less fuel, vehicle management policies that reduce the average service life of cars (e.g., mandatory scrapping of cars of certain age, and heavier taxes on old, gas-guzzling cars) will also help abate CO_2 emissions.

In Section 5.2 we introduce both the modification of the PTS industry's production structure and the database associated with the vintage distinction in TAIVINT. In addition to the vintage distinction, TAIVINT inherits the features of version DURA as introduced in Chapter 4. In Section 5.3, we run an illustrative simulation of motor fuel taxes with TAIVINT. We compare the results of TAIVINT, DURA and the standard TAIGEM.

5.2 Private transport services distinguished by vintages

In TAIVINT, we split the PTS industry into 11 sub-industries[1], divided according to car age. The vintages may have different technical characteristics such as fuel efficiency. We assume that cars of newer vintages have better fuel efficiency than older vintages. We allow the PTS industry to substitute private transport services produced by different vintages of cars. This leads to data modifications, described in

[1] The number of vintages (11) reflected the availability of car use survey data.

Section 5.2.1, and new equations, described in Section 5.2.2. Section 5.2.3 introduces the capital accumulation procedure for each vintage-specific PTS sub-industry. The transmission of vintage-specific embodied technology is described in Section 5.2.4.

5.2.1 Modifying the database to distinguish vintages

We disaggregate each input of the PTS industry into 11 categories to form the cost columns for the 11 vintage-specific sub-industries. We derive the shares for vintage disaggregation from usage survey of privately owned cars. Table 5.1 states sources of data used to subdivide the PTS industry into 11 vintages. (Appendix 5 describes the vintage disaggregation in more detail). Figure 5.1 shows the cost columns of the 11 sub-industries. CO_2 emissions and capital stock of the PTS industry are also disaggregated into 11 categories. We use the disaggregation shares for gasoline and diesel fuel to disaggregate CO_2 emissions of the PTS industry[2]. The capital stock is disaggregated according to the car number of different vintages. Figure 5.2 shows capital stock of the 11 vintage-specific sub-industries of PTS. Table 5.2 shows the cost structure of the 11 sub-industries. As the car numbers and vehicle-kilometres-travelled differ between vintages, the gasoline and diesel fuel shares of vintages do not reveal their relative fuel efficiency. We differentiate the fuel efficiencies of vintages via the vintage-specific technical change variables in TAIVINT. This is introduced in Section 5.2.4.

[2] That is, we assumed that in our initial data year:
(a) old and new cars released the same quantity of CO_2 per gallon of fuel used; and
(b) fuel prices were the same for old and new cars.

		Absorption Matrix											
		"PTS"×V											
	Size	Brand-New	1-Yr-Old	2-Yr-Old	3-Yr-Old	4-Yr-Old	5-Yr-Old	6-Yr-Old	7-Yr-Old	8-Yr-Old	9-Yr-Old	10-Yr-Old	Industry Total
Interm. Inputs, at Purch. Prices	C												
	"gasoline"	4108	9249	6443	7530	6083	5957	5908	4472	2582	1493	3423	57249
	"diesel fuel"	23	52	36	42	34	33	33	25	14	8	19	321
Labour	O	0	0	0	0	0	0	0	0	0	0	0	
Capital	1	6726	13823	12202	11612	9085	8707	8931	7221	4035	2246	5498	90087
Land	1	0	0	0	0	0	0	0	0	0	0	0	0
"Other Costs"	1	0	0	0	0	0	0	0	0	0	0	0	0
FCT	1	1364	2906	2739	2913	2424	2370	2381	1916	1187	700	1753	22653
VLT	1	1174	2502	2358	2508	2087	2040	2050	1650	1022	603	1510	19503
Sub-ind. Total Costs	1	15854	35157	28869	30109	23974	23505	23905	18849	10922	6237	14823	
Total Costs	1	*232204*											

Figure 5.1 The cost structure of the 11 vintage-specific sub-industries of PTS

	Vintage-specific capital stock										
	"PTS"×V										
	Brand-New	1-Yr-Old	2-Yr-Old	3-Yr-Old	4-Yr-Old	5-Yr-Old	6-Yr-Old	7-Yr-Old	8-Yr-Old	9-Yr-Old	10-Yr-Old
Capital stock (Million NT dollar)	226554	189991	179033	190435	158449	154895	155636	125279	77596	45758	114617

Figure 5.2 Vintage-specific capital stock of the PTS industry

Table 5.1 Sources of data used to subdivide the PTS industry into 11 vintages

I/O data of PTS, by vintages*	Description	Statistics Source: MOT(1998)
V1PURPTS_S(c,v)	Gasoline, Diesel Fuel, Lubricants	Average monthly fuel expenses
	Tyres, Vehicle Services, etc.	Average yearly expense on repair and maintenance + parking fee + cleaning expense
	Insurance	Average yearly expense on insurance
V1CAPPTS(v)	Value of car services	Asset values of cars by vintages, at 1994 price
V1VLTPTS(v)	License charge	Car numbers by vintages
V1FCTPTS(v)	Fuel consumption tax	Car numbers by vintages
CAPSTOKPTS(v)	Value of car stocks	Car numbers by vintages

* See Table 5.3 for the definitions of coefficients.

Table 5.2 Cost structures of the 11 vintage-specific sub-industries of PTS

	Vintages										
Inputs	New	1-YO	2-YO	3-YO	4-YO	5-YO	6-YO	7-YO	8-YO	9-YO	10-YO
Gasoline	25.9	26.3	22.3	25.0	25.4	25.3	24.7	23.7	23.6	23.9	23.1
Diesel Fuel	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lubricants	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Rubber Products	2.0	2.6	3.0	3.2	3.2	3.5	3.6	3.6	3.6	3.6	3.3
Metal Products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Machinery	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
House Electronic	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Video Radio	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.4
Insurance	5.2	5.6	2.6	2.4	1.8	1.5	1.3	1.3	1.2	1.1	1.3
Vehicle Services	7.3	9.4	10.9	11.5	11.5	12.4	13.0	12.3	13.0	13.0	11.9
Capital	42.4	39.3	42.3	38.6	37.9	37.1	37.4	38.3	37.0	36.0	37.1
VLT	7.4	7.1	8.2	8.3	8.7	8.7	8.6	8.8	9.4	9.7	10.2
FCT	8.6	8.3	9.5	9.7	10.1	10.1	10.0	10.2	10.9	11.2	11.8
Total	100	100	100	100	100	100	100	100	100	100	100

5.2.2 *The production structure of the 11 vintage-specific PTS sub-industries*

We modify the production structure of the PTS industry for the vintage distinction. Figure 5.3 shows the modified production structure of the PTS industry.

The vintage nest at level 1 shows the substitution between private transport services produced by cars of different vintages. We specify a value of 20 for the CES substitution elasticity[3]. When fuel prices rise, using older cars is more costly than using newer cars as we assume newer cars have better fuel efficiency than older cars.

The lower part of Figure 5.3 shows the production structure for each of the 11 sub-PTS industries. It is analogous to the production structure of the single PTS industry as shown in Figure 4.4 of Chapter 4. While for the single PTS industry, the capital stock comprised both old cars and new cars, for each sub-PTS industry of Figure 5.3, its capital stock refers to the cars acquired in the same year.

As shown in Figure 5.4, the total demand for each composite good g by the single PTS industry is the direct aggregation of the demands of the 11 sub-industries. That is, we do not distinguish basic values and purchaser's prices of inputs for the sub-industries. All sub-industries face the same input price, valued at purchaser's price, so the cost-minimising domestic-to-import ratio of goods is the same for all parts of the PTS industry.

We introduce below the linearised equations derived from the production structure of the PTS industry. Variables and coefficients, and ranges of sets are listed in Table 5.3.

[3] The high value (20) does not imply strong switching between vintages, since stocks of vintages are fixed in the short run. Rather, it implies that improvements in new cars are reflected fairly directly in lower rentals and asset prices for existing cars. By choosing a substitution elasticity less than ∞, we allow for the idea that consumers may have a special preference for, say, new cars, even if existing stocks of older cars are sufficient to meet transport needs.

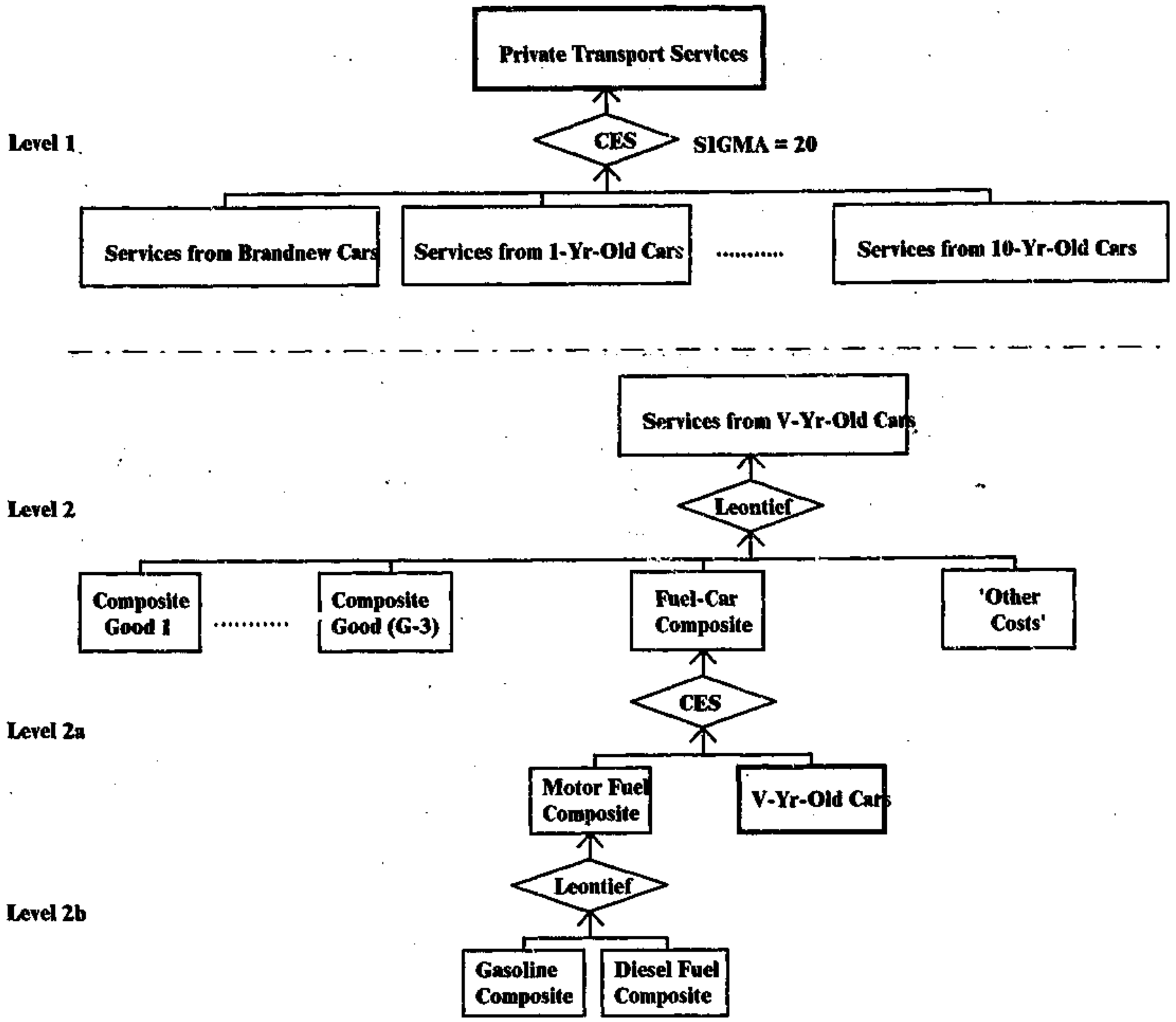


Figure 5.3 The Production Structure of the Sub-PTS industries by Vintages

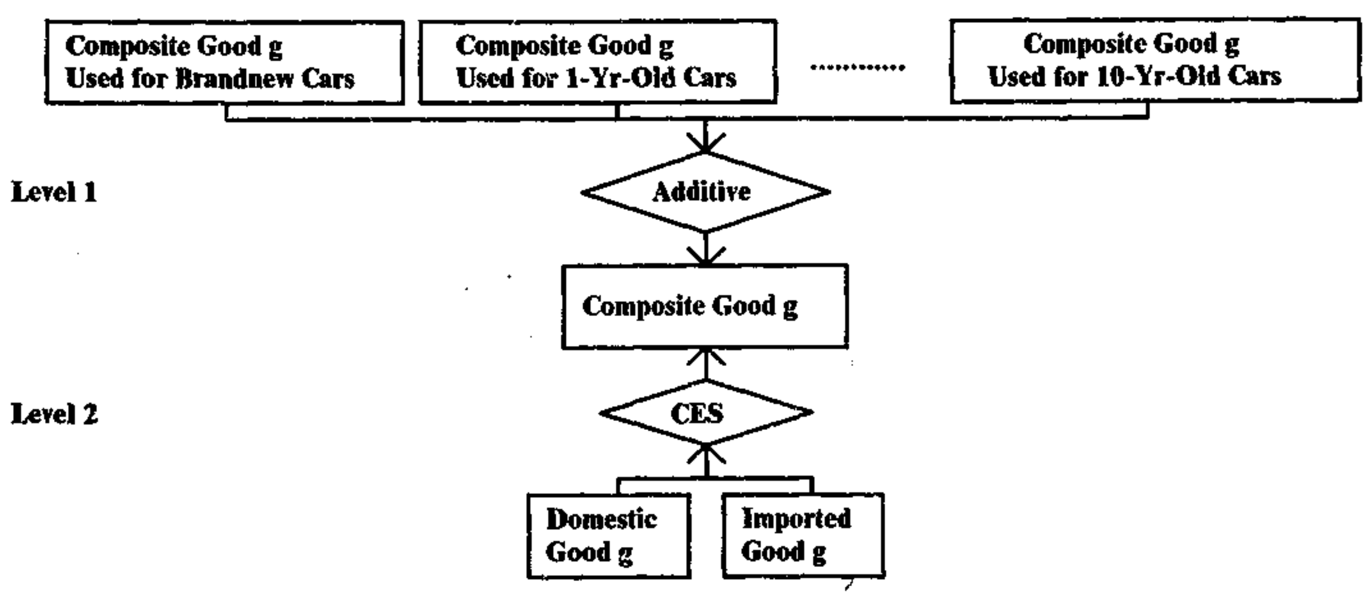


Figure 5.4 Demand of the PTS Industry for Composite Commodities

Table 5.3 New variables, coefficients and sets used in the demand equations of vintage-specific PTS sub-industries

Symbol	Description	Index and range
Set		
COM	refers to all commodities.	c
SRC	refers to two sources: domestic and imported.	s
MVPETROL	refers to motor fuels—gasoline and diesel fuel.	f
NONMVPETROL	= COM - MVPETROL.	c
VINTAGE	refers to all vintages (i.e., zero- to 10-year-old)	v
OLDVINTAGE	refers to vintages of cars other than brand-new.	v
Variable (percentage-change unless otherwise indicated)		
a1(c,s,"PTS")	The input-saving technical change of the PTS industry in using source-specific intermediate input c	c∈COM s∈SRC
a1capPTS(v)	The technical change variable in capital use of the vintage-specific (v) PTS sub-industry	v∈VINTAGE
a1fulprimPTS(v)	The input-saving technical change of the vintage-specific (v) PTS sub-industry in using the fuel-car composite	v∈VINTAGE
a1mvpetrol_f(v)	The input-saving technical change of the vintage-specific (v) PTS sub-industry in using the motor-fuel composite	v∈VINTAGE
a1octPTS(v)	The input-saving technical change of the vintage-specific (v) PTS sub-industry in using "other costs"	v∈VINTAGE
a1primPTS(v)	The input-saving technical change of the vintage-specific (v) PTS sub-industry in using the primary factor composite	v∈VINTAGE
a1PTS_s(c,v)	The input-saving technical change of the vintage-specific (v) PTS sub-industry in using source-composite intermediate input c	c∈COM v∈VINTAGE
a1tot("PTS")	The total factor-saving technical change of the PTS industry	

....continued

Table 5.3 (continued)

Symbol	Description	Index and range
a1vintserv(v)	The total factor productivity variable of the vintage specific (v) PTS sub-industry	v∈VINTAGE
delUnity("PTS")	An ordinary change variable, always shocked by 1.0 in year-on-year simulations	
delV1TOTPTS(v)	The ordinary change in the total cost of vintage-specific (v) private transport services	v∈VINTAGE
f1fctPTS(v)	Shifters in the vintage-specific (v) per-car rates of fuel consumption tax	v∈VINTAGE
f1vltPTS(v)	Shifters in the vintage-specific (v) per-car rates of vehicle license fees	v∈VINTAGE
faccumPTS(v)	Shifters to turn on/off the capital accumulation equations of the vintage-specific (v) PTS sub-industry	v∈VINTAGE
p1(c,s,"PTS")	The purchaser's price of source-specific intermediate input c paid by the PTS industry	c∈COM s∈SRC
p1_s(c,"PTS")	The purchaser's price of source-composite intermediate input c (common to all vintage-specific PTS sub-industries)	c∈COM
p1cap("PTS")	The aggregate rental price of all vintages of cars	
p1capPTS(v)	The rental price of cars of vintage v	v∈VINTAGE
p1fctPTS(v)	The vintage-specific (v) per-car rates of fuel consumption tax	v∈VINTAGE
p1fulprimPTS(v)	The cost-share weighted average of p1mvpetrol_f(v) and p1cappts(v)	v∈VINTAGE
p1mvpetrol_f(v)	The purchaser's price of the motor-fuel composite paid by the vintage-specific (v) PTS sub-industry	v∈VINTAGE
p1octPTS(v)	The unit prices of "other costs" tickets of the vintage-specific (v) PTS sub-industry	v∈VINTAGE
p1primPTS(v)	The cost-share weighted average price of primary factor used by the vintage-specific (v) PTS sub-industry	v∈VINTAGE
p1tot("PTS")	The average output price of the PTS industry	

....continued

Table 5.3 (continued)

Symbol	Description	Index and range
p1vintserv(v)	The unit price of the vintage-specific (v) private transport services	v∈VINTAGE
p1vltPTS(v)	The vintage-specific (v) per-car rates of vehicle license fees	v∈VINTAGE
x1(c,s,"PTS")	The demand by the PTS industry for good c from source s as an intermediate input	c∈COM s∈SRC
x1cap("PTS")	The total car stock of the PTS industry	
x1capPTS(v)	Car stock of vintage v available for use in the current period	v∈VINTAGE
x1fctPTS(v)	The tax bases of the fuel consumption tax, i.e., The stock of cars of vintage v	v∈VINTAGE
x1fulprimPTS(v)	The demand of the vintage-specific (v) PTS sub-industry for the fuel-car composite	v∈VINTAGE
x1mvpetrol_f(v)	The demand by the vintage-specific (v) PTS sub-industry for the motor-fuel composite	v∈VINTAGE
x1octPTS(v)	The demand of the vintage-specific (v) PTS sub-industry for "other costs"	v∈VINTAGE
x1primPTS(v)	The demand of the vintage-specific (v) PTS sub-industry for the primary factor composite	v∈VINTAGE
x1PTS_s(c,v)	The demand by the vintage-specific (v) PTS sub-industry for source-composite good c as an intermediate input	c∈COM v∈VINTAGE
x1tot("PTS")	The output of the PTS industry	
x1vintserv(v)	The output of the vintage-specific (v) PTS sub-industry	v∈VINTAGE
x1vltPTS(v)	The tax bases of the vehicle license fees, i.e., The stock of cars of vintage v	v∈VINTAGE
x2tot("PTS")	Investment of the PTS industry = purchases of brand-new cars	

....continued

Table 5.3 (continued)

Symbol	Description	Index and range
Coefficient		
AF(c,v)	Input-using technological coefficient for good c used by the vintage-specific PTS sub-industry	c∈COM v∈VINTAGE
AFini(c,v)	The initial value of AF(c,v)	c∈COM v∈VINTAGE
AK(v)	Capital-using technological coefficient of the vintage-specific PTS sub-industry	v∈VINTAGE
AKini(v)	The initial value of AK(v)	v∈VINTAGE
CAPADDOLDCAR(v)	Net additions to the capital stock of the vintage-specific (v) PTS sub-industry	v∈VINTAGE
CARCAP(v)	The stock of v year-old cars	v∈VINTAGE
$CARCAP^{ini}(v)$	The stock of v year-old cars at the start of last year	v∈VINTAGE
DPRCPTS(v)	The depreciation rate for cars of vintage v	v∈VINTAGE
INVRATIOAF(c,v)	$=\frac{AF(c,v)}{AFini(c,v)}$	c∈COM v∈VINTAGE
INVRATIOAK(v)	$=\frac{AK(v)}{AKini(v)}$	v∈VINTAGE
QCARCAPOLD(v)	The stock of v year-old cars (excluding new cars), valued at last year's prices	v∈OLDVINTAGE
SIGMA1(c)	The Armington substitution elasticity between domestic and imported good c	c∈COM
SIGMA1FUPRIM(v)	The elasticity of substitution between the motor-fuel composite and cars of vintage v, which is set at 0.2.	v∈VINTAGE
SIGMAVINT	The elasticity of substitution between vintage-specific private transport services, which is set at 20.	
V1CAPPTS(v)	The capital rental value of vintage-specific (v) PTS sub-industry	v∈VINTAGE
V1FCTPTS(v)	The fuel consumption taxes paid by vintage-specific (v) PTS sub-industry	v∈VINTAGE

....continued

Table 5.3 (continued)

Symbol	Description	Index and range
V1OCTPTS(v)	The "other-costs" tickets of vintage-specific (v) PTS sub-industry	v∈VINTAGE
V1PUR(c,s,"PTS")	The value, at purchaser's price, of source-specific intermediate input c used by the PTS industry	c∈COM s∈SRC
V1PUR_S(c,"PTS")	$=\sum_{s\in SRC}$ V1PUR(c,s,"PTS").	c∈COM
V1PURPTS_S(c,v)	The value, at purchaser's price, of intermediate input c used by vintage-specific PTS sub-industry	c∈COM v∈VINTAGE
V1TOTPTS(v)	The total cost of vintage-specific (v) private transport services	v∈VINTAGE
V1VLTPTS(v)	The vehicle license fees (VLT) paid by vintage-specific (v) PTS sub-industry	v∈VINTAGE

Demands for source-specific intermediate inputs, X1(c,s,"PTS"), including motor fuels—gasoline and diesel fuel

(see also the source nest at Level 2 of Figure 5.4)

As mentioned previously, we do not distinguish source-specific intermediate input demands (x1(c,s,"PTS")) by vintages. The equations for x1(c,s,"PTS") and p1_s(c,"PTS") are the same as introduced in Chapter 4 (see Equations 4.1 and 4.2). For reader's convenience, we list them again as follows.

$$\mathrm{x1(c,s,"PTS") = x1\_s(c,"PTS") + RS1(c,s,"PTS")*\{twistsrc(c)+ twistsrc\_c - SIGMA1(c)*[p1(c,"dom","PTS") - p1(c,"imp","PTS")]\}}, \quad c \in \mathrm{COM},\ s \in \mathrm{SRC}. \quad (5.1)$$

$$\mathrm{p1\_s(c,"PTS") = RS1(c,"dom","PTS")*p1(c,"imp","PTS") - RS1(c,"imp","PTS")*p1(c,"dom","PTS")}, \quad c \in \mathrm{COM}, \quad (5.2)$$

where

$$\mathrm{RS1(c,"dom","PTS")} = \left(\frac{\mathrm{V1PUR(c,"imp","PTS")}}{\mathrm{V1PUR\_S(c,"PTS")}}\right), \text{ and}$$

$$\mathrm{RS1(c,"imp","PTS") = RS1(c,"dom","PTS") - 1} = -\left(\frac{\mathrm{V1PUR(c,"dom","PTS")}}{\mathrm{V1PUR\_S(c,"PTS")}}\right), \quad c \in \mathrm{COM}.$$

Demands for motor fuels (gasoline and diesel fuel) by vintages, X1PTS_S(f,v)

(see also the motor-fuel composite nest at Level 2b of Figure 5.3)

$$\mathrm{x1PTS\_s(f,v) - [a1PTS\_s(f,v) + a1mvpetrol\_f(v)] = x1mvpetrol\_f(v)}, \quad f \in \mathrm{MVPETROL},\ v \in \mathrm{VINTAGE}. \quad (5.3)$$

$$\mathrm{p1mvpetrol\_f(v) - a1mvpetrol\_f(v)} = \sum_{f \in \mathrm{MVPETROL}} \left(\frac{\mathrm{V1PURPTS\_S(f,v)}}{\sum_{f \in \mathrm{MVPETROL}} \mathrm{V1PURPTS\_S(f,v)}}\right) \mathrm{*[p1\_s(f,"PTS") + a1PTS\_s(f,v)]}, \quad v \in \mathrm{VINTAGE}. \quad (5.4)$$

Equation 5.3 indicates that gasoline and diesel fuel (in set MVPETROL) are purchased in fixed proportions for each vintage-specific sub-industry. This is an arbitrary assumption as our vintage data do not distinguish between cars fuelled by gasoline and cars fuelled by diesel fuel.

Equation 5.4 defines the cost-share weighted average price of the motor-fuel composite used by the vintage-specific (v) PTS sub-industry (p1mvpetrol_f(v)).

Demands for the motor-fuel composite by vintages, X1MVPETROL_F(v)

(see also the fuel-car composite nest at Level 2a of Figure 5.3)

$$\mathrm{x1mvpetrol\_f(v) - a1mvpetrol\_f(v) = x1fulprimPTS(v) - SIGMA1FUPRIM*[p1mvpetrol\_f(v) + a1mvpetrol\_f(v) - p1fulprimPTS(v)]}, \quad v \in \mathrm{VINTAGE}. \quad (5.5)$$

$$\mathrm{p1fulprimPTS(v) = S1FUELPTS(v)*[p1mvpetrol\_f(v) + a1mvpetrol\_f(v)] + [1.0 - S1FUELPTS(v)]*[p1primPTS(v) + a1primPTS(v) + a1prim\_i]}, \quad v \in \mathrm{VINTAGE}, \quad (5.6)$$

where

$$\mathrm{S1FUELPTS(v)} = \left(\frac{\sum_{f \in \mathrm{MVPETROL}} \mathrm{V1PURPTS\_S(f,v)}}{\mathrm{V1CAPPTS(v)} + \sum_{f \in \mathrm{MVPETROL}} \mathrm{V1PURPTS\_S(f,v)}}\right).$$

Equation 5.5 states the substitution between motor-fuel composite (X1MVPETROL_F(v)) and cars of vintage v (X1CAPPTS(v) or X1PRIMPTS(v)). We specify a value of 0.2 for SIGMA1FUPRIM. The demand for cars of vintage v is determined by Equation 5.8.

In the TABLO code, we use the variable, x1capPTS(v), for percentage changes in the car stock of vintage v. For general purposes, we have equations for the substitution between capital, labour and land. As the PTS industry does not use labour nor land in production, x1primPTS(v) is identical to x1capPTS(v). Analogously, p1primPTS(v) is identical to p1capPTS(v). Here, we only present partially the capital-labour-land substitution equation blocks where x1capPTS(v) appears (see Equation 5.7). Equation 5.6 defines the price of the fuel-car composite as a cost-share weighted average of p1mvpetrol_f(v) and p1capPTS(v) (or p1primPTS(v)).

$$\mathrm{x1capPTS(v) - a1capPTS(v) = x1primPTS(v) - SIGMA1PRIM("PTS")*[p1capPTS(v) + a1capPTS(v) - p1primPTS(v)]}, \quad v \in \mathrm{VINTAGE}. \quad (5.7)$$

The demand for cars of vintage v, X1PRIMPTS(v) or X1CAPPTS(v)

$$\mathrm{x1primPTS(v) - [a1primPTS(v) + a1prim\_i\ ] = x1fulprimPTS(v) - SIGMA1FUPRIM*[p1primPTS(v) + a1primPTS(v) + a1prim\_i - p1fulprimPTS(v)]}, \quad v \in \mathrm{VINTAGE}. \quad (5.8)$$

The demand for non-motor-fuel composite by vintages, X1PTS_S(v)

(see also the intermediate input nest at Level 2 of Figure 5.3)

$$\mathrm{x1PTS\_s(c,v) - [a1PTS\_s(c,v) + a1vintserv(v)] = x1vintserv(v)}, \quad c \in \mathrm{NONMVPETROL},\ v \in \mathrm{VINTAGE}. \quad (5.9)$$

Equation 5.9 states the fixed-proportion relationships of non-motor-fuel inputs (X1PTS_S(v)) to the vintage-specific output (X1VINTSERV(v)). The fuel-car composite demand is also in fixed proportion to x1vintserv(v). This is shown next in Equation 5.10.

The demand for the car-fuel composite by vintages, X1FULPRIMPTS(v)

(see also the fuel-car composite nest at Level 2 of Figure 5.3)

$$\text{x1fulprimPTS}(v) - [\text{a1fulprimPTS}(v) + \text{a1vintserv}(v)] = \text{x1vintserv}(v), \quad v \in \text{VINTAGE}. \quad (5.10)$$

PTS total demands for intermediate inputs, X1PTS_SV(c) or X1_S("PTS")

(see also the vintage-aggregate nest at Level 1 of Figure 5.4)

$$\text{x1PTS\_sv}(c) = \sum_{v \in \text{VINTAGE}} \left(\frac{\text{V1PURPTS\_S}(c,v)}{\sum_{v \in \text{VINTAGE}} \text{V1PURPTS\_S}(c,v)} \right) * \text{x1PTS\_s}(c,v), \quad c \in \text{COM}. \quad (5.11)$$

$$\text{x1PTS\_sv}(c) = \text{x1\_s}(c,\text{"PTS"}), \quad c \in \text{COM}. \quad (5.12)$$

The PTS total demand for intermediate input c (X1PTS_SV(c)) is the sum of vintage-specific demands (X1PTS_S(c,v)). Hence, Equation 5.11 shows that x1PTS_sv(c) is the vintage-share $\left(\frac{\text{V1PURPTS\_S}(c,v)}{\sum_{v \in \text{VINTAGE}} \text{V1PURPTS\_S}(c,v)} \right)$ weighted average of x1PTS_s(c,v). Equation 5.12 simply links x1PTS_sv(c) to x1_s(c,"PTS"), as appeared in Equation 5.1.

The demand for "other-costs" tickets by vintages, X1OCTPTS(v)

(see also the intermediate input nest at Level 2 of Figure 5.3)

$$\text{x1octPTS}(v) - [\text{a1octPTS}(v) + \text{a1vintserv}(v)] = \text{x1vintserv}(v), \quad v \in \text{VINTAGE}. \quad (5.13)$$

The demand for "Other-costs" tickets by the vintage-specific (v) PTS sub-industry (X1OCTPTS(v)) is also assumed to be in fixed proportion to the vintage-specific output (X1VINTSERV(v)). We assume that all vintage-specific PTS sub-industries face the same price of "Other-costs", i.e., P1OCTPTS(v) = P1OCT("PTS").

Fuel consumption tax (FCT) and vehicle license fees (VLT) by vintages

$$\text{x1vltPTS}(v) = \text{x1capPTS}(v), \quad v \in \text{VINTAGE}. \quad (5.14)$$

$$\text{x1fctPTS}(v) = \text{x1capPTS}(v), \quad v \in \text{VINTAGE}. \quad (5.15)$$

$$\text{p1vltPTS}(v) = \text{p3tot} + \text{f1vltPTS}(v), \quad v \in \text{VINTAGE}. \quad (5.16)$$

$$\text{p1fctPTS}(v) = \text{p3tot} + \text{f1fctPTS}(v), \quad v \in \text{VINTAGE}. \quad (5.17)$$

Equations 5.14 and 5.15 show that the vintage-specific car stock (X1CAPPTS(v)) is the tax base of vehicle license fees (VLT) (X1VLTPTS(v)) and fuel consumption tax (FCT) (X1FCTPTS(v)). Recall that the oddly-named FCT (fuel consumption tax) is actually an annual charge on car ownership, not a direct fuel consumption tax. We assume that the rates of these two per-car taxes are CPI indexed, as indicated in Equations 5.16 and 5.17. f1vltPTS(v) and f1fctPTS(v) are shifters, which can be used to impose vintage-differentiated rates of charges on car ownership.

The demand for vintage-specific by vintages, X1VINTSERV(v)

(see also the vintage composite nest at Level 1 of Figure 5.3)

$$\text{x1vintserv}(v) - [\text{a1vintserv}(v) + \text{a1tot}(\text{"PTS"})] = \text{x1tot}(\text{"PTS"}) - \text{SIGMAVINT}*[\text{p1vintserv}(v) + \text{a1vintserv}(v) - \text{p1tot}(\text{"PTS"})], \quad v \in \text{VINTAGE}. \quad (5.18)$$

Equation 5.18 indicates the imperfect substitution between vintage-specific private transport services. As mentioned previously, the value of SIGMAVINT is set to 20.

The vintage-specific average input price (P1VINTSERV(v)) is defined as the cost-share weighted average of all inputs and primary factors. The TABLO code for p1vintserv(v) is shown as follows.

$$\text{V1TOTPTS}(v)*[\text{p1vintserv}(v) + \text{x1vintserv}(v)] = 100*\text{delV1TOTPTS}(v), \quad v \in \text{VINTAGE}. \quad (5.19)$$

V1TOTPTS(v) is the total cost of vintage-specific PTS output. delV1TOTPTS(v) indicates ordinary changes in V1TOTPTS(v), and is defined as follows.

$$\begin{aligned} \text{delV1TOTPTS}(v) = {} & 0.01*\text{V1CAPPTS}(v)*[\text{p1capPTS}(v) + \text{x1capPTS}(v)] + \\ & 0.01* \sum_{c \in \text{COM}} \text{V1PURPTS\_S}(c,v)*[\text{p1\_s}(c,\text{"PTS"}) + \text{x1PTS\_s}(c,v)] + \\ & 0.01*\text{V1OCTPTS}(v)*[\text{p1octPTS}(v) + \text{x1octPTS}(v)] + \\ & 0.01*\text{V1VLTPTS}(v)*[\text{x1vltPTS}(v) + \text{p1vltPTS}(v)] + \\ & 0.01*\text{V1FCTPTS}(v)*[\text{x1fctPTS}(v) + \text{p1fctPTS}(v)], \quad v \in \text{VINTAGE}. \quad (5.20) \end{aligned}$$

Equation 5.21 below sums vintage-specific PTS output to define the average price of PTS (p1tot("PTS")).

$$\text{V1TOT}(\text{"PTS"})*[\text{p1tot}(\text{"PTS"}) - \text{a1tot}(\text{"PTS"})] = \sum_{v \in \text{VINTAGE}} \text{V1TOTPTS}(v)*[\text{p1vintserv}(v) + \text{a1vintserv}(v)]. \quad (5.21)$$

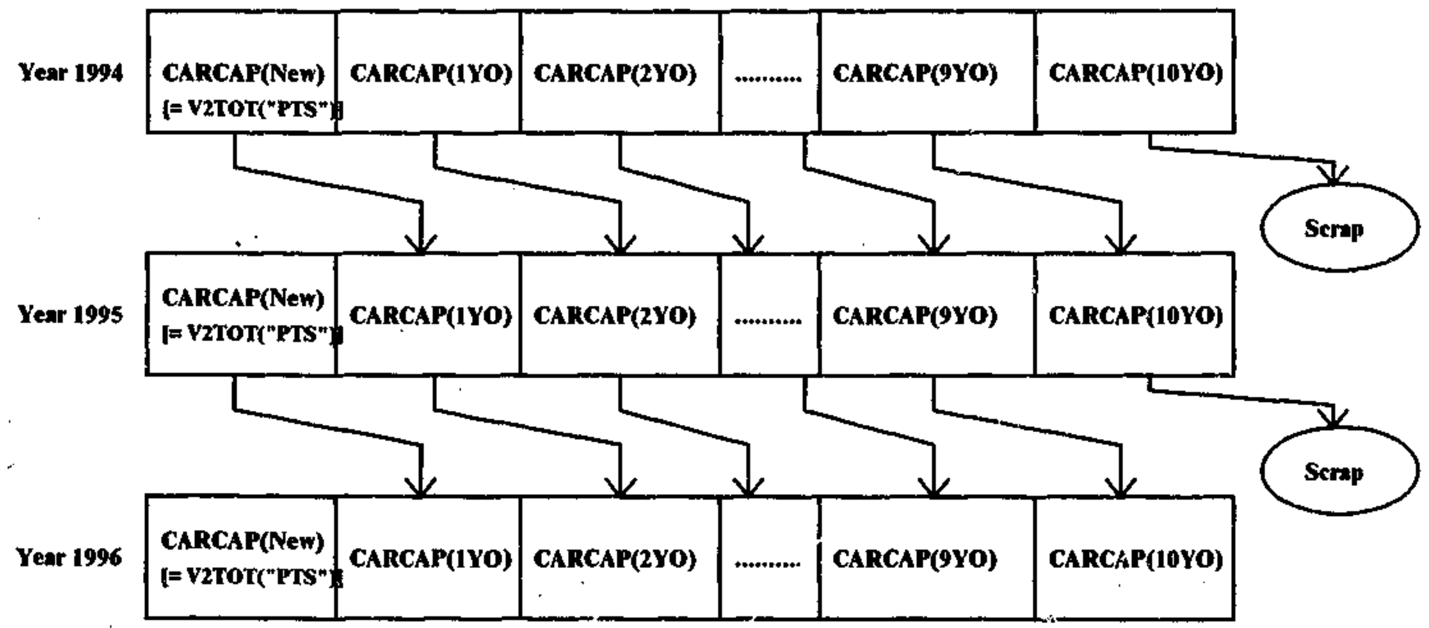
5.2.3 *Recursively annual transmission of car stock of vintages*

As stated previously, the capital stock of each sub-PTS industry consists of cars of a specific age. We need to modify the capital accumulation formula of each vintage-specific sub-PTS industry.

Figure 5.5 illustrates the transmission procedure of ageing vintage-specific car capital from year to year. New cars of this year are transmitted to the next year as one-year-old cars; one-year-old cars of this year are transmitted to the next year as two-year-old cars, and so forth. For each year, we identify 11 vintages of cars, ranging from zero-year-old (brand-new) to ten-year-old. As we assume no 'gestation lag' for new cars to yield services, new-car capital (CARCAP(New)) is equal to the investment of the PTS industry (V2TOT("PTS")). Our base data refers to the year 1994. One-year-old cars in 1994 will become two-year-old cars in 1995, and so forth. We assume that cars are scrapped after ten years of use. We write the following formulae to count the car stock of vintage v available for use in year t.

$$CARCAP_t(\text{"New"}) = V2TOT_t(\text{"PTS"}),$$
$$CARCAP_t(\text{"1YO"}) = [1 - DPRCPTS(\text{"New"})]*CARCAP_{t-1}(\text{"New"}),$$
$$CARCAP_t(\text{"2YO"}) = [1 - DPRCPTS(\text{"1YO"})]*CARCAP_{t-1}(\text{"1YO"}),$$
....
$$CARCAP_t(\text{"10YO"}) = [1 - DPRCPTS(\text{"9YO"})]*CARCAP_{t-1}(\text{"9YO"}).$$

$CARCAP_t(v)$ is the car capital of vintage v in year t, with v referring to 11 vintages (ranging from "New" to "10YO"). $V2TOT_t(\text{"PTS"})$ is investment of the PTS industry (i.e., new-car purchases) in year t. DPRCPTS(v) is the rate of depreciation for cars vintage v. In our simulations presented here, we assume a rate of 12% for all DPRCPTS(v). We may specify different depreciation rates for different vintages of cars. 10 year-old cars are scrapped (their depreciation rate is 100%).



(and so on for the subsequent years.)

Figure 5.5 Recursively annual transmission of vintage-specific car stock

The year-to-year percentage-change capital transmission equations in TABLO code are set out as follows.

$$0.01*QCARCAPOLD(v)*x1capPTS(v) = CAPADDOLDCAR(v)*delUnity + faccumPTS(v), \quad v \in OLDVINTAGE. \quad (5.22)$$

Equations 5.22[4] determines percentage changes in the capital stock of cars other than new ones (i.e., x1capPTS(v), for v∈OLDVINTAGE). QCARCAPOLD(v) is the car stock of old vintage v in use during the current year, valued at last year's prices. In a multi-step computation, QCARCAPOLD(v) is updated by the percentage-change quantity variable, x1capPTS(v), for v∈OLDVINTAGE, but not adjusted to changes in asset prices. The same as introduced in Chapters 3 and 4, delUnity is an ordinary change variable, which is always set exogenous and shocked at 1.0 when running year-on-year (dynamic) simulations. The shift variable, faccumPTS(v), is set exogenous (endogenous) to turn on (off) Equation 5.22.

CAPADDOLDCAR(v) is the net addition to the car stock of old vintage v. In TABLO, CAPADDOLDCAR(v) is defined as follows:

$$CAPADDOLDCAR(\text{"1YO"}) = [1 - DPRCPTS(v)]*V2TOT^{ini}(\text{"PTS"}) - CARCAP^{ini}(\text{"1YO"}),$$
$$CAPADDOLDCAR(\text{"2YO"}) = [1 - DPRCPTS(v)]*CARCAP^{ini}(\text{"1YO"}) - CARCAP^{ini}(\text{"2YO"}),$$
....
$$CAPADDOLDCAR(\text{"10YO"}) = [1 - DPRCPTS(v)]*CARCAP^{ini}(\text{"9YO"}) - CARCAP^{ini}(\text{"10YO"}). \quad (5.23)$$

CAPADDOLDCAR(v) is evaluated with the initial values of its constituents (with superscript "ini") but not updated in a multi-step computation. $CARCAP^{ini}(v)$ is the car stock of old vintage v at the start of last year. $V2TOT^{ini}(v)$ is the new-car acquisition in last year.

The percentage change in new-car stock (i.e., x1capPTS("New")) is identical to the investment growth of the PTS industry. This is indicated in Equation 5.24. faccumPTS("New") is a shifter variable: set as exogenous (endogenous) to turn on (off) Equation 5.24.

$$x1capPTS(\text{"New"}) = x2tot(\text{"PTS"}) + faccumPTS(\text{"New"}) \quad (5.24)$$

Equation 5.25 indicates that the total capital stock of the PTS industry is the sum of the car stocks of all vintages. We use rental shares as weights for this aggregation. Equation 5.26 defines the percentage change in the rental price of the PTS industry (p1cap("PTS")) as the rental-share weighted average of vintage-specific rental prices (p1capPTS(v)).

[4] As Equation 5.22 applies to old vintages of cars, it is similar to Equation 4.12 in Chapter 4.

$$x1cap("PTS") = \sum_{v\in VINTAGE}\left(\frac{V1CAPPTS(v)}{\sum_{v\in VINTAGE} V1CAPPTS(v)}\right)*x1capPTS(v). \quad (5.25)$$

$$p1cap("PTS") = \sum_{v\in VINTAGE}\left(\frac{V1CAPPTS(v)}{\sum_{v\in VINTAGE} V1CAPPTS(v)}\right)*p1capPTS(v). \quad (5.26)$$

The mechanism to determine the investment of the PTS industry (i.e., purchases of new cars) is the same as that for other industries. See Section 3.9 of Chapter 3 for details[5].

5.2.4 *Transmission of embodied technology of vintages*

In recursive dynamic simulations, the embodied technology of vintage-specific cars is transmitted from year to year as cars age. We add the following equations to govern this.

For intermediate inputs:

$$INVRATIOAF(c,v)*a1PTS\_s(c,v) = 100*\left(\left(\frac{AFini(c,v\text{-}1)}{AFini(c,v)}\right) - 1\right)*delUnity, \quad c\in COM,\ v\in OLDVINTAGE, \quad (5.27)$$

where

$$INVRATIOAF(c,v) = \frac{AF(c,v)}{AFini(c,v)}, \quad c\in COM,\ v\in OLDVINTAGE.$$

For car capital:

$$INVRATIOAK(v)*a1capPTS(v) = 100*\left(\left(\frac{AKini(v\text{-}1)}{AKini(v)}\right) - 1\right)*delUnity, \quad v\in OLDVINTAGE, \quad (5.28)$$

where

$$INVRATIOAK(v) = \frac{AK(v)}{AKini(v)}, \quad v\in OLDVINTAGE.$$

Index v-1 refers to the vintage one year newer than vintage v.

For the initial vintage structure, we assume that cars purchased in year T are 1% more efficient in fuel consumption than cars purchased in year T-1. In the base-year (1994) data, the technological coefficient of fuel consumption by brand-new cars may be arbitrarily set to one, i.e., AFini(f,"New") = 1.0, f∈MVPETROL. AFini(f,"1YO") is set as 1.01; AFini(f,"2YO") is set as 1.0201; and so forth. Variable a1PTS_s(f,v) measures the annual percentage change in the fuel-using technology coefficient, AF(f,v). AF(f,v) is updated stepwise by a1PTS_s(f,v) in the multi-step computation procedure. The homotopy variable, delUnity, governs the transmission of AF(f,v) of a newer vintage to an older vintage in the annually recursive simulations. delUnity is defined as an ordinary change variable and is always shocked at one.

[5] An implication is that we relate PTS investment—purchases of new cars—to the average rental price of all cars. An alternative, which could be explored in future work, would be to relate new car purchases to the rental value of new cars only.

With this design, AF(f,v) for vintages other than brand-new one (i.e., v∈OLDVINTAGE) is endogenously determined in recursive dynamic simulations. Beyond 1994, values of AFini(c,v) are read in from the updated AF(c,v) of the previous year run. That is, values for AFini(c,v) of year T are equal to the updated AF(c,v) of year T-1.

In running recursive dynamic simulations, we shock the fuel-using technology of new cars, a1PTS_s(f,"New"), to reflect the fuel efficiency improvement of new cars. To be consistent with the annual transmission of ageing vintage-specific car stock, Equation 5.27 assures that v year-old cars in year t is 1% more fuel-efficient than v year-old cars in year t-1. We could also shock a1PTS_s(c,v) to simulate greater needs for non-motor-fuel commodities, such as tyres.

Table 5.4 demonstrates the initial values of AF(c,v) in some years of the recursive simulations where a1PTS_s(f,"New") is either shocked at a non-zero value or not shocked. Column (A) shows the initial values of AF(c,v)—i.e., AFini(c,v)—in the 1995 run. They are read in from the base data of 1994 and reveal our assumption for relative fuel efficiency of vintages in 1994 as mentioned above. Column (B) shows the initial values of AF(c,v) in the 1996 run, with shocks on a1PTS_s(c,"New") in 1995. Hence, the initial values of AF(c,"New") in the 1996 run is 0.99. This indicates that new cars purchased in 1995 are 1% more fuel-efficient than new cars purchased in 1994—one-year-old cars in 1995. Columns (C) and (D), respectively, show the initial values of AF(c,v) in the 1999 run, with and without shocks on a1PTS_s(c,"New") from 1995 through 1998.

AK(v), AKini(v) and a1capPTS(v) function analogously to the above demonstration for input-saving technological change. In most of our simulations, AK(v) of all vintages are set at unity in the 1994 base data and we do not shock a1capPTS(v) in the whole period of simulations.

Table 5.4 Demonstration of the values of AF(c,v) in recursive dynamic simulations

	Initial values for the input-saving technological coefficient, AF(c,v), in year t:			
Year t	1995	1996	1999	
Vintages	(read from the 1994 base data)	With a1PTS_s(c,"New") of 1995 = -1.0	With a1PTS_s(c,"New") of 1995-1998 = -1.0	With a1PTS_s(c,"New") of 1995-1998 = 0.0,
Row/column identifier	(A)	(B)	(C)	(D)
(1) New	***1.0000***	0.9900	0.9606	1.0000
(2) 1YO	1.0100	***1.0000***	0.9703	1.0000
(3) 2YO	1.0201	1.0100	0.9801	1.0000
(4) 3YO	1.0303	1.0201	0.9900	1.0000
(5) 4YO	1.0406	1.0303	***.0000***	***1.0000***
(6) 5YO	1.0510	1.0406	1.0100	1.0100
(7) 6YO	1.0615	1.0510	1.0201	1.0201
(8) 7YO	1.0721	1.0615	1.0303	1.0303
(9) 8YO	1.0829	1.0721	1.0406	1.0406
(10) 9YO	1.0937	1.0829	1.0510	1.0510
(11) 10YO	1.1046	1.0937	1.0615	1.0615

5.3 An illustrative recursive dynamic simulations: an increase in motor fuel tax

We ran an illustrative recursive dynamic simulation of motor fuel taxes with the three versions of TAIGEM—STD, DURA and TAIVINT. We impose a 15% *ad valorem* tax in 2003 on purchases of motor fuels for private transport purposes—gasoline and diesel fuel purchased by households of version STD and by the PTS industry of versions DURA and TAIVINT.

Section 5.3.1 describes the closure setting and the scenarios for the recursive dynamic simulations. In Section 5.3.2 we report the results of the motor-fuel tax simulations as percentage deviations from control. We discuss the differences between the results of STD, DURA and TAIVINT.

5.3.1 Closures and scenarios

(A) Closures and scenarios for the business-as-usual forecasting simulations

In doing the business-as-usual (henceforth, BAU) forecasting simulations, we recognised two periods. The first period, covering recent history, is from 1995[6] to 2002.

6 The base-year database we use refers to 1994.

The second period is from 2003 to 2027. Recursive dynamic simulations require one closure for each year. We use the same closure for the first eight years (i.e., 1995 to 2002) and an alternative closure for 2003 and subsequent years.

For the historical 1995-2002 period, we exogenise and shock some TAIGEM variables by their growth rates obtained from external sources. Examples are components of GDP, GDP deflator, aggregate export and import volumes and aggregate employment. Table 5.5 shows main the macroeconomic values of 1995-2002 used in the BAU simulations. We also shock variables for technology progress and household preferences to account for government set targets of autonomous energy efficiency improvements. These settings direct the BAU forecasting simulations to produce a sensible business-as-usual economic growth path which agrees with specialist forecasts of this period. The penultimate row of Table 5.5 shows GDP growth rates of 1995-2002 produced in our BAU simulations.

To accommodate these macroeconomic forecasts of 1995-2002 in the BAU forecasting simulations, we need to swap the corresponding TAIGEM variables with other naturally exogenous variables as in comparative static simulations. We endogenise overall factor productivity while all components of GDP in both expenditure and income sides are exogenised. The last row of Table 5.5 shows the 1995-2002 growth rates of overall factor productivity endogenously determined in the BAU simulations (negative numbers reflect progress; 2001 was a bad year for electronic exports). We also put into the model values for both export prices and volumes. Therefore, we endogenise the shifter variables f4q(c) (see Equations 3.102, 3.105, and 3.110 of Chapter 3) so as to locate the export demand schedule consistent with these forecasts.

For the second, post-shock, period (2003 onwards), we set the closure similar to those used for conventional comparative static simulations. That is, aggregate consumption, aggregate investment, and government expenditure are endogenous while naturally exogenous variables, such as the position of foreign demand curves, are exogenous. We assume the economy will attain a balanced annual growth of 3% in the long run via specifying a 1% annual growth of labour force and a 2% annual growth of overall factor productivity from 2003 onwards. We also assume that CPI rises 1% per annum and number of households grows 2% each year.

(B) Closures for the perturbed forecasting simulations

In doing the perturbed forecasting simulations, we produce a path that shows the deviation of the economy away from its BAU path due to the additional policy shock. In this illustrative simulation, a 15% *ad valorem* tax on gasoline and diesel fuel consumed by households (version STD) or the PTS industry (versions DURA and

TAIVINT). We use in the perturbed simulations the same set of annual closures as in the BAU forecasting simulations. Note that our shock is imposed post 2003—where we used a typical policy closure for the BAU case.

Table 5.5 Main macroeconomic forecasts of 1995-2002 for the BAU simulations

	Year							
Annual growth rates of:	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Aggregate employment	1.23	0.22	1.21	1.20	1.08	1.06	-1.15	1.00
Labour force	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Aggregate import price index	9.51	-1.85	-0.11	2.30	-3.12	4.34	-0.96	0.08
Aggregate export price index	6.53	1.29	1.26	3.88	-6.19	-0.27	-0.18	0.20
Nominal exchange rate	0.07	3.50	4.19	14.37	-3.55	-3.44	6.00	-1.50
GDP deflator	2.02	3.11	1.68	2.64	-1.42	-1.61	0.66	0.05
Household numbers	2.94	3.09	3.32	2.76	2.52	3.00	2.00	2.00
Private consumption	5.56	7.38	8.70	6.94	4.80	4.72	1.37	2.61
Aggregate investment	5.78	1.68	10.01	7.19	0.77	5.91	-18.17	1.14
Government consumption	2.67	6.92	6.56	3.95	-7.10	0.71	-1.95	-1.93
Exports	12.50	7.16	10.13	2.49	10.99	17.12	-8.17	6.21
Imports	9.77	6.27	15.02	6.62	3.70	14.88	-13.50	7.22
Inventories	5.78	1.68	10.01	7.19	0.77	5.91	-44.00	200.00
GDP	6.43	6.31	6.61	4.52	5.48	5.73	-1.38	2.60
Overall factor productivity	-4.14	-4.66	-4.01	-1.98	-2.83	-3.08	2.10	-0.81

5.3.2 *Simulation results*

We imposed a permanent increase of the motor fuel taxes starting in 2003, i.e., fuel prices from 2003 are 15% higher than in the BAU case. In Table 5.6 we present the cumulative percentage deviations in key variables at different points of time. Columns A, B, and C, respectively, show the first-year (short-run), the fifth-year (medium run), and the tenth-year (long-run) cumulative deviation results of version STD. Columns D, E, and F, respectively, show the first-year (2003), the fifth-year (2007) and the tenth-year (2012) cumulative deviation results of version DURA. Columns G, H, and I, respectively, show the cumulative percentage deviations of key variables of version TAIVINT in year 2003, 2007 and 2012.

DURA compared to STD

We first compare the percentage deviation results of STD and DURA. They are similar to the comparative static results as presented in Section 4.5.4 of Chapter 4. In the recursive dynamic simulations presented here, we only imposed taxes on gasoline and diesel fuel for private transport purposes. In the illustrative comparative static simulations presented in Section 4.5.4 of Chapter 4, we imposed tax increases on all purchases of petroleum products. Yet, this does not pose big difference in demand for transportation fuels and motor vehicles. The results presented in Table 5.6 again show that our innovations with version DURA fix the problems concerning household demand for motor vehicles and motor fuels. In the short run (the first year), households of version STD reduce consumption of gasoline and diesel fuel by 3.699% and 4.436%, respectively, with a 0.1% decrease in their total expenditure. The fall in household expenditure causes a slight reduction in household demand for new cars (by -0.055%). The long-run (the tenth year) results show more clearly the problem with version STD: households reduce gasoline and diesel fuel consumption (by 4.081% and 5.017% respectively) and increase purchases of new cars (by 0.001%) in the presence of a 0.08% fall in total expenditure. On the other hand, in version DURA the PTS industry uses less motor fuels (by 1.981% for both fuels) and reduce purchases of new cars (by 0.975%) in accordance with a 0.135% shrinkage of its car stock in the short run. In the long run (the 10th year), the PTS industry scales further down its car stock by 1.026% with a 1.072% reduction of new car purchases, and thus consumes less motor fuels (by 2.578%). Again, version DURA models more realistically household demand for private transport related commodities. The unreasonable results arise in the simulations with version STD because cars and motor fuels are treated as substitutes in household demand (the Linear Expenditure System). In version DURA, we relate household consumption of motor fuels to their cars and treat them as complements to each other. This treatment produces convincing results.

In addition, version DURA has PTS, railway transport services (RTS) and land transport services (LTS) grouped in the "land transport" bundle in the household Linear Expenditure System. It produces more sensible results reflecting household responses in the demand for other transport options (RTS or LTS) in the face of higher costs of self-driving (PTS). In the simulations with both versions STD and DURA, aggregate household expenditure has similar magnitudes of deviation from the BAU case. Results of version DURA show that households would switch to RTS or LTS when self-driving is more costly. LTS is relatively more expensive than RTS because of the price rise of diesel fuel (the main input of LTS). We next explain the price rise of diesel fuel.

The basic price of gasoline falls while diesel fuel price rises in context of the multi-product production structure. As described in Chapter 3, gasoline and diesel fuel are products of the Oil Refinery industry. We specify a Constant Elasticity of Transformation (CET) function to govern the output mix of the multi-product industry. Gasoline is the main product of the oil refinery industry. The Land Transport Services industry is the main customer of domestically produced diesel fuel. The household sector of version STD (or the PTS industry of versions DURA and TAIVINT) is the main customer of domestically produced gasoline. The Land Transport Services industry has rather small scope to substitute for diesel fuel in production, even though we allow for inter-fuel and fuel-primary-factor substitution[7] (described in Chapter 3). The household demand elasticity of gasoline is 0.65. In addition, we only impose taxes on gasoline and diesel fuel consumption by households or the PTS industry in the illustrative simulations. Diesel fuel purchases of the Land Transport Service industry are not taxed. Hence, the market demand for gasoline is more elastic than that for diesel fuel. This contributes to the rise in the basic price of diesel fuel and the drop of gasoline basic price.

In general, the basic price of gasoline falls less in DURA, comparing with STD. Consistently, the purchasers' prices of gasoline and diesel fuel rise more in DURA. This is because the market demand for gasoline is less elastic in DURA—the demand for gasoline is derived from the demand for PTS, which is subject to the car stock. In the short run, the car stock is fixed and this explains the bigger difference in the fall of the gasoline basic price (-1.931% in STD v.s. -0.469% in DURA). In the medium and long run, the PTS industry in version DURA can adjust its car stock. Hence the basic price of gasoline falls more (-0.562% in the medium run and -0.535% in the long run). Analogous reasoning applies for the case of diesel fuel.

In accordance to the reduction in household consumption of gasoline and diesel fuel, contributions to CO_2 emissions due to use of motor fuels by households in STD is bigger than that by the PTS industry in DURA. By "contribution" we mean the product of the CO_2 emissions share and the percentage change in the consumption of the commodity (e.g., gasoline). Table 5.6 shows that in the long run motor fuel consumption by households in STD contributes slightly less than that by the PTS industry in DURA. This is because the CO_2 emissions shares of motor fuels consumed by households in STD have been reduced faster in the earlier years via the bigger reductions in motor fuel consumption.

Next we explain the results regarding the car capital in version DURA. In the short run, the PTS industry is not able to adjust its car stock and thus incurs a sharper drop in capital rental (-1.735%). As the time scope enlarges, the PTS industry can reduce more of the car stock (-1.026%) than in the short and medium run

[7] The elasticity of substitution between fuels is set to 0.3 and the elasticity of substitution between fuel composite and primary factors is 0.2.

(-0.135%[8] and -0.815%, respectively). Hence the capital rental of the PTS industry falls less in the long run (-0.09%) relative to the short and medium run (-1.735% and -0.357%). We also present in Table 5.6 the results of the old car stock of the PTS industry. In the first year there is no change in the old car stock which is predetermined by the new car purchases made in the previous year. The cumulative percentage deviations in the old car stock are parallel to those in the whole car stock of the PTS industry, except that the whole car stock counts in new cars purchased in the current year. Consistently, the percentage deviations of the whole PTS car stock (-0.135%, -0.815%, and -1.026% for the short, the medium, and the long run, respectively) reveal the trend in the cumulative percentage deviations in new car purchases (-0.975%, -1.498%, and -1.072% for the short, the medium, and the long run, respectively) on top of the changes in the old car stock (0%, -0.686%, and -1.018% for the short, the medium, and the long run, respectively).

[8] The 0.135% drop in the PTS car stock in the short run is due to the reduction in new car purchases (-0.975%).

Table 5.6 Key results of the illustrative simulations: 15% *ad valorem* tax on motor fuels in household/PTS consumption

Column identifier	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
Versions of TAIGEM		STD			DURA			TAIVINT	
Timing	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)
Agents	HH	HH	HH	PTS	PTS	PTS	PTS	PTS	PTS
HH demand for:									
PTS	n/a	n/a	n/a	-0.737	-1.367	-1.641	-0.577	-1.368	-1.694
Railway transport services (RTS)	-0.051	-0.027	0.00	0.024	0.055	0.117	0.014	0.033	0.098
Land transport services (LTS)	-0.082	-0.066	-0.052	0.008	0.025	0.072	0.000	0.003	0.051
Composite land transport (PTS+RTS+LTS)	n/a	n/a	n/a	-0.552	-1.019	-1.204	-0.439	-1.03	-1.254
HH purchasers' prices of:									
PTS	n/a	n/a	n/a	1.034	1.922	2.351	0.8	1.895	2.396
Railway transport services (RTS)	-0.063	-0.099	-0.116	-0.065	-0.169	-0.245	-0.051	-0.145	-0.223
Land transport services (LTS)	0.027	0.003	0.00	-0.036	-0.103	-0.147	-0.032	-0.102	-0.155
Composite land transport (PTS+RTS+LTS)	n/a	n/a	n/a	0.766	1.409	1.703	0.6	1.395	1.742
Demands for, by agents:									
Gasoline	-3.699	-3.886	-4.081	-1.981	-2.388	-2.579	-1.9	-2.422	-2.639
Diesel fuel	-4.436	-4.735	-5.017	-1.981	-2.388	-2.579	-1.9	-2.422	-2.639
Motor vehicles (new)	-0.055	-0.035	0.001	-0.975	-1.498	-1.072	-0.725	-1.395	-0.915
Aggregate household expenditure	-0.100	-0.138	-0.151	-0.091	-0.162	-0.162	-0.075	-0.168	-0.169

....continued

Table 5.6 (continued)

Column identifier	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
Versions of TAIGEM		STD			DURA			TAIVINT	
Timing	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)
Agents	HH	HH	HH	PTS	PTS	PTS	PTS	PTS	PTS
Per-household utility	-0.157	-0.137	-0.11	-0.143	-0.238	-0.22	-0.118	-0.245	-0.233
Basic price of motor fuels:									
Gasoline	-1.931	-1.913	-1.825	-0.469	-0.562	-0.535	-0.424	-0.555	-0.539
Diesel fuel	1.011	1.087	1.207	0.147	0.143	0.132	0.139	0.141	0.126
Purchasers' prices of, paid by agents:									
Gasoline	5.886	5.999	6.163	7.861	7.922	8.119	7.89	7.944	8.135
Diesel fuel	8.153	8.329	8.532	7.988	8.039	8.138	8.006	8.048	8.151
Motor vehicles (new)	-0.091	-0.098	-0.109	-0.099	-0.143	-0.145	-0.084	-0.146	-0.15
Contributions to CO_2 emissions due to use of, by agents:									
Gasoline	-0.178	-0.206	-0.236	-0.129	-0.186	-0.243	-0.119	-0.190	-0.250
Diesel fuel	-0.002	-0.002	-0.003	-0.001	-0.001	-0.002	-0.001	-0.001	-0.002
CO_2 emissions by agents:	-0.180	-0.208	-0.238	-0.130	-0.187	-0.245	-0.120	-0.191	-0.252
Capital (cars) rental of PTS	n/a	n/a	n/a	-1.735	-0.357	-0.09	-1.589	-0.265	0.154
Whole car stock of PTS	n/a	n/a	n/a	-0.135	-0.815	-1.026	-0.076	-0.855	-1.122
Old car stock of PTS	n/a	n/a	n/a	0	-0.686	-1.018		(See Table 5.7 for details)	

TAIVINT compared to DURA

Like DURA, Version TAIVINT also produces sensible results regarding the demand for motor fuels and cars for private transport purposes. The percentage deviation results of TAIVINT have similar pattern as those of DURA but the magnitudes of deviations differ. The difference in the magnitudes of deviations can be attributed to the vintage distinction and the "embodied technical change" from new car investment[9].

In TAIVINT, we identify 11 vintages for the car stock of the PTS industry. For physical depreciation of cars, we assume a uniform annual rate of 12% for all vintages. We also specify the same rate of depreciation for the PTS industry of DURA. In this case, the car capital accumulation of version TAIVINT differs from that of version DURA in the mandatory scrapping of cars older than 10 years and the additions of new cars. Analogous to other industries, we assume that the PTS industry determines its investment (new car purchases) according to its expected rate of return for next year. The expected rate of return is formulated on the basis of the rates of return of last year and current year (see Section 3.9 of Chapter 3 for more details). In TAIVINT, we measure the average rental price of the PTS industry as the rental share weighted average of the vintage-specific car rental prices. The motor fuel tax caused cost squeeze in PTS sub-industries using old vintages of cars (other than the brand-new ones) as the capital stock of old vintages are fixed. This is revealed by the percentage deviations of capital rental price of old vintages (see Table 5.7). As described in Section 5.2.2, we assume vintage-specific private transport services being good substitutes by arbitrarily specifying a substitution elasticity of 20. In addition, we assume that all PTS sub-industries face the same purchasers' price of motor fuels. In this illustrative simulation, the increase in the motor fuel tax applies to all PTS sub-industries. In this context, the cost squeeze would fall on the vintage-specific rental prices. As shown in Part II of Table 5.7, percentage deviations of vintage-specific output prices and average motor fuel prices do not vary much between vintages. The different magnitudes of deviation of vintage-specific capital rental prices can be ascribed to the vintage-specific car stocks. Table 5.8 shows the vintage-specific car stock in 2003 and their percentage change deviations of rental prices. Old vintages with bigger car stocks take more cost squeeze caused by the motor fuel tax increase. The average car rental price would affect purchases of new cars in 2003. Motor fuel consumption by vintages also corresponds to the size of the

[9] In the illustrative recursive dynamic simulations, we shock the motor-fuel saving technical change variable for new cars, a1PTS_s("New"), by 1% each year.

vintage-specific stock[10]. As car stocks of vintages are fixed, vintage-specific output is proportional to motor fuel consumption (Table 5.7, Part I).

In general, the PTS industry of version TAIVINT is more elastic in fuel demand. The explanation is: the PTS industry of version TAIVINT is able to throw away cars older than 10 years while in version DURA the whole car stock of PTS follows a geometric pattern of depreciation. As a result, the average capital rental of cars falls less in version TAIVINT[11]. As a result of the more elastic demand for motor fuels, the PTS demands for motor fuels decline more, and the purchasers' prices of motor fuels rise more in version TAIVINT. In the medium and the long run, the PTS industry of version TAIVINT gradually scraps cars of less fuel efficiency. Moreover, the addition of new cars (more fuel-efficient) each year also contributes to a more elastic demand for motor fuels. Accordingly, the PTS emits less CO_2 in TAIVINT.

Table 5.7 Vintage-specific results of the illustrative simulations: 15% *ad valorem* tax on motor fuels in PTS consumption (Part I)

	Percentage-change deviation of vintage-specific:								
	Output			Motor fuel consumption			Car stock		
Timing	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)
Vintage									
New	-1.243	-1.93	-1.508	-2.542	-2.967	-2.468	-0.725	-1.395	-0.915
1-YO	-0.551	-1.966	-1.626	-1.866	-2.992	-2.568	0	-1.402	-0.999
2-YO	-0.443	-1.769	-1.593	-1.772	-2.811	-2.547	0	-1.323	-1.106
3-YO	-0.515	-1.641	-1.794	-1.828	-2.671	-2.727	0	-1.123	-1.224
4-YO	-0.53	-1.265	-1.92	-1.843	-2.304	-2.851	0	-0.725	-1.329
5-YO	-0.522	-0.54	-1.978	-1.828	-1.586	-2.896	0	0	-1.396
6-YO	-0.494	-0.516	-1.955	-1.804	-1.565	-2.877	0	0	-1.402
7-YO	-0.476	-0.503	-1.858	-1.802	-1.568	-2.798	0	0	-1.323
8-YO	-0.499	-0.52	-1.68	-1.832	-1.587	-2.623	0	0	-1.121
9-YO	-0.526	-0.534	-1.304	-1.838	-1.577	-2.231	0	0	-0.724
10-YO	-0.465	-0.465	-0.513	-1.789	-1.528	-1.48	0	0	0
PTS	-0.577	-1.368	-1.694	-1.9	-2.422	-2.639	-0.076	-0.855	-1.122

[10] We did not consider vehicle-kilometres-travelled by vintage-specific cars. Our explanation here is based on the assumption that each car within the vintage has the vehicle-kilimetres-traveled.

[11] It is an artefact of our database construction that cars, on average, last longer in DURA than in TAIVINT. So, adjustment to desired car stocks is quicker in TAIVINT.

Table 5.7 (Part II)

	Percentage-change deviation of vintage-specific:								
	Output price			Capital rental price			Average motor fuel price		
Timing	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)	1st year (short run)	5th year (medium run)	10th year (long run)
Vintage									
New	0.834	1.924	2.387	-1.658	-0.41	-0.095	7.895	7.949	8.139
1-YO	0.799	1.926	2.393	-1.819	-0.493	-0.174	7.895	7.949	8.139
2-YO	0.793	1.915	2.391	-1.254	0.138	0.573	7.895	7.949	8.139
3-YO	0.797	1.909	2.402	-1.637	-0.261	0.14	7.895	7.949	8.139
4-YO	0.798	1.89	2.409	-1.714	-0.388	0.033	7.895	7.949	8.139
5-YO	0.798	1.852	2.412	-1.684	-0.409	0.09	7.895	7.949	8.139
6-YO	0.796	1.851	2.411	-1.538	-0.266	0.251	7.895	7.949	8.139
7-YO	0.794	1.85	2.405	-1.412	-0.175	0.376	7.895	7.949	8.139
8-YO	0.795	1.85	2.395	-1.502	-0.22	0.307	7.895	7.949	8.139
9-YO	0.798	1.852	2.376	-1.665	-0.312	0.172	7.895	7.949	8.139
10-YO	0.794	1.848	2.334	-1.368	-0.01	0.413	7.895	7.949	8.139
PTS	0.8	1.895	2.396	-1.589	-0.265	0.154	7.895	7.949	8.139

Table 5.8 Vintage-specific car stock in 2003 and their % change deviations of car rental prices

Car vintages of 2003	New car purchases made in year:	New car purchases (A)	Investment price index (B)	Indexed new car purchases [=(A)/(B)]	% change deviation of vintage-specific car rental prices
New	2003	330093.2	1.17623	280636.6	-1.658
1-YO	2002	297559.2	1.17727	252753.6	-1.819
2-YO	2001	276075.1	1.18007	233948	-1.254
3-YO	2000	320829.9	1.1984	267715.2	-1.637
4-YO	1999	270988.7	1.11643	242727.9	-1.714
5-YO	1998	235974.3	1.06808	220933.1	-1.684
6-YO	1997	185615.9	1.0248	181124	-1.538
7-YO	1996	162619.1	1.03802	156662.8	-1.412
8-YO	1995	185455.6	1.0484	176893.9	-1.502
9-YO	1994	226553.8	1	226553.8	-1.665

5.3.3 A short conclusion for this illustrative simulation

The new versions of TAIGEM—DURA and TAIVINT—model household demands for motor fuels and cars better, and also produce more sensible results than standard TAIGEM. The newly established Private Transport Services (PTS) industry identifies both the durable nature of privately-owned motor vehicles and the complementarity in demand between cars and motor fuels. We also account in these two new versions for the immediate provision of services of cars after purchase. The incorporation of other car-use related costs—vehicle license fees and fuel consumption taxes—gives a more accurate account of car-use costs. The distinction of car vintages in version TAIVINT recognises that cars with newer technology take time to filter into the stock—technological changes do not affect pre-existing cars. The vintage treatment facilitates simulations of vehicle management policies concerning the average service life of cars, which has significant effects on the demand for new cars and also on the estimation of CO_2 emissions from car use.

References

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CHAPTER 6
Concluding Remarks and Agenda for Future Research

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6.1 Concluding remarks

In this research, we aim to model transport services more realistically and sensibly in TAIGEM. To this end, we created two new versions of TAIGEM—DURA and TAIVINT—to account for some distinct features of private transport services.

With version DURA, we recognise the durable nature of privately-owned motor vehicles and the complementarity between vehicles and petrol by setting up a new industry, called the Private Transport Services (PTS) industry. The PTS industry produces transport services from petrol and privately-owned motor vehicles (as capital). We impute capital rentals for existing cars. We specify a proper production structure for the PTS industry to ensure that cars and gasoline are complementary in producing transport services. An elasticity of 0.2 is specified for the substitution between car capital and motor fuels to account for price-induced fuel conservation. Current car purchases are treated as investment in this industry. We also recognise, in DURA, that newly-acquired cars provide services immediately after purchase. We assume that new and existing cars are homogenous and that their fuel efficiencies are the same. Households derive utility from transport services yielded by petrol and their cars (both newly-acquired and existing). We incorporate vehicle license fees and per-car fuel consumption tax to give a more accurate account of car user costs. In addition to the treatment of private transport services, we also recognize in the household demand system the special substitution relationships between railway transport, land transport and private transport services. Thanks to the innovations, version DURA produces more sensible results than conventional CGE models.

Based on DURA, version TAIVINT further identifies 11 vintages of privately-owned motor vehicles, ranging from zero year old (brand-new) to ten years old. We assume that newer vintages have better fuel efficiency and cars are fully scrapped after 11 years of use. With this treatment, TAIVINT accounts for "embodied technical change" via the new-car additions to the capital stock. The vintage distinction enhances the capacity of TAIGEM to analyse vehicle management policies in terms of greenhouse gas abatement (e.g., tougher standards of fuel efficiency for new cars).

With the two new versions of TAIGEM, we successfully tackle several problems of conventional CGE models in modelling the demand for privately-owned motor vehicles. Due to the use of additive demand systems, most CGE models (e.g., the MONASH Model and the standard TAIGEM model) inappropriately treat cars and gasoline as substitutes, rather than complements, in household demand. As shown in Chapter 4, this specification produces odd results—e.g., households buy less gasoline but more cars when gas prices rise, even though motor vehicles require gasoline to provide transport services. Additive utility does not allow for complementary commodities. In the example of private transport services, the marginal utility of cars is closely related to motor fuel consumption.

Our new versions DURA and TAIVINT also account for the durable nature of privately owned motor vehicles, which is also mistreated in conventional CGE models and input-output accounting as well. In Taiwan, cars normally run for seven to ten years. However, input-output accounts—the main data source for most CGE models—simply deal with newly-acquired cars and treat them as perishables in household consumption. Pre-existing privately-owned cars are not counted in the input-output accounts. This biases estimates of the economy's true consumption. In a CGE model, this mistreatment of privately-owned durables would also affect the projection of the responses of related economic agents. In addition, versions DURA and TAIVINT realistically account for the immediate provision of services of cars after purchase. Vehicle license fees and fuel consumption taxes are also recognised to reflect real costs of car use.

The "vintage capital" distinction of cars in TAIVINT accounts for the *gradual* change in the intensity of fuel consumption (and thus transport emissions) due to scrapping of older and gas-guzzling cars. TAIVINT recognises that new technology (e.g., vehicles with better fuel efficiency) takes time to filter into the stock of cars. TAIVINT preserves the technology of existing cars and counts in technological changes in new generations of cars. Other dynamic models, such as MONASH, assume that technical change affects the whole of the capital stock immediately. This is not realistic.

6.2 Future research agenda

In future research, we intend to consider endogenously-determined depreciation rates for cars of different vintages. This would recognise that car owners may like to scrap old cars sooner (rather than waiting until 11 years of service). Higher gas taxes, or improvements in new cars, might accelerate the scrapping rate. Trade-in of old cars for new ones is another practice to change the vintage structure of the car fleet—which we could model. Market saturation levels for cars also affect purchases of new cars. To capture these affects, we must further develop our investment mechanism for new cars.

EPA statistics show that there are about 15,600 motor vehicles (mainly taxis) fuelled by liquefied petroleum gas (LPG) by 1997. Less-polluting cars are expected to penetrate the market gradually in the foreseeable future. The technical transmission variables in TAIVINT can be further elaborated to accommodate for motor fuels not conventionally used (e.g., LPG, electricity, fuel cell and methanol).

Recent literature has discussed the "rebound effect" in gasoline consumption due to fuel efficiency improvements (more efficient cars are cheaper to run, so travel increases). Thus, we would also like to incorporate specifically "vehicle miles travelled" (VMT) and "miles per gallon" (MPG) of cars as commonly employed in partial-equilibrium econometric models. This would permit us to consider the evident short-run effect of gasoline price changes on VMT and thus on gasoline consumption. The incorporation of MPG would allow us to more practically measure energy efficiency, as described in engineering models.

Due to the aggregate level of the Taiwan input-output table, the Land Transport Services industry in TAIGEM refers to taxis, buses and trucks, while the Railway Transport Services industry comprises conventional railway transport and Mass Rapid Transit Systems. As these five types of commercial transport serve different needs, it is desirable to disaggregate them so that we can specify separately the substitution between them in terms of passenger transport and freight. In addition, Air Transport in TAIGEM does not distinguish domestic and foreign flights. Domestic flights are good substitutes for railway and long-distance highway transport.

To fully reflect the externality brought about by transportation, we also plan to include other vehicle pollutants (e.g., NO_X, SO_X, and PM) in TAIGEM's emissions accounting. This would facilitate analyses of abatement costs of multi-pollutants.

Motorcycles have been the most popular type of vehicle in Taiwan during the past few decades. They are easy to park and handy in traffic. Cheap to buy and to run, they are particularly popular among the less well-off. The problems we have addressed concerning motor vehicles pertain also to motorcycles. Hence, we intend to apply our DURA/TAIVINT approach to motorcycles. To consider the relationship between ownership of vehicles (both cars and motorcycles) and income distribution is another item on our research agenda.

APPENDICES

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APPENDIX 1
Sectors, Variables, Coefficients in TAIVINT

List of Tables

Table A1.1 Commodity names in the TAIGEM database

No.	Abbreviated names	Full names of TAIGEM commodities	No.	Abbreviated names	Full names of TAIGEM commodities*
1	Paddy_Rice	Paddy rice	44	Leather	Leather
2	CmnCrp_NEC	Other common crops	45	LeathFootw	Leather footwear
3	SugarCane	Sugarcane	46	LthPrd_NEC	Other leather products
4	SpeCrp_NEC	Other special crops	47	Lumber	Lumber
5	Fruits	Fruit	48	Plywood	Plywood
6	Vegetables	Vegetable	49	WoodProds	Wood, bamboo and rattan products
7	HrtCrp_NEC	Other horticultural crops	50	NMetFurnit	Non-metallic furniture
8	Hogs	Hogs	51	PulpPaper	Pulp paper
9	Livstk_NEC	Other livestock	52	PaperProds	Paper products
10	AgrService	Agriculture services	53	BookMagazn	Books and magazines
11	Forestry	Forestry	54	Print_NEC	Other printed materials
12	Fisheries	Fisheries	55	PetChemRaw	Petrochemical raw materials
13	Coal	Coal	56	IndChemNEC	Other industrial chemicals
14	CrudeOil	Crude oil	57	ChemFertil	Chemical fertilisers
15	NaturalGas	Natural gas	58	SynthFibre	Synthetic fibres
16	MetMineral	Metallic minerals	59	ArtFibrNEC	Other artificial fibres
17	Salt	Salt	60	Plastics	Plastics (synthetic resins)
18	NmtMin_NEC	Other non-metallic minerals	61	ChemMatNEC	Other chemical materials
19	Slaughter	Butchery	62	Coatings	Coatings
20	Fats	Edible oil and fat by-products	63	Medicines	Medicines
21	Flour	Flour	64	Pesticides	Pesticides and herbicides
22	Rice	Rice	65	Detergents	Synthetic detergents and washing preparations and cosmetics
23	Sugar	Sugar	66	MiscChem	Misc. chemical manufactures
24	AnimalFeed	Animal feeds	67	Gasoline	Gasoline
25	CannedFood	Canned foods	68	DieselFuel	Diesel fuel
26	FrozenFood	Frozen foods	69	AviaFuel	Aviation fuel
27	MSG	MSG	70	FuelOils	Fuel oils
28	Seasonings	Seasonings	71	Kerosene	Kerosene
29	DairyProds	Dairy products	72	Lubricants	Lubricants
30	ConfectBak	Sugar confectionery and bakery products	73	Naphtha	Naphtha
31	Food_NEC	Misc. Food products	74	RefineGas	Refinery gas
32	NonAlcBev	Non-alcoholic beverages	75	Asphalt	Asphalt
33	AlcBeverag	Alcoholic beverages	76	PetRef_NEC	Other petroleum products
34	Tobacco	Tobacco	77	CoalProds	Coal products
35	CottonFabr	Cotton and cotton fabrics	78	RubberProd	Rubber and rubber products
36	WoolFabric	Wool and worsted fabrics	79	PlastFootW	Plastic footwear
37	ArtiFabric	Artificial fabrics	80	PlsPrd_NEC	Other plastic products
38	Garments	Knitted fabrics	81	Ceramics	Ceramics
39	KntFab_NEC	Other fabrics and fabric products	82	GlassProds	Glass and glass products
40	Dyeing	Printing, dyeing and finishing	83	Cement	Cement
41	FabPrd_NEC	Tatted garments	84	CemntProds	Cement products
42	ApparelNEC	Knitted garments	85	NonMetlNEC	Misc. non-metallic
43	WearAccess	Fabric products, wearing apparel and accessories	86	PigIron	Pig iron and crude steel

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Table A1.1 (continued)

No.	Abbreviated names	Full names of TAIGEM commodities	No.	Abbreviated names	Full names of TAIGEM commodities*
87	BasicIron	Primary iron and steel products	123	Diesel	Power generated by diesel engine
88	Aluminum	Aluminum	124	NuclearEle	Nuclear electricity
89	Metals_NEC	Miscellaneous metals	125	EndUseElec	End-use supplier (EUS)
90	MtlPrdHous	Metallic products for household use	126	Gas	Gas
91	HandTools	Metallic hand tools	127	Water	City water, steam and hot water
92	SteelProds	Iron and steel products	128	ResidBuild	Residential building construction
93	AluminProd	Aluminum products	129	NResidBuil	Non-residential building construction
94	MetPrd_NEC	Misc. Metallic products	130	PublicWork	Public works
95	SurfcTreat	Surface treating of metal products	131	Cnstrc_NEC	Other construction
96	IndMachnry	General industrial machinery	132	Wholesale	Wholesale trade
97	MetlPrcMch	Metal processing machinery	133	Retail	Retail trade
98	IndMachine	Industrial machinery	134	ForeignTrd	Foreign trade
99	MachineNEC	Other machinery	135	FoodBevSer	Food and beverage services
100	MachMaintn	Machinery parts, repair and maintenance	136	RailTrnspt	Railway transportation
101	HouseElect	Household electrical appliances	137	LandTrnNEC	Other land transportation
102	LightEquip	Lighting equipment	138	WaterTrnsp	Water transportation
103	ElecMachin	Power generation, transmission and distribution machinery	139	AirTranspt	Air transportation
104	DataProcEq	Computer and peripheral products	140	ServTrnspt	Services incidental to transport
105	VideoRadio	Video and radio electronic products	141	Warehouse	Warehousing
106	CommunEqip	Communication apparatus	142	PostalServ	Postal services
107	ElctrnComp	Other electrical materials	143	Telephone	Telegram and telephone
108	ShipBuild	Shipbuilding	144	Finance	Finance
109	MotorVehic	Motor vehicle	145	Security	Security and future
110	MotorCycle	Motorcycles	146	Insurance	Insurance
111	Bicycles	Bicycles	147	HouseServ	House services
112	TrnpEq_NEC	Other transport equipment	148	Hotels	Hotel services
113	PrcisInstr	Precision instruments and apparatus	149	RealEstate	Real estate services
114	Manfac_NEC	Other manufactures	150	LegalAccnt	Legal and accounting services
115	HydroElect	Hydro-electricity	151	Consulting	Consulting services
116	Steam_Oil	Power generated by oil-fired steam engine	152	InformServ	Data processing and information services
117	Steam_Coal	Power generated by coal-fired steam engine	153	Advertisng	Advertising services
118	Steam_Gas	Power generated by gas-fired steam engine	154	RentingSer	Renting and leasing services
119	CombCy_Oil	Power generated by oil-fired combined-cycle engine	155	BusServNEC	Misc. services for business
120	CombCy_Gas	Power generated by gas-fired combined-cycle engine	156	PubAdmServ	Public administration services
121	GasTur_Oil	Power generated by oil-fired gas turbine	157	EnvSanServ	Environmental sanitary services
122	GasTur_Gas	Power generated by gas-fired gas turbine	158	EduTrnServ	Educational training services

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Table A1.1 (continued)

No.	Abbreviated names	Full names of TAIGEM commodities	No.	Abbreviated names	Full names of TAIGEM commodities*
159	SciResServ	Scientific research and services	166	VehicleSer	Vehicles services
160	MedHelServ	Medical and health services	167	RepairsNEC	Other repair services
161	SocWelServ	Social welfare services	168	HouService	Household services
162	ServCivAss	Services of civil association	169	PerSer_NEC	Other personal services
163	SocSer_NEC	Other social services	170	Undistribt	Undistributed items
164	TelevisSer	Radio, television and movies services	171	PrivTransp**	Private transport services
165	Recreation	Recreational and cultural services			

* English translation of commodity names follows Lin, H.-C., Chung, L.-C., and Liou, R.-W. (2002), Chapter 11.F: Taiwan, from B. V. Dimaranan and R. A. McDougall (Eds.), *Global Trade, Assistance, and Production: The GTAP 5 Data Base* (Vol. Part III: Sources and Procedures for the Version 5 Data Base, pp. 11-F-1-6). Center for Global Trade Analysis, Purdue University West Lafayette, Indiana, U.S.A.

** In the text of Chapters 4 and 5, we use "PTS" for brevity.

Table A1.2 Commodity mapping: 171 commodities to 76 commodities

No.	Aggregate commodity: Full names	Aggregate commodity: Abbr. names	Contains disaggregated commodities: Abbr. names
1	Agriculture	Agriculture	Paddy_Rice, CmnCrp_NEC, SugarCane, SpeCrp_NEC, Fruits, Vegetables, HrtCrp_NEC, Hogs, Livstk_NEC, AgrService, Forestry
2	Fisheries	Fisheries	Fisheries
3	Coal	Coal	Coal
4	Crude Oil	CrudeOil	CrudeOil
5	Natural Gas	NaturalGas	NaturalGas
6	Mineral	Mineral	MetMineral, Salt
7	Other non-metallic minerals	nmtMin_NEC	NmtMin_NEC
8	Food products	FoodManuf	Slaughter, Fats, Flour, Rice, Sugar, AnimalFeed, CannedFood, FrozenFood, MSG, Seasonings, DairyProds, ConfectBak, Food_NEC, NonAlcBev, AlcBeverag, Tobacco
9	Clothing products	ClothesManuf	CottonFabr, WoolFabric, ArtiFabric, Garments, KntFab_NEC, Dyeing, FabPrd_NEC, ApparelNEC, WearAccess, Leather, LeathFootw, LthPrd_NEC
10	Wood products	WoodManuf	Lumber, Plywood, WoodProds, NMetFurnit
11	Paper	Paper	PulpPaper, PaperProds
12	Printed materials	BookPrint	BookMagazn, Print_NEC
13	Petrochemical raw materials	PetChemRaw	PetChemRaw
14	Other industrial chemicals	IndChemNEC	IndChemNEC
15	Chemistry products	ChemProds	ChemFertil, SynthFibre, ArtFibrNEC, Plastics, ChemMatNEC, Coatings, Medicines, Pesticides, Detergents, MiscChem, PlastFootW, PlsPrd_NEC
16	Gasoline	Gasoline	Gasoline
17	Diesel fuel	DieselFuel	DieselFuel
18	Aviation fuel	AviaFuel	AviaFuel
19	Fuel oils	FuelOils	FuelOils
20	Kerosene	Kerosene	Kerosene
21	Lubricants	Lubricants	Lubricants
22	Naphtha	Naphtha	Naphtha
23	Refinery gas	RefineGas	RefineGas
24	Asphalt	Asphalt	Asphalt
25	Other petroleum products	PetRef_NEC	PetRef_NEC
26	Coal products	CoalProds	CoalProds
27	Rubber products	RubberProd	RubberProd
28	Non-metallic product	NonMetalic	Ceramics, GlassProds, NonMetlNEC
29	Cement	Cement	Cement
30	Cement products	CemntProds	CemntProds
31	Pig iron and crude steel	PigIron	PigIron
32	Primary iron and steel products	BasicIron	BasicIron
33	Aluminum	Aluminum	Aluminum
34	Metal products	MetalProds	Metals_NEC, MtlPrdHous, HandTools, SteelProds, AluminProd, MetPrd_NEC, SurfcTreat
35	Machinery	Machinery	IndMachnry, MetlPrcMch, IndMachine, MachineNEC, MachMaintn, LightEquip, ElecMachin
36	Household electrical appliances	HouseElect	HouseElect
37	Communication apparatus	CompCommuni	DataProcEq, CommunEqip, ElctrnComp

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Table A1.2 (continued)

No.	Aggregate commodity: Full names	Aggregate commodity: Abbr. names	Contains disaggregated commodities: Abbr. names
38	Video and radio electronic products	VideoRadio	VideoRadio
39	Transport equipment	TranspEquip	ShipBuild, Bicycles, TrnpEq_NEC
40	Motor vehicle	MotorVehic	MotorVehic
41	Motorcycles	MotorCycle	MotorCycle
42	Other manufactures	OtherManuf	PrcisInstr, Manfac_NEC
43	Hydro-electricity	HydroElect	HydroElect
44	Power generated by oil-fired steam engine	Steam_Oil	Steam_Oil
45	Power generated by coal-fired steam engine	Steam_Coal	Steam_Coal
46	Power generated by gas-fired steam engine	Steam_Gas	Steam_Gas
47	Power generated by oil-fired combined-cycle engine	CombCy_Oil	CombCy_Oil
48	Power generated by gas-fired combined-cycle engine	CombCy_Gas	CombCy_Gas
49	Power generated by oil-fired gas turbine	GasTur_Oil	GasTur_Oil
50	Power generated by gas-fired gas turbine	GasTur_Gas	GasTur_Gas
51	Power generated by diesel engine	Diesel	Diesel
52	Nuclear electricity	NuclearEle	NuclearEle
53	End-use supplier (EUS)	EndUseElec	EndUseElec
54	Gas	Gas	Gas
55	City water, steam and hot water	Water	Water
56	Construction	Construction	ResidBuild, NResidBuil, PublicWork, Cnstrc_NEC
57	Wholesale trade	Wholesale	Wholesale
58	Retail trade	Retail	Retail
59	Foreign trade	ForeignTrd	ForeignTrd
60	Railway transportation	RailTrnspt	RailTrnspt
61	Other land transportation	LandTrnNEC	LandTrnNEC
62	Water transportation	WaterTrnsp	WaterTrnsp
63	Air transportation	AirTranspt	AirTranspt
64	Services incidental to transport	ServTrnspt	ServTrnspt
65	Restaurant and hotel services	RestauHotel	FoodBevSer, Hotels
66	Telegram and telephone	Telephone	Telephone
67	Finance and insurance	FinanInsur	Finance, Security, Insurance
68	House services	HouseServ	HouseServ
69	Real estate services	RealEstate	RealEstate
70	Other services	OtherServic	Warehouse, PostalServ, LegalAccnt, Consulting, InformServ, Advertisng, BusServNEC, EnvSanServ, EduTrnServ, SciResServ, MedHelServ, SocWelServ, ServCivAss, SocSer_NEC, TelevisSer, Recreation, PerSer_NE
71	Renting and leasing services	RentingSer	RentingSer
72	Public administration services	PubAdmServ	PubAdmServ
73	Vehicles services	VehicleSer	VehicleSer
74	Other repair services	RepairsNEC	RepairsNEC
75	Household services	HouService	HouService
76	Private Transport Services	PrivTransp	PrivTransp

Table A1.3 Consolidated list of sets used in TAIGEM, DURA and TAIVINT

Set	Description	Association of sets
COM	All commodities	= MAR + NONMAR = TRADEXP + NTRADEXP
IND	All industries	= ELECIND + ORDINARYIND = EXOGINV + ENDOGINV
IND65	All industries except PTS (or "PrivTransp"*)	= IND - "PTS"
ELECIND	Power-generating industries plus the distributor industry	subset of IND
ELECGEN	Power-generating industries/output	subset of ELECIND subset of IND subset of COM
NONELECCOM	Output of non-power-generating industries	= COM - ELECGEN
ORDINARYIND**	Industries other than ELECIND	subset of IND
EXOGINV	Industries whose investment plans are regulated	subset of IND
ENDOGINV	Industries other than EXOGINV	subset of IND
LOCALUSERS	Local users of CO_2-emitting commodities	= IND + "Invest" + "HouseH" + "GovGE"
MVPETROL	Motor fuels: gasoline and diesel fuel.	
NONMVPETROL	Commodities excluding motor fuels	= COM - MVPETROL
HIGHWAY	Land transport services (LTS) and PTS	subset of COM
RAILWAY	Railway transport services (RTS)	subset of COM
ISLANDTRANSP	PTS, LTS and RTS	= HIGHWAY + RAILWAY
COMNOILANTRN	Commodities excluding PTS, LTS and RTS	= COM - ISLANDTRANSP
ILANTRN	A composite of PTS, LTS and RTS	
COMT	The composite of PTS, LTS and RTS, plus other commodities	= COMNOILANTRN + ILANTRN
MAR	Margins commodities	subset of COM
NONMAR	Non-margins commodities	subset of COM
TRADEXP	Commodities that are highly export oriented	subset of COM
NTRADEXP	Commodities other than TRADEXP	subset of COM = MAREXP + OTHEREXP
MAREXP	Commodities, the demands for which are closely related to international trade volume	subset of NTRADEXP subset of COM
OTHEREXP	NTRADEXP commodities other than MAREXP	subset of NTRADEXP subset of COM
ENERCOM	Energy commodities subject to CES substitution	subset of COM
NONENERCOM	Commodities not subject to the inter-fuel CES substitution	= COM - ENERCOM
BADCOM	CO_2-emitting commodities	subset of COM
SRC	Sources of commodities: domestic ("dom"); imported ("imp")	
DST	Destinations of domestically-produced commodities: the local market; export	
OCC	Occupations of labour	
FAC	Primary factors—labour, capital, and land	
VINTAGE	All vintages of cars (ranging from zero- to ten-year-old)	
OLDVINTAGE	Car vintages other than brand-new ones.	subset of VINTAGE

* As listed in Table A1.1, we use the name "PrivTransp" for private transport services in the database. In the text of Chapters 4 and 5, we use "PTS" for brevity.

** Again for brevity, we use the name "ORDINARY" in the text of Chapter 3. In the TABLO code, we use "ORDINARYIND".

Table A1.4 Coefficients in version TAIVINT (in alphabetical order)

Coefficient	Index range	Description
AF(c,v)	c∈COM v∈VINTAGE	Input-saving technological coefficient, by vintage
AFini(c,v)	c∈COM v∈VINTAGE	Initial input-saving technological coefficient, by vintage
AK(v)	v∈VINTAGE	Capital-using technological coefficient, by vintage
AKini(v)	v∈VINTAGE	Initial capital-using technological coefficient, by vintage
ALPHA(i)	i∈IND	Investment elasticity
B3LUX(c)	c∈COMT	Ratio, (supernumerary expenditure/total expenditure), by commodity
BASECO2TOT		Initial total CO2 emission
CAPADD(i)	i∈IND	Addition to CAPSTOK from last year investment
CAPADDOLDCAR(v)	v∈OLDVINTAGE	Addition to old car capital available for use in current year, at initial prices
CAPSTOK(i)	i∈IND	Current CAPSTOK measured in current prices
CAPSTOK_i		Aggregate K
CAPSTOK_OLDP(i)	i∈IND65	Current CAPSTOK measured in last years prices
CARCAP(v)	v∈VINTAGE	Stock of vintaged cars, valued at current prices
CARCAP_V		Total stock of cars, valued at current prices
CO2(c,s,u)	c∈BADCOM s∈SRC u∈LOCALUSER	
CO2TOT		Total CO2 emission
DOMSALES(c)	c∈COM	Total sales to local market
DPRC(i)	i∈IND	Rates of Depreciation
ELASTWAGE		Elasticity of wage to employment
EMPRAT		(Actual/trend)employment
EMPRAT0		Initial (actual/trend)employment
EPS(c)	c∈COMT	Household expenditure elasticities: 74 commodities
EPS76(c)	c∈COM	Household expenditure elasticities
EPSTOT		Average Engel elasticity: should = 1
EXP_ELAST(c)	c∈COM	Export demand elasticities: typical value -20.0
EXP_ELAST_NT		Non-traditional export demand elasticity
FRISCH		Frisch LES 'parameter' = - (total/luxury)
GRETEXP(i)	i∈IND	Expected gross rate of return
GRETEXP0(i)	i∈IND	Initial expected gross rate of return
GROMAX(i)	i∈IND	Maximum investment/capital ratio
GROSSGRO(i)	i∈IND	Investment/capital ratio
GROSSRET(i)	i∈IND	PK/PI
GROSSRET0(i)	i∈IND	Initial PK/PI
GROTREND(i)	i∈IND	Trend investment/capital ratio
INITCO2		Initial CO_2 emission
INVRATIOAF(c,v)	c∈COM v∈VINTAGE	
INVRATIOAK(v)	v∈VINTAGE	
IsELEC(c)	c∈COM	1 for types of electricity,else 0
IsELECDIST(i)	i∈IND	1 for EndUseElec, else 0
ISENER(c)	c∈COM	

....continued

Table A1.4 (continued)

Coefficient	Index range	Description
IsENERSUB(c,i)	c∈COM i∈IND	Mapping: energy-substituting industries
ISORDINARY(i)	i∈IND	
LEVP0(c,s)	c∈COM s∈SRC	Levels basic prices
LOCSALES(c)	c∈COM	Total local sales of dom + imp commodity c
LOST_GOODS(c)	c∈COM	SALES-MAKE_I : should be zero
MAKE(c,i)	c∈COM i∈IND	multi-production matrix
MAKE_C(i)	i∈IND	All production by industry i
MAKE_I(c)	c∈COM	Total production of commodities
MARSALES(c)	c∈COM	Total usage for margins purposes
NETGRO(i)	i∈IND	Net capital growth rate
NETRET(i)	i∈IND	Net rate of return
PURE_PROFITS(i)	i∈IND	COSTS-MAKE_C : should be zero
QCARCAPOLD(v)	v∈OLDVINTAGE	Stock of old cars, aged more than 1 year, at init. prices
QRATIO(i)	i∈IND	(Max/trend) investment/capital ratio
RNORMAL(i)	i∈IND	Normal gross rate of return
RS1(c,s,i)	c∈COM s∈SRC i∈IND	Intermediate source shares
RS2(c,s,i)	c∈COM s∈SRC i∈IND	Investment source shares
RS3(c,s)	c∈COM s∈SRC	Households source shares
S1FUELPTS(v)	v∈VINTAGE	Share of MVPETROL in MVPETROL + Primary factor: PTS industry
S1MVPETROL(f,v)	f∈MVPETROL v∈VINTAGE	
S1PRIMPTS(v)	v∈VINTAGE	Share of Primary in MVPETROL + Primary factor: PTS industry
S3_ISLANTRN(c)	c∈ISLANDTRANSP	
S3_S(c)	c∈COMT	Household average budget shares
S3LUX(c)	c∈COMT	Marginal household budget shares
SALES(c)	c∈COM	Total sales of domestic commodities
SIGELEC		Substitution elasticity between electricity types
SIGISLANTRN		
SIGMA1(c)	c∈COM	Armington elasticities: intermediate
SIGMA1ENER(i)	i∈IND65	
SIGMA1EPRIM(i)	i∈IND65	
SIGMA1FUPRIM		
SIGMA1LAB(i)	i∈IND	CES substitution between skill types
SIGMA1OUT(i)	i∈IND	CET transformation elasticities
SIGMA1PRIM(i)	i∈IND	CES substitution, primary factors
SIGMA2(c)	c∈COM	Armington elasticities: investment

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Table A1.4 (continued)

Coefficient	Index range	Description
SIGMA3(c)	c∈COM	Armington elasticities: households
SIGMAVINT		
SPECINDEX		Index for specific taxes, 1 in 1994
TAU(c)	c∈COM	1/elasticity. Of transformation, exportable/locally used
TAXBASE1(c,s,i)	c∈COM s∈SRC i∈IND	Base for specific tax
TAXBASE2(c,s,i)	c∈COM s∈SRC i∈IND	Base for specific tax
TAXBASE3(c,s)	c∈COM s∈SRC	Base for specific tax
TAXBASE4(c)	c∈COM	Base for specific tax
TAXBASE5(c,s)	c∈COM s∈SRC	Base for specific tax
TINY		Small number to prevent singular matrix
TRADEVOL		Sum of all exports and imports
V0CIF(c)	c∈COM	Total ex-duty imports of good c
V0CIF_C		Total $NT import costs, excluding tariffs
V0GDPEXP		Nominal GDP from expenditure side
V0GDPINC		Nominal GDP from income side
V0IMP(c)	c∈COM	Total basic-value imports of good c
V0IMP_C		Total basic-value imports (includes tariffs)
V0TAR(c)	c∈COM	Tariff revenue
V0TAR_C		Total tariff revenue
V0TAX_CSI		Total indirect tax revenue
V1BAS(c,s,i)	c∈COM s∈SRC i∈IND	Intermediate basic flows
V1CAP(i)	i∈IND	Capital rentals
V1CAP_I		Total payments to capital
V1CAPPTS(v)	v∈VINTAGE	Capital rental for cars of diff. Vintages
V1CAPPTS_V		Capital rentals: PTS
V1FCTPTS(v)	v∈VINTAGE	FCT
V1FCTPTS_V		Total FCT revenue
V1FULPRIMPTS(v)	v∈VINTAGE	MVPETROL + primary factor: PTS industry
V1LAB(i,o)	i∈IND o∈OCC	Wage bill matrix
V1LAB_I(o)	o∈OCC	Total wages, occupation o
V1LAB_IO		Total payments to labour
V1LAB_O(i)	i∈IND	Total labour bill in industry i
V1LABPTS(v,o)	v∈VINTAGE o∈OCC	Wage bills for cars of different vintages
V1LABPTS_O(v)	v∈VINTAGE	
V1LND(i)	i∈IND	Land rentals
V1LND_I		Total payments to land
V1LNDPTS(v)	v∈VINTAGE	Land rental for cars of different vintages
V1MVPETROL_F(v)	v∈VINTAGE	

....continued

Table A1.4 (continued)

Coefficient	Index range	Description
V1MAR(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Intermediate margins
V1OCT(i)	i∈IND	Other cost tickets
V1OCT_I		Total other cost ticket payments
V1OCTPTS(v)	v∈VINTAGE	Other cost tickets for cars of diff. Vintages
V1PRIM(i)	i∈IND	Total factor input to industry i
V1PRIM_I		Total primary factor payments
V1PRIMPTS(v)	v∈VINTAGE	Primary factor: PTS industry
V1PUR(c,s,i)	c∈COM s∈SRC i∈IND	Intermediate purch. Value
V1PUR_S(c,i)	c∈COM i∈IND	Dom+imp intermediate purchasers' value
V1PUR_SI(c)	c∈COM	Dom+imp intermediate purchasers' value
V1PURPTS_S(c,v)	c∈COM v∈VINTAGE	Input cost, by vintage, at purchasers' price
V1PURPTS_SV(c)	c∈COM	
V1PURUP(c)	c∈COM	
V1STX(c,s,i)	c∈COM s∈SRC i∈IND	SP taxes on intermediate
V1TAX(c,s,i)	c∈COM s∈SRC i∈IND	AV taxes on intermediate
V1TAX_CSI		Total intermediate tax revenue
V1TOT(i)	i∈IND	Total cost of industry i
V1TOTPTS(v)	v∈VINTAGE	Total costs, by vintage
V1VALAD(i)	i∈IND	Total value-added, industry i
V1VLTPTS(v)	v∈VINTAGE	VLT
V1VLTPTS_V		Total VLT revenue
V2BAS(c,s,i)	c∈COM s∈SRC i∈IND	Investment basic flows
V2BAS_I(c,s)	c∈COM s∈SRC	Total investment use by com and src
V2MAR(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Investment margins
V2PUR(c,s,i)	c∈COM s∈SRC i∈IND	Investment purch. value
V2PUR_S(c,i)	c∈COM i∈IND	Dom+imp investment purch. value
V2PUR_SI(c)	c∈COM	Dom+imp investment purch. value
V2TAX_CSI		Total investment tax revenue

....continued

Table A1.4 (continued)

Coefficient	Index range	Description
V2STX(c,s,i)	c∈COM s∈SRC i∈IND	SP taxes on investment
V2TAX(c,s,i)	c∈COM s∈SRC i∈IND	AV taxes on investment
V2TOT(i)	i∈IND	Total capital created for industry i
V2TOT_I		Total investment usage
V3BAS(c,s)	c∈COM s∈SRC	Household basic flows
V3ISLANTRN		
V3MAR(c,s,m)	c∈COM s∈SRC m∈MAR	Households margins
V3PUR(c,s)	c∈COM s∈SRC	Households purch. value
V3PUR_S(c)	c∈COM	Dom+imp households purch. value
V3STX(c,s)	c∈COM s∈SRC	SP taxes on households
V3TAX(c,s)	c∈COM s∈SRC	AV taxes on households
V3TAX_CS		Total households tax revenue
V3TOT		Total purchases by households
V4BAS(c)	c∈COM	Export basic flows
V4BSTOT		Sum of all exports at basic price
V4MAR(c,m)	c∈COM m∈MAR	Export margins
V4OTHEREXP		Total non-traditional export earnings
V4PUR(c)	c∈COM	Export purch. value
V4STX(c)	c∈COM	SP taxes on export
V4TAX(c)	c∈COM	AV taxes on export
V4TAX_C		Total export tax revenue
V4TOT		Total export earnings
V5BAS(c,s)	c∈COM s∈SRC	Government basic flows
V5MAR(c,s,m)	c∈COM s∈SRC m∈MAR	Government margins
V5PUR(c,s)	c∈COM s∈SRC	Government purch. value
V5STX(c,s)	c∈COM s∈SRC	SP taxes on government
V5TAX(c,s)	c∈COM s∈SRC	AV taxes on government
V5TAX_CS		Total government tax revenue
V5TOT		Total value of government demands
V6BAS(c,s)	c∈COM s∈SRC	Inventories basic flows
V6TOT		Total value of inventories
VALRAT(i)	i∈IND	V1CAP/V2TOT
WAGERATE		Index of real wages

Table A1.5 Variables in version TAIVINT (in alphabetical order)

Variable	Index range	Description
a1_s(c,i)	c∈COM i∈IND65	Tech change, intermediate imp/dom composite
a1cap(i)	i∈IND65	Capital augmenting technical change
a1capPTS(v)	v∈VINTAGE	Capital augmenting technical change, by vintage
a1ener(i)	i∈IND65	Energy-saving technical change
a1enerprim(i)	i∈IND65	Energy-factor-saving technical change
a1fulprimPTS(v)	v∈VINTAGE	Motor-fuel-factor-saving technical change, by vintage
a1lab_o(i)	i∈IND65	Labor augmenting technical change
a1labPTS_o(v)	v∈VINTAGE	Labor augmenting technical change, by vintage
a1lnd(i)	i∈IND65	Land augmenting technical change
a1lndPTS(v)	v∈VINTAGE	Land augmenting technical change, by vintage
a1mar(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Intermediate margin tech change
a1mvpetrol_f(v)	v∈VINTAGE	Motor-fuel-saving technical change, by vintage
a1oct(i)	i∈IND65	"Other cost" ticket augmenting technical change
a1octPTS(v)	v∈VINTAGE	"Other cost" ticket augmenting technical change, by vintage
a1prim(i)	i∈IND65	All factor augmenting technical change
a1prim_i		Overall factor-augmenting technical change
a1primPTS(v)	v∈VINTAGE	All factor augmenting technical change, by vintage
a1PTS_s(c,v)	c∈COM v∈VINTAGE	Input augmenting technical change, by vintage
a1tot(i)	i∈IND	All input augmenting technical change
a1vintserv(v)	v∈VINTAGE	All input augmenting technical change, by vintage
a2_s(c,i)	c∈COM i∈IND	Tech. change, investment imp/dom composite
a2mar(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Investment margin tech change
a2tot(i)	i∈IND	Neutral technical change - investment
a3_s(c)	c∈COMT	Taste change, household imp/dom composite
a3lux(c)	c∈COMT	Taste change, supernumerary demands
a3mar(c,s,m)	c∈COM s∈SRC m∈MAR	Household margin tech change
a3sub(c)	c∈COMT	Taste change, subsistence demands
a4mar(c,m)	c∈COM m∈MAR	Export margin tech change
a5mar(c,s,m)	c∈COM s∈SRC m∈MAR	Government margin tech change
acom(c)	c∈COM	Uniform tech shift by commodity
aelec		Ray movement of frontier

....continued

Table A1.5 (continued)

Variable	Index range	Description
allco2		Change in total CO2 emissions
allco2badcom(c)	c∈BADCOM1	Total CO2 emissions by BADCOM
allco2user(u)	u∈LOCALUSER1	Total CO2 emissions by LOCALUSER
contco2(c,s,u)	c∈BADCOM1 s∈SRC1 u∈LOCALUSER1	Contributions to total CO2 emissions, by com, by src, by local users
contfuelp(e,s,i)	e∈ENERCOM s∈SRC i∈ELECIND	Contributions to aggregate fuel prices by ELECIND
contRawEelc(e,s)	e∈ELECGEN s∈SRC	Contributions to total raw electricity purchases by "EndUseElec"
delB		(Balance of trade)/GDP
delctax(c)	c∈COM	Carbon tax instrument
delctax_c		Carbon tax instrument
delctax1		Carbon tax instrument
delctax2		Carbon tax instrument
delctax3		Carbon tax instrument
delctax4		Carbon tax instrument
delctax5		Carbon tax instrument
delempratio		Ordinary change in (actual/trend)employment
delfwage		Shifter for real wage adjustment mechanism
delgret(i)	i∈IND	Ordinary change in gross rate of return
delgretexp(i)	i∈IND	Ordinary change in expected rate of return
delp1fuel_s(i)	i∈ELECIND	Ordinary change in fuel price
dels1(c,s,i)	c∈COM s∈SRC i∈IND	Ordinary change in (specific rate) tax intermediate
dels2(c,s,i)	c∈COM s∈SRC i∈IND	Ordinary change in (specific rate) tax investment
dels3(c,s)	c∈COM s∈SRC	Ordinary change in (specific rate) tax household
dels4(c)	c∈COM	Ordinary change in (specific rate) tax export
dels5(c,s)	c∈COM s∈SRC	Ordinary change in (specific rate) tax government
delUnity		Dummy variable, always exogenously set to one
delv0_s(c)	c∈COM	General sales tax shifter
delv1(c,s,i)	c∈COM s∈SRC i∈IND	Ordinary change in (% *ad valorem* rate) tax intermediate
delv1_csi		Uniform change in % AV rate of tax on intermediate
delV1CSTPTS(v)	v∈VINTAGE	Change in VLT + FCT exclusive cost of production
delV1FCTPTS(v)	v∈VINTAGE	Change in FCT
delV1PRIMPTS(v)	v∈VINTAGE	Ordinary change in cost of primary factors
delV1TOTPTS(v)	v∈VINTAGE	Change in VLT + FCT inclusive total cost of production

....continued

Table A1.5 (continued)

Variable	Index range	Description
delV1VLTPTS(v)	v∈VINTAGE	Change in VLT
delv2(c,s,i)	c∈COM s∈SRC i∈IND	Ordinary change in (% *ad valorem* rate) tax investment
delv2_csi		Uniform change in % AV rate of tax on investment
delv3(c,s)	c∈COM s∈SRC	Ordinary change in (% *ad valorem* rate) tax household
delv3_cs		Uniform change in % AV rate of tax on household
delv4(c)	c∈COM	Ordinary change in (% *ad valorem* rate) tax export
delv4_ntrad		Uniform change in % AV rate of tax, non-traditional exports
delv4_trad		Uniform change in % AV rate of tax, traditional exports
delv5(c,s)	c∈COM s∈SRC	Ordinary change in (% *ad valorem* rate) tax government
delv5_cs		Uniform change in % *ad valorem* rate of tax on household
delvci1_s(c,i)	c∈COM i∈IND	Ordinary percentage change *ad valorem* tax on Petroleum, for producers
delvci2_s(c,i)	c∈COM i∈IND	Ordinary percentage change *ad valorem* tax on Petroleum, for investors
delvci3_s(c)	c∈COM	Ordinary percentage change *ad valorem* tax on Petroleum, for households
delw4tax_c		Aggregate revenue from indirect taxes on export
delw5tax_cs		Aggregate revenue from indirect taxes on government
delwagerate		Change in real wage index
delx6(c,s)	c∈COM s∈SRC	Inventories demands (ordinary change)
delxRawElecV		Result close to xRawElecV = amount of raw electricity, value weights
electwist(c)	c∈COM	Twist variable for electricity sourcing
electwist_c		Average of electwist
employ(i)	i∈IND	Employment by industry
employ_i		Aggregate employment: wage bill weights
emptrend		Trend employment
f1fctPTS(v)	v∈VINTAGE	Shifter for p1fctPTS
f1lab(i,o)	i∈IND o∈OCC	Wage shift variable
f1lab_i(o)	o∈OCC	Occupation-specific wage shifter
f1lab_io		Overall wage shifter
f1lab_o(i)	i∈IND	Industry-specific wage shifter
f1oct(i)	i∈IND	Shift in price of "other cost" tickets
f1vltPTS(v)	v∈VINTAGE	Shifter for p1vltPTS
f3tot		Ratio, consumption/GDP
f4p(c)	c∈COM	Price (upward) shift in export demand schedule
f4p_c		Overall price (upward) demand shift for exports
f4p_ntrad		Upward demand shift, non-traditional export aggregate
f4q(c)	c∈COM	Quantity (right) shift in export demands

....continued

Table A1.5 (continued)

Variable	Index range	Description
f4q_c		Overall quantity (right) demand shift for exports
f4q_ntrad		Right demand shift, non-traditional export aggregate
f4q_trad		Right demand shift, traditional export aggregate
f5(c,s)	c∈COM s∈SRC	Government demand shift
f5tot		Overall shift term for government demands
f5tot2		Ratio between f5tot and x3tot
faccum(i)	i∈IND	Shifter to switch on accumulation equation
faccumPTS(v)	v∈VINTAGE	Shifter for the PTS industry only
fandecomp(c,f)	c∈COM f∈FANCAT	Fan decomposition
finv(i)	i∈EXOGINV	Investment shifter
finv2(i)	i∈IND	Shifter to toggle long-run investment rule
finv2_i		Overall shifter for investment rule
fpf0cif(c)	c∈COM	Shift variable for pf0cif(c)
fpf0cif_c		Shift variable for aggregate pf0cif(c)
fx6(c,s)	c∈COM s∈SRC	Shifter on rule for stocks (ordinary change)
fx6B(c,s)	c∈COM s∈SRC	Shifter for stock rule B
fx6B_c		Shifter for stock rule B
gretxp(i)	i∈IND	Percent change in expected rate of return
gro(i)	i∈IND	Planned investment/capital ratio
gtrend(i)	i∈IND	Trend investment/capital ratio
hislandtrnsp		Household transport on the Taiwan island
LEVCO2		Total CO2 emission level
mratio(i)	i∈IND	Ratio, (expected/normal) rate of return
p0(c,s)	c∈COM s∈SRC	Basic prices by commodity and source
p0cif(c)	c∈COM	C.i.f. domestic currency import prices
p0cif_c		Imports price index, c.i.f., $NT
p0com(c)	c∈COM	Output price of locally-produced commodity
p0dom(c)	c∈COM	Basic price of domestic goods = p0(c,"dom")
p0gdpexp		GDP price index, expenditure side
p0imp(c)	c∈COM	Basic price of imported goods = p0(c,"imp")
p0imp_c		Duty-paid imports price index, $NT
p0realdev		Real devaluation
p0toft		Terms of trade
p1(c,s,i)	c∈COM s∈SRC i∈IND	Purchaser's price, intermediate inputs
p1_s(c,i)	c∈COM i∈IND	Price, intermediate imp/dom composite
p1cap(i)	i∈IND	Rental price of capital

....*continued*

Table A1.5 (continued)

Variable	Index range	Description
p1cap_i		Average capital rental
p1capPTS(v)	v∈VINTAGE	Capital rental, by vintage
p1com(c)	c∈COM	Average intermediate user price
p1ener(i)	i∈IND65	Price of composite energy
p1enerprim(i)	i∈IND65	Price of energy-primary-factor composite
p1fctPTS(v)	v∈VINTAGE	Rate of fuel consumption tax (FCT)
p1fuel(s,i)	s∈SRC i∈IND	Index of fuel costs (dom/imp)
p1fuel_s(i)	i∈IND	Index of fuel costs (dom+imp)
p1fulprimPTS(v)	v∈VINTAGE	Price of energy-primary-factor composite, by vintage
p1lab(i,o)	i∈IND o∈OCC	Wages by industry and occupation
p1lab_io		Average nominal wage
p1lab_o(i)	i∈IND	Price of labour composite
p1labPTS(v,o)	v∈VINTAGE o∈OCC	Price of labour composite, by vintage, by occupation
p1labPTS_o(v)	v∈VINTAGE	Price of labour composite, by vintage
p1lnd(i)	i∈IND	Rental price of land
p1lndPTS(v)	v∈VINTAGE	Rental price of land, by vintage
p1mat(i)	i∈IND	Index of material costs
p1mvpetrol_f(v)	v∈VINTAGE	Price of composite motor fuel, by vintage
p1oct(i)	i∈IND	Price of "other cost" tickets
p1octPTS(v)	v∈VINTAGE	Price of "other cost" tickets, by vintage
p1prim(i)	i∈IND	Effective price of primary factor composite
p1primPTS(v)	v∈VINTAGE	Effective price of primary factor composite, by vintage
p1tot(i)	i∈IND	Average input/output price
p1vintserv(v)	v∈VINTAGE	Average input/output price, by vintage
p1vltPTS(v)	v∈VINTAGE	Rate of vehicle license tax (VLT)
p2(c,s,i)	c∈COM s∈SRC i∈IND	Purchaser's price, investment
p2_s(c,i)	c∈COM i∈IND	Price, investment imp/dom composite
p2tot(i)	i∈IND	Cost of unit of capital
p2tot_i		Aggregate investment price index
p3(c,s)	c∈COM s∈SRC	Purchaser's price, household consumption
p3_s(c)	c∈COM	Price, household imp/dom composite
p3tot		Consumer price index
p4(c)	c∈COM	Purchaser's price, exports $NT
p4_ntrad		Price, non-traditional export aggregate
p4tot		Exports price index
p5(c,s)	c∈COM s∈SRC	Purchaser's price, government

....*continued*

Table A1.5 (continued)

Variable	Index range	Description
p5tot		Government price index
p6tot		Inventories price index
pe(c)	c∈COM	Basic price of export commodity
pf0cif(c)	c∈COM	C.i.f. foreign currency import prices
phi		Exchange rate, $NT/$world
phislantrnsp		Price of island transport (= Highway + Railway)
pRawElec		Average price to EndUseElec of electric power
q		Number of households
q1(c,i)	c∈COM i∈IND	Output by commodity and industry
realwage		Average real wage
rnorm(i)	i∈IND	Normal gross rate of return
spindex		Price index for specific taxes
t0imp(c)	c∈COM	Power of tariff
totco2		Total CO2 emission
trdvol		Volume of international trade
twistexp		Rotate EXP/DOM CET frontier = pe - p0dom
twistsrc(c)	c∈COM	Dom/imp ratio twist
twistsrc_c		Overall dom/imp ratio twist
utility		Utility per household
w0cif_c		C.i.f. $NT value of imports
w0gdpexp		Nominal GDP from expenditure side
w0gdpinc		Nominal GDP from income side
w0imp_c		Value of imports plus duty
w0tar_c		Aggregate tariff revenue
w0tax_csi		Aggregate revenue from all indirect taxes
w1cap_i		Aggregate payments to capital
w1lab_io		Aggregate payments to labour
w1lnd_i		Aggregate payments to land
w1oct_i		Aggregate "other cost" ticket payments
w1tax_csi		Aggregate revenue from indirect taxes on intermediate
w2tax_csi		Aggregate revenue from indirect taxes on investment
w2tot_i		Aggregate nominal investment
w3lux		Total nominal supernumerary household expenditure
w3tax_cs		Aggregate revenue from indirect taxes on households
w3tot		Nominal total household consumption
w4tot		$NT border value of exports
w5tot		Aggregate nominal value of government demands
w6tot		Aggregate nominal value of inventories
x0cif_c		Import volume index, c.i.f. weights
x0com(c)	c∈COM	Output of commodities
x0dom(c)	c∈COM	Output of commodities for local market
x0gdpexp		Real GDP from expenditure side

....continued

Table A1.5 (continued)

Variable	Index range	Description
x0imp(c)	c∈COM	Total supplies of imported goods
x0imp_c		Import volume index, duty-paid weights
x0loc(c)	c∈COM	Real percent change in LOCSALES (dom+imp)
x1(c,s,i)	c∈COM s∈SRC i∈IND	Intermediate basic demands
x1_s(c,i)	c∈COM i∈IND	Intermediate use of imp/dom composite
x1_sEndUse(e)	e∈ELECGEN	Demand for ELECGEN by "EndUseElec"
x1ass_i		Aggregate usage of capital, asset weights
x1cap(i)	i∈IND	Current capital stock
x1cap_i		Aggregate capital stock, rental weights
x1capPTS(v)	v∈VINTAGE	Current capital stock, by vintage
x1capQ		Aggregate capital stock of private cars
x1fctPTS(v)	v∈VINTAGE	Tax base of FCT
x1fulprimPTS(v)	v∈VINTAGE	Motor-fuel-primary-factor composite, by vintage
x1lab(i,o)	i∈IND o∈OCC	Employment by industry and occupation
x1lab_i(o)	o∈OCC	Employment by occupation
x1lab_o(i)	i∈IND	Effective labour input
x1labPTS(v,o)	v∈VINTAGE o∈OCC	Effective labour input, by vintage, by occupation
x1labPTS_o(v)	v∈VINTAGE	Effective labour input, by vintage
x1lnd(i)	i∈IND	Use of land
x1lndPTS(v)	v∈VINTAGE	Use of land, by vintage
x1mar(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Intermediate margin demands
x1mvpetrol_f(v)	v∈VINTAGE	Composite motor fuel
x1oct(i)	i∈IND	Demand for "other cost" tickets
x1octPTS(v)	v∈VINTAGE	Demand for "other cost" tickets, by vintage
x1prim(i)	i∈IND	Primary factor composite
x1prim_i		Aggregate output: value-added weights
x1primPTS(v)	v∈VINTAGE	Primary factor composite, by vintage
x1PTS_s(c,v)	c∈COM v∈VINTAGE	Dom+imp intermediate basic demands of vintaged cars
x1PTS_sv(c)	c∈COM	Dom+imp intermediate basic demands of PTS
x1tot(i)	i∈IND	Activity level or value-added
x1vintserv(v)	v∈VINTAGE	Activity level or value-added, by vintage
x1vltPTS(v)	v∈VINTAGE	Tax base of VLT
x2(c,s,i)	c∈COM s∈SRC i∈IND	Investment basic demands

....continued

Table A1.5 (continued)

Variable	Index range	Description
x2_i(c,s)	c∈COM s∈SRC	Total investment use by commodity and source
x2_s(c,i)	c∈COM i∈IND	Investment use of imp/dom composite
x2mar(c,s,i,m)	c∈COM s∈SRC i∈IND m∈MAR	Investment margin demands
x2tot(i)	i∈IND	Investment by using industry
x2tot_i		Aggregate real investment expenditure
x3(c,s)	c∈COM s∈SRC	Household basic demands
x3_s(c)	c∈COM	Household use of imp/dom composite
x3lux(c)	c∈COMT	Household - supernumerary demands
x3mar(c,s,m)	c∈COM s∈SRC m∈MAR	Household margin demands
x3sub(c)	c∈COMT	Household - subsistence demands
x3tot		Real household consumption
x4(c)	c∈COM	Export basic demands
x4_ntrad		Quantity, non-traditional export aggregate
x4mar(c,m)	c∈COM m∈MAR	Export margin demands
x4tot		Export volume index
x5(c,s)	c∈COM s∈SRC	Government basic demands
x5mar(c,s,m)	c∈COM s∈SRC m∈MAR	Government margin demands
x5tot		Aggregate real government demands
x6(c,s)	c∈COM s∈SRC	Inventories demands
x6tot		Aggregate real inventories
xRawElecP		Amount of raw electricity, mega-watt hour weights
xRawElecV		Amount of raw electricity, value weights

APPENDIX 2
Typical Comparative Static and Dynamic Closures Used in Standard TAIGEM

The table below lists exogenous variables used in recursive dynamic simulations described in Section 3.11. As explained in the text, different closures are used for the historical period 1995-97 and the forecast period 1999 onwards (the year 1998 is an intermediate case). The first four rows below show which variables were exogenous in 1995-97, and from 1998 onwards. The remaining rows show which variables were exogenous in 1995-98, and from 1999 onwards. For a short-run comparative static simulation, the closure of the forecasting period 1999 onwards could be used.

Variable description	Size	Year 1995-97	Year 1998	Year 1999 onwards
Aggregate employment: wage bill weights	1	employ_i		delfwage
GDP price index	1	p0gdpexp		p3tot
Exports price index	1	p4tot		twistexp
Exchange rate, $NT/$world	1	phi		a1prim_i
Real household consumption	1		x3tot	f3tot
Aggregate real investment expenditure	1		x2tot_i	finv2_i
Aggregate real government demands	1		x5tot	f5tot2
Aggregate real inventories	1		x6tot	fx6B_c
shifter for stock rule B	COM*SRC	fx6B(SMALLSTOK,SRC)		x6(SMALLSTOK,SRC)
Export volume index	1		x4tot	f4p_c
Import volume index, duty-paid weights	1		x0imp_c	twistsrc_c
Inventories demands	COM*SRC		x6(BIGSTOK,SRC)	x6(BIGSTOK,SRC)

(Remaining exogenous variables are the same in all closures.)

APPENDIX 3
CES: Linearised Equations, Reverse Shares and Twist Variables[1]

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1 The derivation shown here draws largely on Horridge, Parmenter, and Pearson (1998, Appendix A).

Derivation of the linearised equations of a CES nest

We derive the linearised equations of a CES nest as follows.

Choose X_c, for all c∈ENER, to minimise total cost,

$$C = \sum_{c\in ENER} P_c X_c ,$$

subject to

$$Z = \left(\sum_{c\in ENER} \delta_c \left(\frac{X_c}{A_c}\right)^{-\rho}\right)^{-1/\rho}, \quad \sum_{c\in ENER} \delta_c = 1, \; -1 \le \rho < 0. \qquad \text{(A3.1)}$$

Setting

$$\tilde{X}_c = \frac{X_c}{A_c}, \text{ and, } \tilde{P}_c = P_c A_c , \qquad k\in ENER, \quad \text{(A3.2)}$$

we rewrite the problem as:

choose $\tilde{X}_c$, for all c∈ENER, to minimise total cost,

$$C = \sum_{c\in ENER} \tilde{P}_c \tilde{X}_c ,$$

subject to

$$Z = \left(\sum_{c\in ENER} \delta_c \tilde{X}_c^{-\rho}\right)^{-1/\rho}. \qquad \text{(A3.3)}$$

The associated first order conditions are:

$$\tilde{P}_k = \Lambda \frac{\partial Z}{\partial \tilde{X}_k} = \Lambda \delta_k \tilde{X}_k^{-(1+\rho)} \left(\sum_{c\in ENER} \delta_c \tilde{X}_c^{-\rho}\right)^{-(1+\rho)/\rho}, \qquad k\in ENER. \quad \text{(A3.4)}$$

Hence,

$$\frac{\tilde{P}_k}{\tilde{P}_c} = \frac{\delta_k}{\delta_c}\left(\frac{\tilde{X}_c}{\tilde{X}_k}\right)^{1+\rho}, \qquad c, k\in ENER, \quad \text{(A3.5)}$$

or,

$$\tilde{X}_c^{-\rho} = \left(\frac{\delta_c \tilde{P}_k}{\delta_k \tilde{P}_c}\right)^{-\rho/(\rho+1)} \tilde{X}_k^{-\rho}, \qquad c\in ENER. \quad \text{(A3.6)}$$

Substituting the above expression back into Equation A3.3, we obtain:

$$Z = \tilde{X}_k \left(\sum_{c\in ENER} \delta_c \left(\frac{\delta_k \tilde{P}_c}{\delta_c \tilde{P}_k}\right)^{\rho/(\rho+1)}\right)^{-1/\rho}. \qquad \text{(A3.7)}$$

This gives the input demand functions:

$$\tilde{X}_k = Z * \left(\sum_{c\in ENER} \delta_c \left(\frac{\delta_k \tilde{P}_c}{\delta_c \tilde{P}_k}\right)^{\rho/(\rho+1)}\right)^{1/\rho}, \qquad k\in ENER, \quad \text{(A3.8)}$$

or,

$$\tilde{X}_k = Z * \delta_k^{1/(\rho+1)} * \left(\frac{\tilde{P}_k}{\tilde{P}_{ave}}\right)^{-1/(\rho+1)}, \qquad k\in ENER, \quad \text{(A3.9)}$$

where

$$\tilde{P}_{ave} = \left(\sum_{c\in ENER} \delta_c^{1/(\rho+1)} \tilde{P}_c^{\rho/(\rho+1)}\right)^{(\rho+1)/\rho}. \qquad \text{(A3.10)}$$

Transforming to percentage changes we get:

$$\tilde{x}_k = z - \sigma * \left(\tilde{p}_k - \tilde{p}_{ave}\right), \qquad k\in ENER, \quad \text{(A3.11)}$$

and

$$\tilde{p}_{ave} = \sum_{c\in ENER} S_c \tilde{p}_c , \qquad \text{(A3.12)}$$

where

$$\sigma = \frac{1}{\rho+1} \text{ and } S_c = \frac{\delta_c^{1/(\rho+1)} \tilde{P}_c^{\rho/(\rho+1)}}{\sum_{k\in ENER} \delta_k^{1/(\rho+1)} \tilde{P}_k^{\rho/(\rho+1)}}, \qquad c\in ENER. \quad \text{(A3.13)}$$

Multiplying both sides of Equation A3.9 by $\tilde{P}_k$ we get:

$$\tilde{P}_k \tilde{X}_k = Z * \delta_k^{1/(\rho+1)} * \tilde{P}_k^{\rho/(\rho+1)} * \tilde{P}_{ave}^{1/(\rho+1)}. \qquad k\in ENER, \quad \text{(A3.14)}$$

Hence,

$$\frac{\tilde{P}_k \tilde{X}_k}{\sum_{c\in ENER} \tilde{P}_c \tilde{X}_c} = \frac{\delta_k^{1/(\rho+1)} \tilde{P}_k^{\rho/(\rho+1)}}{\sum_{c\in ENER} \delta_c^{1/(\rho+1)} \tilde{P}_c^{\rho/(\rho+1)}} = S_k, \qquad k\in ENER. \quad \text{(A3.15)}$$

That is, the S_c (Equation A3.13) measure cost shares.

But from Equation A3.2, $\tilde{x}_k = x_k - a_k$, and $\tilde{p}_k = p_k + a_k$, giving:

$$x_k - a_k = z - \sigma[p_k + a_k - \tilde{p}_{ave}], \qquad k\in ENER, \quad \text{(A3.16)}$$

where

$$\tilde{p}_{ave} = \sum_{c\in ENER} S_c (p_c + a_c). \qquad \text{(A3.17)}$$

Adjusting to technical change (the a variables), $\tilde{x}_k$, $\tilde{p}_k$ and $\tilde{p}_{ave}$ refer to *effective* input quantities and prices.

Reverse shares in a two-input CES case

In GEMPACK's TABLO code, we use "reverse shares" in a two-input CES (e.g., the source substitution) case to speed up computation. Equations A3.16 and A3.17, with index c referring to 2 arguments, can be rewritten as:

$$x_1 - a_1 = z - \sigma[p_1 + a_1 - S_1(p_1 + a_1) - S_2(p_2 + a_2)], \qquad \text{(A3.18)}$$

and

$$x_2 - a_2 = z - \sigma[p_2 + a_2 - S_1(p_1 + a_1) - S_2(p_2 + a_2)]. \qquad \text{(A3.19)}$$

Since $S_2 = 1 - S_1$,

$$x_1 - a_1 = z - \sigma S_2[(p_1 + a_1) - (p_2 + a_2)], \qquad \text{(A3.20)}$$

and

$$x_2 - a_2 = z + \sigma S_1[(p_1 + a_1) - (p_2 + a_2)]. \qquad \text{(A3.21)}$$

When condensing the model, collecting Equations A3.20 and A3.21 into a single vector equation enables the software to substitute out x.

$$x_k - a_k = z - \sigma R_k[(p_1 + a_1) - (p_2 + a_2)], \qquad k = 1, 2. \text{ (A3.22)}$$

The R_k are dubbed *reverse shares*, defined by:

$$R_1 = S_2$$

and

$$R_2 = R_1 - 1 = S_2 - 1 = - S_1 . \qquad \text{(A3.23)}$$

Note that $R_1 - R_2 = 1$.

Equation A3.17 is rewritten as:

$$\tilde{p}_{ave} = \sum_{i=1}^{2} S_i\,(p_i + a_i) = R_1(p_2 + a_2) - R_2(p_1 + a_1). \qquad \text{(A3.24)}$$

Twist for two input CES

A twist is a combination of small technical changes which, taken together, are locally cost neutral. For example, we might ask, what values for a_1 and a_2 would, in the absence of price changes, cause the ratio $(x_1 - x_2)$ to increase by t% without affecting p_{ave}?

That is, given all p_i's unchanged, Equation A3.17 becomes:

$$S_1 a_1 + S_2 a_2 = 0, \qquad \text{(A3.25)}$$

and Equations A3.20 and A3.21 are consolidated into:

$$x_1 - x_2 = (1 - \sigma)*(a_1 - a_2). \qquad \text{(A3.26)}$$

We are to find the combination of a_1 and a_2 which give rise to $(x_1 - x_2) = t$.

Equation A3.26 hence can be written as:

$$a_1 = \frac{t}{1 - \sigma} + a_2 . \qquad \text{(A3.27)}$$

Substituting Equation A3.27 into A3.25, we get:

$$a_1 = S_2\left(\frac{t}{1 - \sigma}\right),$$

and

$$a_2 = -S_1\left(\frac{t}{1 - \sigma}\right). \qquad \text{(A3.28)}$$

Adopting the *reverse share* notation,

$$a_k = R_k\left(\frac{t}{1 - \sigma}\right), \qquad k = 1, 2. \qquad \text{(A3.29)}$$

Substituting Equation A3.29 back into Equation A3.16, we get:

$$x_k = z + R_k\left(\frac{t}{1 - \sigma}\right) - \sigma R_k\left[p_1 - p_2 + (R_1 - R_2)*\left(\frac{t}{1 - \sigma}\right)\right], k = 1, 2.$$

Since $R_1 - R_2 = 1$,

$$x_k = z + R_k t - \sigma R_k(p_1 - p_2), \qquad k = 1, 2.$$

With the twist variable, Equation A3.16 can be rewritten as:

$$x_k = z + R_k[t - \sigma(p_1 - p_2)], \qquad k = 1, 2, \text{ (A3.30)}$$

and Equation A3.24 can be rewritten as:

$$\tilde{p}_{ave} = R_1 p_2 - R_2 p_1. \qquad \text{(A3.31)}$$

Twist variables (variable t in the example above) are added to account for non-price induced changes in the ratios of imperfect substitutes. Figure A3.1 illustrates the function of "twist" variables for the domestic/imports CES nesting. Curve AA is an indifference curve indicating the combinations of domestic (X_{dom}) and imported (X_{imp}) goods that yield the same utility. Point X indicates the utility-maximising combination with given budget. Changes in preference (i.e., variations in a_1 and a_2) pivot curve AA around point X to the position of curve BB. Point X′ denotes the desired combination after the pivoting of the indifference curve. The shift is cost neutral in the sense that the original bundle yields the same utility. In the diagram, bundle X' costs less than bundle X, but this cost reduction is of second-order significance only. Twist variables explain the variation of the domestic/imports ratio (i.e., from X to X′) while prices are held constant.

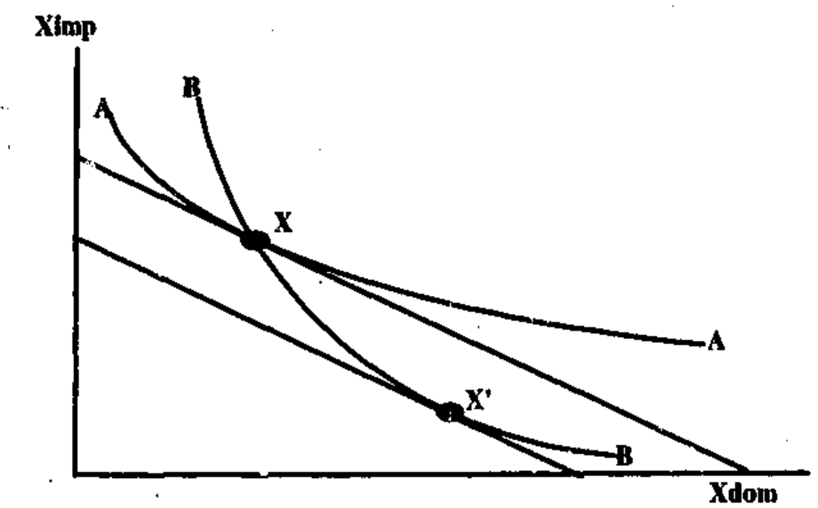

Figure A3.1 Locally cost-neutral twist of the isoquant

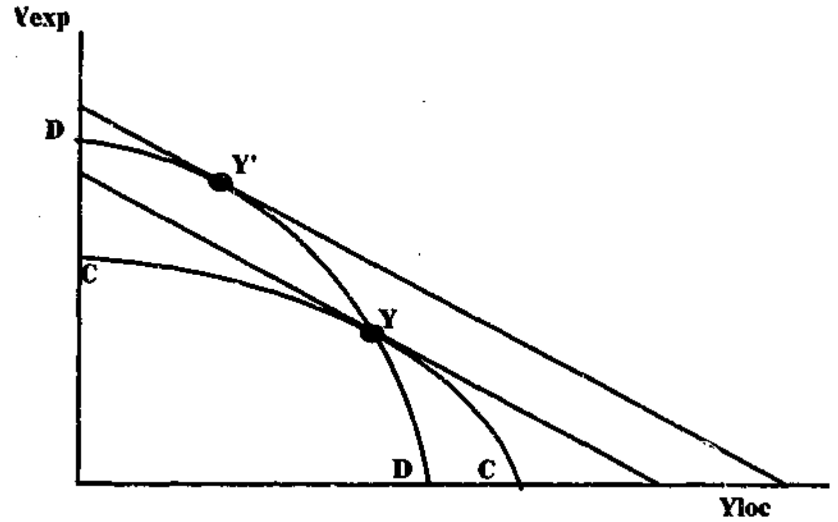

Figure A3.2 Locally revenue-neutral twist of the transformation frontier

Analogously, Figure A3.2 shows how twist variables work in the case of the CET output transformation. Changes in transformation technology pivot transformation frontier CC around point Y to frontier DD. This leads to changes in the ratio of Y_{loc} and Y_{exp}, i.e., from point Y to point Y'.

Twist variables are useful when running historical simulations with the dynamic version of TAIGEM. For example, in simulations where import volumes and prices are exogenously given, we specify the twist variables endogenous to account for the observed changes in import volumes.

In TAIGEM, we use such twist variables in: (a) the domestic/import CES nesting for goods as intermediate inputs, capital-creating inputs and for household consumption; (b) the 10-source raw electricity CES nesting for the End-use supplier (EUS) industry; and (c) the local/overseas sales CET nesting for domestically-produced goods. We explain them below.

(a) The domestic/import CES nesting for goods as intermediate inputs, capital-creating inputs and for household consumption

We use the domestic/import intermediate input demand as an example. Equation 3.16a of Chapter 3 is quoted below for readers' convenience.

$$\text{x1(c,s,i)} = \text{x1\_s(c,i)} + \text{RS1(c,s,i)}*\{\text{twistsrc(c)} + \text{twistsrc\_c} - \text{SIGMA1(c)}*[\text{p1(c,"dom",i)} - \text{p1(c,"imp",i)}]\}, \quad c\in\text{COM},\ s\in\text{SRC},\ i\in\text{IND}. \quad (3.16a)$$

In Equation 3.16a, a positive percentage change, say 1%, in twistsrc(c) causes an S1(c,"imp",i)% (= RS1(c,"dom",i)) in favour of domestically-produced good c, and an S1(c,"dom",i)% (= RS1(c,"imp",i)) decrease in demand for imported good c. S1(c,s,i) is the share of good c from source s purchased by industry i as an input to current production, i.e., $\text{S1(c,s,i)} = \left(\frac{\text{V1PUR(c,s,i)}}{\text{V1PUR\_S(c,i)}}\right)$. Variable twistsrc_c functions the same as the commodity-specific twist(c), except that it affects all commodities at once.

(b) The 10-source raw electricity CES nesting for the End-use Supplier industry

$$\text{x1\_s(j,"EUS")} - \text{a1\_s(j,"EUS")} = \text{xRawElec} + \text{electwist(j)} - \text{electwist\_c} - \text{SIGELEC}*[\text{p1\_s(j,"EUS")} - \text{pRawElec}], \quad j\in\text{ELECGEN}. \quad (3.31a)$$

$$\text{electwist\_c} = \sum_{j\in\text{ELECGEN}}\left(\frac{\text{V1PUR\_S(j,"EUS")}}{\text{VRAWELEC}}\right)*\text{electwist(j)}. \quad (3.33)$$

In Equation 3.31a and 3.33 of Chapter 3, a 1% increase in electwist(j) causes an (1 - Sj)% increase in demand by the EUS industry for raw electricity from source j, and an Sj% decrease in demands for each of the other sources of raw electricity. Sj is the share of raw electricity j purchased by the EUS industry, i.e., Sj = $\left(\frac{\text{V1PUR\_S(j,"EUS")}}{\text{VRAWELEC}}\right)$.

(c) The local/overseas sales CET nesting for domestically-produced goods

$$\text{TAU(c)}*[\text{x0dom(c)} - \text{x4(c)} - \text{twistexp}] = \text{p0dom(c)} - \text{pe(c)}, \quad c\in\text{COM}, \quad (3.71)$$

For clarity, we rearrange Equations 3.66, 3.67 and 3.71 of Chapter 3 as follows, with the *reverse share* idea:

$$\text{x0dom(c)} = \text{x0com(c)} + \text{EXPSHR(c)}*\{\text{twistexp} + \text{SIGMA1DEST(c)}*[\text{p0dom(c)} - \text{pe(c)}], \quad c\in\text{COM}. \quad (3.66a)$$

$$\text{x4(c)} = \text{x0com(c)} + [\text{EXPSHR(c)} - 1]*\{\text{twistexp} + \text{SIGMA1DEST(c)}*[\text{p0dom(c)} - \text{pe(c)}], \quad c\in\text{COM}. \quad (3.67a)$$

In Equation 3.71 of Chapter 3, we have an across-the-board twist variable (i.e., twistexp) for all commodities. A 1% increase in twistexp causes an EXPSHR(c)% increase in sales of domestically-produced good c to the local market, and an [1 - EXPSHR(c)]% decrease in overseas sales of domestically-produced good c.

EXPSHR(c) is the share of domestically-produced good c exported, i.e., $EXPSHR(c) = \left(\frac{V4BAS(c)}{SALES(c)}\right)$.

APPENDIX 4
Calculations for Contributions of Variables

Some equations of the model are included to define reporting or summary variables. One example is the equation for contco2(c,s,u), the contribution of a particular commodity/source/agent to the percentage change in total CO_2 emissions. The contco2(c,s,u) are ordinary change variables which add up to the total percentage change. In this appendix we show how they are derived.

In levels, total emissions are given by:

$$CO2TOT = \sum_{c \in BADCOM} \sum_{s \in SRC} \sum_{u \in LOCALUSERS} CO2(c,s,u). \qquad (3.159)$$

Or, in percentage change form:

$$totco2 = \sum_{c \in BADCOM} \sum_{s \in SRC} \sum_{u \in LOCALUSERS} [CO2(c,s,u)/CO2TOT]*co2(c,s,u).$$

Above, CO2(c,s,u) is a coefficient updated during a multi-step computation; CO2TOT is the total of the CO2(c,s,u).

We define an ordinary change variable contco2(c,s,u) given by:

$$contco2(c,s,u) = [CO2(c,s,u)/BASECO2TOT]*co2(c,s,u),$$

where BASECO2TOT is the *initial* value of CO2TOT. The purpose of this note is to explain why the choice of BASECO2TOT as a denominator leads to values for contco2(c,s,u) that do add up to the final value of totco2.

Assuming that variable X is the sum of A and B in levels:

$$X = A + B.$$

The percentage change form of the above equation is written as:

$$x = [A/X]*a + [B/X]*b. \qquad (A4.1)$$

It seems natural to refer to the terms [A/X]*a and [B/X]*b as the *contributions* of changes in A and B to the changes in X. Unfortunately, contributions calculated in this way do not, in a multi-step computation, add up precisely to the cumulative percentage change in X.

To derive correct expressions for the contributions, it is useful to start from the ordinary change form:

$$\Delta X = \Delta A + \Delta B. \qquad (A4.2)$$

From this we can write:

$$100*\left(\frac{\Delta X}{X^0}\right) = 100*\left(\frac{\Delta A}{X^0}\right) + 100*\left(\frac{\Delta B}{X^0}\right),$$

where X^0 is the initial value of X. The above equation is valid both for small and for finite changes. The LHS expression is, by definition, the percentage change in X. Using the identities, $100\Delta A = Aa$ and $100\Delta B = Bb$, we write:

$$100*\left(\frac{\Delta X}{X^0}\right) = \left(\frac{Aa}{X^0}\right) + \left(\frac{Bb}{X^0}\right),$$

where the term Aa/X^0 is our calculated contribution of the change in A to the percentage change in X.

APPENDIX 5
Disaggregation of the PTS Industry by Vintages

In order to produce the database for the TAIVINT model, it was necessary to split data for the PTS (Private Transport Services) industry into 11 sub-sectors, corresponding to cars aged 0 to 10^+ years. The table below shows the proportions used to perform this split.

		Vintages											
		New	1YO	2YO	3YO	4YO	5YO	6YO	7YO	8YO	9YO	10⁺YO	Total
Number of cars	(A)	252783	538738	507665	539998	449298	439220	441320	355239	220030	129751	325006	4199048
Splitting shares for:													
V1FCT, V1VLT	(B)	0.0602	0.1283	0.1209	0.1286	0.107	0.1046	0.1051	0.0846	0.0524	0.0309	0.0774	1
V1PUR_S(c,"PTS") c = "gasoline", "diesel fuel", "lubricants"	(C)	0.0718	0.1616	0.1125	0.1315	0.1063	0.1041	0.1032	0.0781	0.0451	0.0261	0.0598	1
V1PUR_S(c,"PTS") c = "tyres", "vehicle services"	(D)	0.044	0.1261	0.1196	0.1318	0.1051	0.1112	0.1184	0.0919	0.054	0.0309	0.067	1
V1PUR_S(c,"PTS") c = "insurance"	(E)	0.1363	0.3307	0.1249	0.1177	0.0724	0.0602	0.0525	0.0402	0.0217	0.0117	0.0318	1
V1CAP("PTS")	(F)	0.0747	0.1534	0.1355	0.1289	0.1008	0.0967	0.0991	0.0802	0.0448	0.0249	0.061	1
CAPSTOK("PTS")	(G)	--	0.1365	0.1286	0.1368	0.1139	0.1113	0.1118	0.09	0.0558	0.0329	0.0824	1

All shares were drawn from the 1998 Ministry of Transportation publication (referring to year 1997): Survey of Privately-owned Passenger Vehicle Use, 1997, (in Chinese). Individual rows were derived as follows:

(A) Numbers of cars by age.

(B) Annual taxes V1FCT and V1VLT were split according to the proportions of row (A).

(C) Motor fuels and lubricants shares from average monthly fuel expenses.

(D) Tyres and other inputs from average yearly expenses (repair, cleaning, and parking).

(E) Insurance expenses.

(F) Shares for V1CAP("PTS") (services flows from car stocks) derived from asset values of cars at 1994 prices.

(G) Quantity of car stock = (A)*1994 new car price (i.e., measured in 1994-new-car dollar-worth). Note that purchases of new cars are drawn directly from the DURA input-output database.