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WorldScan: a Model for International Economic Policy Analysis

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Abstract in English

WorldScan is a recursively dynamic general equilibrium model for the world economy, developed for the analysis of long-term issues in international economics. The model is used both as a tool to construct long-term scenarios and as an instrument for policy impact assessments, e.g. in the fields of climate change, economic integration and trade. In general, with each application WorldScan is also adapted. This publication brings the model changes together, explains the model's current structure and illustrates the model's usage with some applications.

Key words: applied general equilibrium models, scenario construction, international economic policy analysis

JEL code: C68, O4, F15, Q54

Abstract in Dutch

WorldScan is een recursief dynamisch algemeen evenwichtsmodel voor de wereldeconomie, ontwikkeld voor de analyse van lange termijn vraagstukken in de internationale economie. Het model wordt zowel ingezet voor de bouw van lange termijn scenario's als voor beleidsanalyses, bijvoorbeeld op het gebied van klimaatverandering, economische integratie en handel. In het algemeen wordt WorldScan bij elke toepassing ook inhoudelijk aangepast. Deze publicatie brengt de modelaanpassingen tezamen, beschrijft de huidige modelstructuur en licht het modelgebruik toe met enkele toepassingen.

Steekwoorden: toegepast algemeen evenwichtsmodellen, scenariobouw, internationaal economische beleidsanalyse

Een uitgebreide Nederlandse samenvatting is beschikbaar via www.cpb.nl.

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Preface

WorldScan is a flexible model that CPB developed to explore and analyse long-term issues in the world economy. The model has repeatedly been used as a tool to construct long-term scenarios and is often deployed for policy analysis. In scenario development, WorldScan acts as an organising device to explore and discuss the potential impacts of current trends such as ageing, the rise of emerging countries, the depletion of fossil energy resources or rising emissions of greenhouse gasses. Simulating these developments may reveal important impacts on the world economy and identify related policy problems. Long-run scenarios have frequently been used as baselines for exploring the impacts of alternative policy options with WorldScan, for example in the fields of global warming, economic integration and trade. Specific policy assessments often require adjustments of the model. Hence, WorldScan has frequently been adapted to make the model better geared to specific problems. The purpose of this publication is to elucidate both the model's current structure and the projection methods that are used for scenario development.

Over the years, many people have contributed to WorldScan. The first version of the model was built by Ben Geurts and Hans Timmer for CPB's scenario study 'Scanning the Future' (CPB, 1992). Under the direction of Hans Timmer, the model was developed further by Arjan Gielen, Arjan Lejour, Richard Nahuis and Paul Tang. As a byproduct of their work 'WorldScan, the Core Version' was published in 1999. Since then, Henri de Groot, Willemien Kets, Nico van Leeuwen, Arjan Lejour, Ton Manders, Guido van Steen, Paul Tang and Gerard Verweij were involved in further adapting and adopting WorldScan. Johannes Bollen (of the MNP Netherlands Environmental Agency) also made important contributions and – together with Ton Manders – used the model extensively for policy assessments in the field of climate change. Many contributions of the people mentioned are still visible in WorldScan as it is today. The authors of this publication are indebted to them and furthermore to many other colleagues at CPB for their comments on previous drafts. In particular, they wish to express their gratitude to Stefan Boeters, Henri de Groot and George Gelauff for their detailed comments and insightful remarks and to Jeannette Verbruggen who did an excellent job in shaping the manuscript in its present form.

Casper van Ewijk

Deputy-director CPB

Summary

This publication presents the structure of WorldScan, a recursively dynamic general equilibrium model for the world economy. WorldScan has been developed to construct long-term scenarios for the global economy and to enable policy analyses in the field of international economics. This publication elucidates both the structure of the model and the projection methods that are used in scenario construction. WorldScan can be adapted to arbitrary sector and country classifications if corresponding input-output tables connected by bilateral trade flows are available for a certain base year. Today, this base year is 2001, the accounts being taken from the 6th database release of the Global Trade Analysis Project (GTAP). WorldScan offers a flexible modelling framework for addressing policy issues in international economics. Dedicated versions of the model exist that all are extensions of a core version in separate directions, such as: a climate change version, a version with R&D spillovers, and a version with imperfect competition and increasing returns that is forthcoming. Though the model structure of WorldScan is not exceptional, it has distinguishing features: WorldScan is flexible in its ability to address a wide range of policy issues and the mechanisms of the model are founded on empirical analysis wherever this is feasible.

We start our description of WorldScan with an explanation of its production structure and clarify how economic growth can be targeted in scenarios through adjustments of primary inputs, such as labour, and the rate of technological change. In principle, the growth of total factor productivity is exogenous in WorldScan. However, productivity is affected endogenously if spillovers of R&D on productivity are introduced. Labour supply is exogenous and derived from demographic trends and projected rates of labour participation. Savings depend on the demographic composition of the population and the growth rate of per capita income. Investments are savings-led and capital mobility is internationally less than perfect. Hence, countries will face different real interest rates. Regional households are guided by utility maximisation in buying goods and services. Hence, WorldScan enables to conduct welfare analyses. The model's interregional linkages through trade in goods and services depend on customers' demand for interregional varieties. Trade is impaired by formal barriers to trade and possibly by non-tariff trade barriers as well. We discuss the estimation of the latter and indicate how the estimation results can be used in policy analysis. In the analysis of climate change policies, the model allows coverage of both carbon dioxide and other greenhouse gases, such as methane and nitrous oxide.

All modelling work on WorldScan derives its usefulness from the policy-oriented analyses thus made possible. Hence, we conclude with some recent policy applications, including our long-term scenario studies, assessments of the impacts of EU-accessions and analyses of climate change policies.

1 Introduction

We present the model's main characteristics in a nutshell and briefly guide the reader through the remainder of this document.

1.1 Scenario studies and policy analysis

WorldScan is an applied general equilibrium model for the world economy. The model was developed in the nineties for CPB's scenario study *Scanning the Future* (CPB, 1992). The model has thereafter been used for scenario studies and for policy analyses in various fields, such as global warming, EU-accession and trade liberalisation. Over the years the model has been frequently adapted, either to become better geared to address specific policy issues or to improve its role as a tool to build scenarios. It is the purpose of this publication to describe the structure of WorldScan 'as it is now'and to clarify the empirical foundation of certain model mechanisms.

Over the years WorldScan has repeatedly been used to build long-run scenarios. These serve two purposes. First, they may be used as an organising device to explore and discuss the potential impacts of future developments such as ageing, the rise of emerging countries, the depletion of natural resources or the emissions of greenhouse gasses. Simulating these developments may reveal unexpected impacts on the world economy and identify new policy problems. Second, long-run scenarios can be used as baselines for exploring the impacts of alternative policy options. Here, the choice for a particular scenario as a baseline for assessing policy impacts may influence the outcomes of the analysis. An example of this is the assessment of the economic impacts of policies that aim to reduce greenhouse gas emissions. These will depend on the design of the climate change policy, the size and composition of the coalition of countries involved, and the economic developments in the underlying baseline. Hence, not only current specialisations and growth patterns but also plausible representations of their future development are crucial for policy analysis.

Shaping these scenarios is not at all straightforward, because future developments are fundamentally uncertain and unpredictable. Scenario analysis deals with this uncertainty by constructing alternative development paths. Though these are sometimes interpreted as providing a range of plausible developments, they are perhaps better viewed as worlds that will never materialise but are nevertheless realistic and internally consistent. Such worlds provide a valuable framework for discussion of the future and reflection on possible actions.

Though the model is often used for scenario development, policy analysis is its principal field of application. A wide range of policy issues has been addressed with WorldScan. Over the past few years the impacts have been assessed of EU-accession, the EU Services Directive, R&D, ageing and climate change policies.

The impact assessments made with WorldScan focus on the European dimension of policy problems and often aim to clarify the implications for the Dutch policy point of view.

1.2 General characteristics

WorldScan reflects the global economy with multi-region and multi-sector detail, the regions being connected by bilateral trade flows at industry level. Over the years successive database releases of the Global Trade Analysis Project (GTAP) have fed the model with data. Today these are taken from the GTAP-6 database that comprises complete and consistent accounts for 87 regions and 57 sectors for the year 2001 (see Dimanaran and McDougall, 2006, and Appendix B for a listing of regions and sectors). In general, WorldScan simulations will not show the full detail that this database could provide, but rather – for economy reasons – show outcomes for aggregated sector and country classifications. In our most recent scenario studies, for example, 16 sectors and 16 countries or country aggregates are distinguished (see Appendix B). Different versions of WorldScan will automatically tune to the base year data classifications chosen. Hence, Worldscan has considerable flexibility in showing regional and industry detail.

WorldScan comes in different versions. A basic core version is extended in separate directions to form dedicated versions, such as: a climate change version, a version with R&D spillovers, and a version with imperfect competition and increasing returns to scale that is forthcoming. Hence, WorldScan has considerable flexibility in incorporating those economic mechanisms that are thought to be of most interest for specific policy applications. With the exception of imperfect competition (see de Bruijn, 2006), all mechanisms of the different model versions are explained in this document. Hence, this model publication is more elaborate than the previous publication about WorldScan (CPB, 1999) that only explained the model's core version.

WorldScan fits into the tradition of applied general equilibrium models: it builds upon neoclassical theory, has strong micro-foundations and explicitly determines simultaneous equilibrium on a large number of markets. The model is solved as an equation system and thus is cast in a Computable General Equilibrium (CGE) format rather than in a welfare maximisation format. Many similar models exist. For example, the structure of the GTAP model (Hertel, 1997) is very similar to the one of WorldScan's core version, the most important difference being that GTAP is essentially a static model whereas WorldScan is recursively dynamic. The MIRAGE model (Bchir *et al.*, 2002) and the LINKAGE model (van der Mensbrugge, 2005) are recursively dynamic as well. Though many modelling details differ, their approach and structure are basically the same as WorldScan's. The climate change version of WorldScan is comparable to MIT's EPPA model (Paltsev *et al.*, 2005) and to the GEM-E3 model (Pathos, 1997), though the latter models are more detailed with respect to the environment.

WorldScan has several distinguishing features. The model is relatively versatile in its ability to address various policy issues as it enables to address policy questions in the fields of climate change, trade, European integration and R&D. The mechanisms of the model are founded on empirical analysis where possible. Examples are the empirical foundation of R&D spillovers, non-tariff trade barriers, the degree of international capital mobility, savings rates, total factor productivity growth and projected labour supply.

1.3 Overview of Worldscan

General equilibrium models describe the supply and demand relations on markets and account for the generation of income. Prices of inputs and outputs adjust until demands equal supplies. The interactions between markets are predominant. For example, given prices firms determine the inputs necessary to produce a final good. At market equilibrium, supply of the final good is determined as well as the inputs needed for production and therefore demands at input markets. Assume that consumers' preferences shift in favour of a particular good and that final demand for that good increases. Then, the price of the good will increase, firms will want to produce more of it and will demand more inputs. As a result, input prices may increase because of the increase in demand of the final good. We call these mechanisms general equilibrium effects.

WorldScan can distinguish as many goods and services markets as are accounted for in its database and describes both a labour market and a capital market. By assumption each producing sector produces one type of good. All goods are produced using labour, capital and intermediate inputs, albeit in different proportions. The relative demand for each of these inputs depends on the characteristics of the sectoral production function. In general, we assume that labour and capital substitute rather well. Although intermediate inputs generally are also good substitutes, there are hardly any substitution possibilities between intermediate inputs on the one hand, and capital and labour on the other hand.

Consumers demand the different consumption goods and services, and provide labour and capital to the firms. The consumption bundle of the different goods and services is determined such that it brings maximal utility to the consumer, given his budget constraint. We assume that the supply of labour is exogenous. Because consumers save part of their income, they are able to supply capital to the firms in return for income. Savings depend on income growth and demographic characteristics. In industrialised countries the demographic structure reflects an ageing population, which harms savings because the elderly save less.

Consumers supply labour and firms demand it. Two types of labour are distinguished: high-skilled and low-skilled. We assume that labour markets are cleared at the national level and that the prices of both types of labour (the wage rates) are flexible. For each labour type, supply and demand will become equal at the market-clearing wage. Unemployment is projected exogenously. Part of labour supply is then unemployed and labour supply minus the unemployed will equal labour demand in equilibrium.

Consumers supply the capital that firms demand. Equality of global demand and supply determines the price of capital. In contrast to the labour market, the regional capital markets are assumed to be linked to each other. Thus, if capital is abundant in one region (and hence relatively inexpensive), it is invested in another region in which capital is scarce (and relatively expensive). However, there are some barriers to investing abroad. Hence, interregional capital mobility does reduce, but not eliminate, capital price differentials between regions. If price differentials would vanish, we would have a perfect global capital market. Capital can only be used in production if producers buy investment goods. An investment good consists of a bundle of outputs from various sectors, such as capital goods, services, and buildings (construction). Producers supply these goods. Total demand for goods and services is determined by both consumers and producers, who demand intermediate and investment goods.

As for capital, international markets for goods and services are linked to each other as well. The demand for a good is not only expressed at the home market, but also at foreign markets. We assume that in each region a different variety of that good is being produced. In principle, customers demand all the varieties. The demand for each of the varieties depends on its relative price, the substitution possibilities between the varieties, transportation costs, trade barriers and preferences for the variety. If the price of a particular variety goes up, demand will decrease in favour of other varieties. Total demand for each variety depends thus on the demand at the home and foreign markets.

WorldScan does not model the government in much detail. The government collects taxes on imports and consumption. It spends tax income on (export) subsidies and consumption. As the government is part of the regional household there is no need to impose the government budget to balance and all tax and tariff rates are exogenous.

So far, we have viewed the model only from a static perspective, neglecting the dynamics. Valued added grows by the increase of labour productivity and the rise of labour supply. Labour productivity is determined by technological progress and capital growth per unit of labour. Employment growth is exogenous, and derived from population growth, its age-composition, age-specific participation rates, and the unemployment rate. Hence, technological progress and the factors underlying labour supply are the main driving forces for diverging development patterns.

1.4 Plan of the publication

We start our description of WorldScan in the next chapter with a description of its production structure. We also explain how economic growth can be targeted in scenarios. Value added grows only if there is an increase in inputs. These inputs are technology, labour and capital.

The growth of technology is discussed in Chapter 3. Chapter 4 discusses how labour participation is projected. Chapter 5 presents the modelling of savings, capital and capital mobility in WorldScan.

On the basis of their preferences, consumers decide how to spend their budget on consumer goods and services. Chapter 6 describes how consumer preferences are modelled in WorldScan and how these are calibrated to empirical data. The inclusion of consumer preferences enables us to conduct welfare analyses with WorldScan. Chapter 7 is devoted to the model's interregional linkages through trade in goods and services. It describes demand for interregional varieties and discusses both the formal barriers to trade and the estimation and modelling of non-tariff trade barriers. The analysis of climate change policies is the subject of Chapter 8. WorldScan 'as it is now' covers both carbon dioxide and other greenhouse gases, such as methane and nitrous oxide.

All the modelling work described in these chapters derives its usefulness from the policy-oriented analyses thus made possible. Hence, the final chapter highlights some recent policy applications, including our long- term scenario studies, assessments of the impacts of EU-accessions and analyses of climate change policies. Finally, in appendices the reader can find a technical description of the full WorldScan model, the sector and country classifications that can be chosen and an overview of studies with WorldScan policy applications that were published in the past six years.

2 Production and Economic Growth

Production generates income and welfare. This chapter focuses on production and on economic growth in WorldScan. Section 2.1 specifies the behaviour of firms. Firms are profit maximisers taking account of demand and production technologies.These technologies are specified and we derive producer prices and inputs of production. The calibration of the production functions is discussed in Section 2.2. Based on value added that firms generate, we derive GDP in Section 2.3. This section also explains the targetting of economic growth in WorldScan.

2.1 Production

Each sector within a region[1] produces a unique variety of a good. There is one representative firm per sector within a region. Factor demand is derived from cost minimisation, given production technology. Output equals demand, which, in turn, is determined by the producer prices, besides other factors.

The production function

The production technology is represented by a production function which relates output to factor inputs and intermediate inputs. The main factor inputs are high- and low-skilled labour, and capital.[2] Intermediate inputs are goods, services and energy. The inputs are to some extent substitutable. The relevance of each of these inputs for production and their substitutability is represented in the production function.

The production technology is modelled as a nested structure of constant elasticities of substitution (CES) functions. As in nearly all applied general equilibrium (AGE) models we assume the same production structure for all sectors and regions.[3] The values of the substitution parameters reflect the substitution possibilities between inputs. These values may differ across sectors reflecting the different substitution possibilities of (factor) inputs within the producing sectors. Figure 2.1 illustrates the nesting structure.

The production function can be expressed by equation (2.1) for the nesting at the top level.[4] At the top level, an aggregate of all variable inputs q_{TIR} is combined with a fixed factor q_{FIX} to

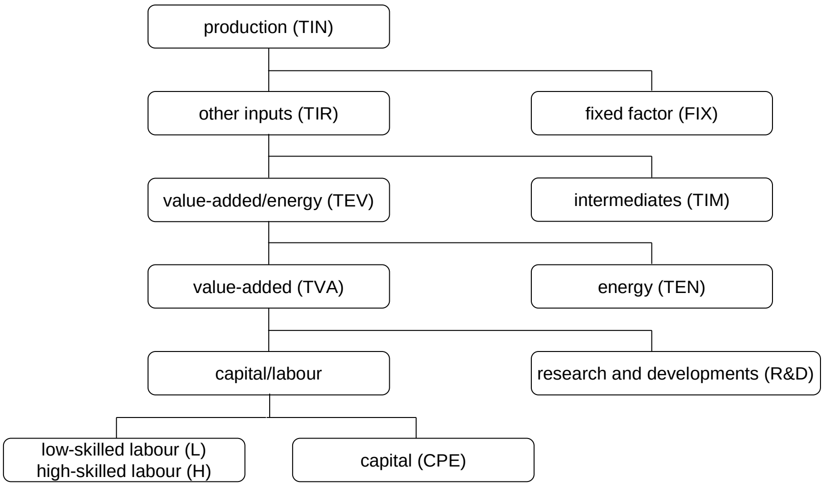
[1] Often, we will use the term region. A region can be a single country or an aggregate of several countries.

[2] Research and development (R&D) is also modelled as a separate factor input. We will treat this issue in chapter 3, and ignore it in this chapter.

[3] Examples are the GTAP model (Hertel, 1997), the Mirage model (Bchir *et al*., 2002), the Linkage model (Van der Mensbrugghe, 2005), and the G-cubed model of McKibbin and Wilcoxen (1999).

[4] For ease of notation we omit indices for sectors and regions.

Figure 2.1 Production structure



generate output q_{TIN}. The nests at the lower levels are analogously defined.

$$\begin{aligned} q_{TIN} &= CES\left(q_{TIR}, q_{FIX}; \rho_{TIN}\right) \\ &= \left(\alpha_{TIR}^{1-\rho_{TIN}} q_{TIR}^{\rho_{TIN}} + \alpha_{FIX}^{1-\rho_{TIN}} q_{FIX}^{\rho_{TIN}}\right)^{\frac{1}{\rho_{TIN}}} \qquad 0 < \rho_{TIN} < \infty \end{aligned} \tag{2.1}$$

The share parameters of the inputs are represented by α_{TIR} and α_{FIX} in equation (2.1).[5] The elasticity of substitution between the inputs TIR and FIX is σ_{TIN}, where $\sigma_{TIN} = 1/(1-\rho_{TIN})$. Even though substitution parameters are identical across regions for each sector, the production functions differ because the parameters α differ. These parameters are derived from cost shares in the input-output data in the base year, see Section 2.2.

The nests, TIR, TVE, and TIM are modelled in the same way as TIN. The value-added nest is modelled somewhat differently, because it also includes the level of total factor productivity. For some applications we assume that the substitutability between capital and labour is one. Then the CES function boils down to the Cobb-Douglas function, $\rho_{TVA} = 0$. This implies that the shares of labour and capital income within value added are fixed. The labour nest is modelled as a Cobb Douglas-function combining high- and low-skilled labour. Sometimes we replace this by a CES function with higher substitutability between both skill types. An example is the study of Lejour and Tang (2000) on the effects of globalisation on wage equality.

Cost functions, prices and factor demand

The costs for the individual firm (and sector) are defined as

$$Q_{TIN} = \sum_j p_j q_j \qquad j \in FIX, CPE, L_l, L_h, S \qquad \text{with S} = s_1, \ldots, s_S \tag{2.2}$$

[5] Since not all prices equal one in the base year, the share parameters α_j are not equal to the cost shares in the relevant nests. Sometimes these parameters are called location parameters. We use the term share parameter, because this is more informative. Within a nest, the parameters add up to one.

The CES structure in production

A nesting structure reflects views on substitution possibilities. Choosing a specific structure restricts substitution possibilities between production factors. When there are more than two production factors the possibility of complementarity between factors arises. Two factors are complements if demand for one factor *decreases* in response to a price rise in the other. The compensated cross-price elasticity has a *negative* sign. A nested structure creates the possibility of complementarity between certain factors, but excludes complementarity between others. Choosing a structure is often the outcome of a trade-off between different, often competing, properties. A production function should be flexible, easy to compute, parsimonious in the number of parameters, and based on sound theoretical properties. The latter means that the cost function (the dual of the production function) should be concave, non-decreasing and positive. A nested CES structure is restrictive, but its properties are well understood, and it yields convenient analytical expressions. Parameter values may further restrict substitution in the model. Our considerations for choosing certain values for substitution elasticities are discussed in section 2.2.

where p_j denotes the price of factor or intermediate j. The factors consist of intermediate inputs from all other sectors (s_1 to s_S), capital (CPE), high- and low-skilled labour (L_l and L_h) and the fixed factor (FIX). Unit cost minimisation leads to expressions for nested factor prices and input demand.

$$p_{TIN} = \left(\alpha_{FIX} p_{FIX}^{1-\sigma_{TIN}} + \alpha_{TIR} p_{TIR}^{1-\sigma_{TIN}}\right)^{\frac{1}{1-\sigma_{TIN}}} \qquad \sigma_{TIN} = \frac{1}{1-\rho_{TIN}} \tag{2.3}$$

The other equations are presented in Appendix A which lists all model equations. The price of labour is a Cobb-Douglas aggregate of the wages for high- and low-skilled labour. The price of value added, p_{TVA} is a CES aggregate of the price of labour and the price of capital.[6] Because we assume that the existing capital stock could be sold after each period – correcting for depreciation – capital costs are equal to the real return on capital, r, compensation for entrepreneurial risk, o^K,[7] and depreciation times the investment price, P_I.[8]

$$p_{CPE} = p_I\,(r + o^K + \delta^K) \tag{2.4}$$

The price of the composite intermediate goods, p_{TIM}, is a CES aggregate of the prices of the underlying intermediates. This is also the case for the input energy.

Factor demand is determined by the cost-share parameter, the output at the higher nest level, the price ratio and the substitution parameters (equal to one in the Cobb-Douglas labour nest).

[6] Note that the fixed factor, which normally also contributes to value added, is not a part of the nest TVA in our production structure.

[7] This is a reward which increases the return on capital above r. Risk itself is not modelled in WorldScan.

[8] The price of capital services is derived as follows. The capital stock corrected for depreciation, δ^K, can be sold after each period at the investment price in the next period,$p_{I,t+1}$. Capital that is to be used in the succeeding period has to be bought in the current period at price,$p_{I,t}$. Firms have to pay capital owners for the use of their wealth, and producers receive some income as a reward for entrepreneurship. This reward is a proportion of the return on capital, and is denoted by o^K. It is consumed in the home country. Therefore, it is treated in the same way as labour income in the consumer maximisation problem. Given all other inputs, the capital price follows from minimising $(1+r)(1+o^K)P_{I,t}K - (1-\delta^K)P_{I,t+1}K$ given the production volume.

We illustrate this for the fixed factor and the aggregate of all other inputs TIR in equation 2.5.

$$q_f = \alpha_f \, q_{TIN} \left(\frac{p_{TIN}}{p_f} \right)^{\sigma_{TIN}} \qquad f = \text{FIX,TIR} \tag{2.5}$$

The factor-demand equations determine all input volumes if prices (see equation (2.3)) and the production volume, q_{TIN}, are known. Production equals total demand which consists of consumer demand, intermediate demand and investment demand. Consumer demand is discussed in Chapters 6 and 7. The derivation of intermediate demand and investment demand is explained below.

Intermediate demand

Intermediate demand is derived from the input-demand equations. Equation (2.6) represents total demand for intermediate inputs of type f. This is the aggregate demand over all sectors

$$q_f = \sum_s q_{fs} \qquad f = s_1, ..., s_S \tag{2.6}$$

Investment demand

The volume of investment in region r, i_r, equals the volume of savings, here expressed as the value of savings, S_r, divided by the investment price, $p_{I,r}$. The capital owners buy investment goods, and a part of these investment goods is exported to or imported from other countries. Chapter 5 treats this topic extensively.

$$i_r = S_r / p_{I,r} \tag{2.7}$$

The investment goods are assumed to be a Cobb-Douglas aggregate of investment goods from all sectors. The production function of investment reads

$$i = \prod_s (i_s)^{\alpha_s^I} \qquad \sum_s \alpha_s^I = 1 \tag{2.8}$$

The weights, α_s^I, are derived from the calibration data, as will be explained in section 2.2. So given investment demand in equation (2.7), the value of investment demand for good s is a fixed share of total investment demand.

$$I_s = \alpha_s^I \, p^I \, i \qquad \text{and} \qquad p^I = \prod_s \left(\frac{p_s^I}{\alpha_s^I} \right)^{\alpha_s^I} \tag{2.9}$$

The investment price is a Cobb-Douglas aggregate of the input prices.

It follows from profit maximisation that the producer price equals the unit cost (equation (2.3)) plus a proportional mark-up because every firm produces a unique variety. The mark-up depends on the Armington elasticity of demand of the home country.[9]

[9] In practice, we ignore the theoretical outcome of a mark-up in price setting. Thus aggregate unit costs, p_{TIN}, equal producer prices. This assumption is of minor importance, because labour, capital and profit income all flow to the consumers. The assumption was motivated by the empirically low values for the Armington elasticities, and consequently implausibly high values for the mark ups. At the moment we are implementing imperfect competition with increasing returns to scale in WorldScan. At the same time we also calibrate the mark up, see De Bruijn (2006).

2.2 Calibration

Production possibilities are captured by a CES function with several levels (see Figure 2.1 and equation (2.1)). The production function contains three sets of parameters: substitution elasticities, share parameters and technology levels. First, we discuss the choice of the elasticities.

Production TIN is a nesting of the fixed factor FIX and the other inputs. The fixed factor represents land in the sector agriculture and natural resources in the sectors energy carriers and raw materials. In the other sectors the fixed factor is not relevant: production equals the output generated by the other inputs. The substitution elasticity is low (.10) for the sector energy carriers, implying nearly a Leontief production structure.[10] For the sectors agriculture and raw materials the substitution possibilities with the other input factors are larger (σ = .60), reflecting the possibility to use the fixed factor more or less intensively.

In the next level of the production tree, value-added plus energy carriers TEV and material inputs TIM are aggregated. This CES-function has a very low substitution elasticity (.01), resembling a Leontief structure.[11] Only for the sector agriculture (fertilizers, herbicides, etc.) we assume a larger elasticity (.30).

All intermediate inputs, except for energy carriers, are bundled in the nest of material inputs TIM. It has a substitution elasticity of .60. which allows some substitution among the different material inputs. This contrasts with the assumption in many (static) AGE models in which nearly no substitution between these inputs is possible. However, WorldScan is a dynamic model which focuses on the long-term effects of policy alternatives. In the long-term substitution possibilities between intermediate inputs are larger due to technological innovations, for example.

We assume relatively high substitution elasticities of 0.5 between value-added TVA and energy carriers TEN. For the sector Agriculture this reflects the possibility of mechanisation. The sectors raw materials and energy carriers form an exception with limited substitution possibilities (.10). In this version of the model energy carriers such as refined oil, coal, and natural gas are considered as one sector for convenience. This classification is obviously too aggregated for the analysis of climate-change issues which we also conduct using WorldScan. For these analyses we use the climate-change version of the model in which the nest of energy carriers is broken down further (see Chapter 8).

The value-added nest is a composite of capital-labour and research and development (R&D). This structure is novel within AGE models. Most models neglect R&D or do not let R&D

[10] A Leontief structure implies that the inputs are not substitutable.

[11] Very limited substitution possibilities between value added and intermediates are quite common in AGE models. Mirage (Bchir *et al*. 2002) assumes a Leontief structure. It does not separate energy from the other intermediates, since Mirage is not developed to analyse climate-change policies. Other models, like Linkage (Van der Mensbrugghe, 2005) have a value added energy nest in production. We prefer to model a more flexible CES structure instead of an explicit Leontief structure.

contribute to value added, but consider R&D expenditures as an intermediate input, often as a part of other (business) services This new feature deserves an extensive treatment which we postpone to chapter 3. For the moment we concentrate on the more general features of the production structure.

The capital-labour nest assumes high substitutability of 0.85 between labour and capital. The high substitutability implies that the labour income share remains more or less constant over periods of thirty or forty years. We consider this as a desirable property of the model.[12] The input factors of the labour-nest are low-skilled labour and high-skilled labour with a substitution elasticity of 1. Technological progress is exogenous and factor neutral (Hicks-neutral disembodied technological progress). The values of the substitution elasticities are summarised in Table 2.1.

Table 2.1 Sectoral substitution elasticities in production (σ)

	Agriculture	Energy and other raw materials	Other sectors
Fixed factor and rest	0.90	0.10	0.00
Intermediates and value added/energy	0.30	0.01	0.01
Energy and value added	0.60	0.10	0.50
Capital and labour	0.85	0.85	0.85
Intermediates	0.60	0.60	0.60
Labour	1.00	1.00	1.00

The overall technology index (TFP-index) in the value-added nest is set at one in the base year. The share parameters are calculated by inverting the input-demand equations (2.5). These equations determine the input shares in output, which are provided by the GTAP database.

Producer prices in equation (2.3) are set to 1 for all sectors, then cost prices are determined as well. If producer prices (before producer taxes) are equal to 1, most user prices are slightly higher, due to taxes and transportation costs. These include producer taxes, consumption or investment taxes, and in case of trade also trade taxes, and transportation costs. Given unit costs, it is easy to derive the share parameters of the CES functions. We follow a bottom up approach. For illustrative purposes we only present the calibration of the cost parameters for the value-added energy nest in production.

$$\alpha_f = \left(\frac{p_{TEV} q_{TEV}}{p_f q_f}\right)_0 \left(\frac{p_{TEV}}{p_f}\right)^{1-\sigma_{TIN}} \qquad f = \text{TVA,TEN} \tag{2.10}$$

The subscript 0 indicates that the first term on the right-hand side in equation (2.10), the relevant

[12] Bchir *et al*. (2002) assume a substitution elasticity of 0.6 for capital and high-skilled labour. Broer *et al*. (2000) estimate an elasticity of 0.35 for the Netherlands.

input share, is derived from the GTAP database. The prices are defined in equation (2.3) and calculated simultaneously with the share parameters. The two share parameters add up to one by definition.[13]

2.3 Gross domestic product and growth

This section presents the definition of GDP in market prices. Moreover, we derive GDP in constant prices, because we want to compare real GDP at different time periods. Further on, we discuss our method of targeting GDP in time. Quite often we want to reproduce a certain GDP path with WorldScan. The reason is that in many scenario studies time paths for GDP and other variables need to be imposed.[14]

Definition of GDP

Value added in sector s equals the value of production minus the costs of intermediate products of that sector. Taxes on intermediate products are included in these costs. The volume of intermediate products is represented by q_{fs}

$$Y_s^{VA} = q_s^S p_s^S - \sum_f q_{fs} p_{fs} \tag{2.11}$$

Gross Domestic Product (GDP) in market prices in country r is defined as the sum of sectoral value added in producer prices plus taxes, T. We add tax proceeds, because we use in general the concept *GDP in market prices*.

$$Y^{GDP} \equiv y^{GDP} p^{GDP} = \sum_s Y_s^{VA} + T \tag{2.12}$$

The tax proceeds consist of the taxes on consumer goods, intermediate goods, investment goods, production, imports and exports in a region.[15] All these taxes are sector dependent. The import taxes vary by country of origin, and the export taxes vary by country of destination.

The value of GDP (in current market prices) is also equal to the value of consumption, investment and exports minus imports (GDP in expenditures). The prices for consumption and investment are user prices that may include consumption and investment taxes and import levies. Because taxes on consumption, investment and intermediate goods normally differ, the market

[13] This is however not the case for the nesting at the top level, because the cost price p_{TIN} is derived from the producer price. Then, the share parameters do not add up to one.

[14] Note that all prices in the GTAP database are expressed in US dollars. Values of GDP in national currencies are translated into US dollars by using market exchange rates, because the GTAP database highlights international trade relations, and trade values are always expressed US dollars using market exchange rates. GDP values in market prices are not a good indicator for purchase power comparisons, because non tradable goods and services are differently priced in the various regions. By consequence, GDP developments of various regions can not be used for purchase power comparisons.

[15] In the energy version of the model, carbon taxes are added to this equation.

prices for these three uses differ in the model. The values of exports and imports are measured in world prices:[16]

$$Y^{EXP} = C + I + X - M \tag{2.13}$$

The value of GDP in equation (2.13) equals the value of GDP of equation (2.12) by definition.

GDP in constant prices (base year)

We split the value of GDP in a price and volume component. First, we calculate price indices for GDP and its components in period t, pi_t^k. p_t represent prices in period t. $t = 0$ represents the base year. The price for investment goods is already defined in equation (2.9). The other prices will be defined later.

$$pi_t^k = \frac{p_t^k}{p_0^k} \qquad k{=}GDP\ ,C,I,X,M \tag{2.14}$$

We can now express the values in prices of year 1, thereby defining volumes in constant prices:

$$\tilde{k}_t = \frac{K_t}{pi_t^k} \tag{2.15}$$

This method guarantees that the value of GDP in constant prices is equal to the aggregate of its components in constant prices.

Targets for GDP growth

We want to be able to target GDP per capita growth in the model. The model establishes a direct relation between macro TFP growth and GDP per capita growth. The production function relates output to TFP, labour, capital, and intermediate inputs. The growth rates of output, capital and intermediate inputs are endogenous. These growth rates will be more or less similar at a stable growth path. The growth of labour inputs depends on labour supply, which is exogenous in the model. TFP growth thus determines GDP (per capita) growth or vice versa.

If we target GDP per capita growth, we have the choice to determine TFP growth or GDP growth. Both options have their merits. In constructing scenarios, we form opinions on GDP growth (and not directly on TFP growth, which is the unobserved growth variable). Then we prefer to target GDP per capita growth directly.

In other studies we want to develop a baseline characterised by developments in labour productivity growth, trade integration and so on. Then we want to target the TFP rate and let GDP growth to be determined by the model mechanisms. GDP per capita growth equals:

$$\mathring{y}_{c,t}^{GDP} = \left(\frac{y_{c,t}^{GDP}}{y_{c,t-1}^{GDP}} - 1\right)100 \qquad \text{with} \qquad y_c^{GDP} = \frac{y^{GDP}}{POP} \tag{2.16}$$

[16] The world price of a good or service is defined as the price of a good or service once it has passed the border of the exporting country (so it includes possibly export taxes), but before entering the importing country (so it does not include import taxes, nor transport costs).

$\mathring{y}_{c,t}$ represents the growth rate of the volume of GDP per capita in period t, and *pop*, the size of the population. Population size is an exogenous variable. The population data are discussed in chapter 4. The volume of GDP is derived from equation (2.17):

$$y_t^{GDP} = \sum_k q_t^k \frac{p_{t-1}^k}{p_{t-1}^{GDP}} - q_t^M \frac{p_{t-1}^M}{p_{t-1}^{GDP}} \qquad k = \text{C,I,X} \tag{2.17}$$

q_t^k is the volume of final demand k in period t. The volumes times the prices, p_t^k, are the values in equation (2.13). The price for GDP in period t is equal to its value divided by the volume defined in (2.15). In the base year, we assume that the price for GDP is equal to 1.

If we target GDP per capita growth in equation (2.16), TFP growth must be endogenous to meet that growth target. We introduce an algorithm in the model, ensuring that in each year GDP per capita meets its targeted growth rate by adapting the TFP growth rate. Thus:

$$\mathring{a}_{TVA} = G\left(\mathring{y}_c^{GDP} = \hat{y}_c^{GDP}\right) \tag{2.18}$$

in which $\mathring{a}_{TVA}$ represents the targeted TFP growth rate in period t. G is a function in which the growth rate of GDP per capita has to be equal to the targeted growth rate, $\hat{y}_c^{GDP}$.

The macro TFP growth rate is an aggregate of the sectoral TFP growth rates. In earlier versions of WorldScan we have assumed that the value-added growth rates by sector are identical and derived the implied sectoral TFP growth rates, see CPB (1999). Now we have incorporated differences in sectoral TFP growth rates in the model based upon historical time series. Section 3.2 estimates the sectoral TFP growth relative to the macro TFP growth rates We have imputed these numbers in the model in such a way that the sectoral TFP growth rates equal:

$$\mathring{a}_{TVA,s} = (\mathring{a}_{TVA} + 1)\left(\frac{\bar{a}_{TVA,s}}{\bar{a}_{TVA}} + 1\right) - 1 \tag{2.19}$$

$\bar{a}_{TVA,s}$ equals the historical TFP growth rate in sector s and $\bar{a}_{TVA}$ equals the historical macro TFP growth rate. $\mathring{a}_{TVA}$ is endogenous, and is derived by combining equations (2.18) and (2.19).

3 Total Factor Productivity and Research and Development

This chapter focuses on sectoral productivity growth. Sections 3.1 and 3.2 discuss total factor productivity (TFP) growth of the various sectors in the model. Empirically, we derive a relation between sectoral TFP growth and macro TFP growth. So far TFP growth represents all productivity growth that is not explained by production factors like labour and capital. Sections 3.3 and 3.4 introduce R&D in the model which redefines TFP growth. Section 3.3 models R&D stocks as an explicit production factor, and Section 3.4 models and estimates the spillover effects of R&D to productivity. Both model extensions explain some total productivity growth which was hidden in TFP growth before.

This chapter explains in more depth sectoral TFP growth in WorldScan. Equation (2.19) described sectoral TFP growth as a function of macro-TFP growth and sectoral TFP growth relative to the macro-TFP growth rate. The latter variable is an exogenous variable in the model. The values are derived from historical data. These data and the construction of the sectoral TFP growth rates relative to the macroeconomic mean are presented in Sections 3.1 and 3.2 in this chapter.[17] TFP growth represents productivity growth which is not captured by growth in high- and low-skilled labour and capital. This productivity growth could be due to changes in technology, competitiveness, market structure, government regulation, business environment and so on. The second part of this chapter changes this interpretation, because R&D is explicitly modelled. Section 3.3 models R&D as a stock that contributes to value added, besides high- and low-skilled labour and capital, and Section 3.4 estimates and models the spillovers of R&D to TFP growth. These model extensions explain a part of productivity growth which is hidden in TFP growth in the standard model. Thus the spillovers do not increase the sectoral TFP growth rate compared with the case that these spillovers are not modelled. The spillovers endogenise (and explain) to some extent TFP growth. The exogenous part of TFP growth becomes smaller such that total TFP growth will not change.

3.1 Sectoral TFP growth rates

In a dynamic multi-sectoral AGE model as WorldScan, we have to determine TFP growth by sector. Even if TFP growth is determined at the macro-economic level, sectoral TFP developments can differ. A well-known stylised fact tells us that TFP-growth in developed countries is highest in agriculture, followed by manufacturing and the services sector. So far, however, TFP growth comparisons were lacking at a more detailed sectoral level. Other dynamic AGE models, such as the G-Cubed model (McKibbin and Wilcoxen, 1999), the Linkage model (Van der Mensbrugghe, 2005), the dynamic GTAP model (Walmsley *et al*., 2000), and the

[17] These two sections draw heavily on Kets and Lejour (2003).

Mirage model (Bchir *et al*., 2002) do not give much guidance. In the G-Cubed model productivity growth is equal for all sectors within a country, except for the energy sector. In the Linkage model sectoral TFP is affected by the export ratio and a parameter to allow for exogenous differences between the sectors. The endogenous mechanism via the export ratios represents the idea that higher export ratios could lead to more international (knowledge) spillovers which increase sectoral productivity. The parameter that allows for exogenous differences in the Linkage model ensures that productivity growth in agriculture exceeds productivity growth in manufacturing and services. Apart from this stylised fact on productivity differences, the parameter lacks an empirical underpinning. The documentation on the dynamic GTAP model does not discuss productivity by sector. From private conversations with the researchers involved we understood that their treatment of TFP growth differences in the model is not based on data on productivity growth differences by sector.

In order to design an empirically-based allocation scheme for TFP growth, Kets and Lejour (2003) have examined the historical developments in sectoral TFP using the International Sectoral Database 1998 (ISDB98) of OECD (OECD, 1998). They compare the relative TFP growth rates of various sectors and different countries. The ISDB distinguishes 29 sectors in total, of which we consider 20.[18] The period 1970 to 1990 is chosen because of the ample availability of complete time series for this period.[19] For the various service sectors only few time series are available. This is the case for communication, transport and storage, financial institutions and insurance and real estate and business services. No time series are available for the government sector, nor for the ISDB sector mining and quarrying, which makes up the WorldScan sectors energy and other raw materials.

With the TFP time series, the average yearly growth rate in the period t_0 to t_n (where $t_0 = 1970$, and $t_n = 1990$) is calculated for sector s and region r[20] as

$$\mathring{a}_{s,r} = \left[\frac{tfp_{s,r}\,(t_n)}{tfp_{s,r}\,(t_0)}\right]^{\dfrac{1}{(t_n - t_0)}} - 1 \tag{3.1}$$

Kets and Lejour (2003) have examined the variation of average TFP growth between sectors. They have considered four different sectoral classifications. Here we present the results of the most aggregated classification in manufacturing, agriculture, raw materials and services, and the WorldScan 16-sector classification, as these two yield most insights.

For each of the classifications we have averaged the TFP growth rate (1970 - 1990) over all

[18] For the other sectors insufficient data points are available.

[19] The time period could be updated using the STAN database of the OECD. In that case also more countries could be included in the analysis, although there are hardly any data available for these extra countries for the 1970's.

[20] Of course, TFP-growth in the years t_0 and t_n can be higher or lower than the average growth rate, suggesting a time trend. This is not very unlikely, as TFP growth varies over the business cycle. Furthermore, TFP growth is by its nature very hard to measure. Possible anomalies are averaged out over the 20 year period, however. To get some insight in fluctuations over time, we also performed a regression analysis using a time trend, see Kets and Lejour (2003).

countries r[21] for which time series are available, weighted by their value added share:

$$\mathring{a}_s = \sum_r \mathring{a}_{sr} \left(\frac{y^{VA}_{s,r,\bar{t}}}{y^{VA}_{s,\bar{t}}} \right) \tag{3.2}$$

where $\mathring{a}_{sr}$ represents the TFP growth by sector and country, averaged over the period 1970 - 1990, $y^{VA}_{s,\bar{t}} = \sum_r y^{VA}_{sr,\bar{t}}$, and the symbol $\bar{t}$ denotes the average over 1970-1990. Subsequently, the sectoral TFP growth rate (averaged over countries) is averaged over the sectors that make up a WorldScan sector Z, weighted with the value added shares.

$$\mathring{a}_Z = \sum_s \mathring{a}_s \left(\frac{y^{VA}_{s,\bar{t}}}{y^{VA}_{Z,\bar{t}}} \right) \quad s \in Z \tag{3.3}$$

with $y^{VA}_{Z,\bar{t}} = \sum_s y^{VA}_{s,\bar{t}}$. This method implies that we average first over countries, and then over ISDB sectors to derive TFP growth rates for WorldScan sectors. The order of averaging is not neutral because we miss data points for several countries and sectors. We have chosen for this procedure because it yields more data points than another ordering.[22]

3.2 Sectoral TFP growth

Equation (3.3) yields an average growth rate (averaged over all countries) for 1970 - 1990 for the aggregate sectors and the 16-sector classification. The average yearly TFP growth varies considerably across sectors, as can be seen from Table 3.1 (aggregate classification) and Table 3.2 (WorldScan '16-sector'aggregation). The results for alternative aggregations can be found in Kets and Lejour (2003).

Table 3.1 Sectoral TFP growth rates, 1970-1990, averaged over OECD countries

Sector	Growth rate
Agriculture	2.68
Manufacturing	1.95
Services	0.42
Raw materials	0.68
Average[a]	0.87

[a] Excluding raw materials, because of poor quality of the data.
Source: Kets and Lejour (2003).

At both aggregation levels, the well-known stylised fact is reproduced that TFP growth is highest in agriculture, followed by growth in manufacturing, while total factor productivity in services shows virtually no growth at the aggregate level. However, the growth rates within the service

[21] We have left the Netherlands out of our calculations of international averages because only data for a few sectors are available.

[22] Kets and Lejour (2003) discuss this issue more extensively.

Table 3.2 Sectoral TFP growth rates, 1970-1990, averaged over OECD countries

Sector	Growth	Sector	Growth
Agriculture	2.68	Transport services	1.38
Energy and other raw materials	0.68	Construction	0.03
Food processing	1.05	Trade services	0.52
Other consumption goods	1.57	Communication	3.38
Paper, publishing and printing	0.99	Financial services	− 0.06
Chemicals, rubber and plastics	2.93	Other business services	0.24
Metals	2.04	Other services	0.24
Capital goods	2.08		

Source: Kets and Lejour (2003).

sectors are rather different. High growth (3.4 percent) for the communication sector is remarkable. This can be the result of the spur in technological progress in ICT. TFP growth has been steadily rising since 1970. It is unclear whether this acceleration of the growth rate will continue to persist in the longer run.

Furthermore, the low or negative growth rates of construction, financial services, and community and other services are remarkable. In the latter case, the negative growth rate is mainly due to the fall in productivity in personal services. Generally, a persistent negative growth rate is unlikely. These results could be affected by the low quality of the data. Another remarkable feature is the strong growth for the transport sector which is traditionally part of the service sector. The results comply with Baumol's law: almost no growth in services, and positive growth rates in technologically progressive service sectors such as communication and transport. The dispersion within the manufacturing sector is also quite large: from 1.0 percent for paper and paper products to more than 2 percent for chemical, rubber and plastic products and for capital goods. The latter sectors are capital intensive. This could imply relatively high growth rates, if capital intensity was tantamount to a high intensity of innovation and of adoption of new technologies. The growth rate in the other consumer goods sector is also high, which is mainly the result of high growth in the ISDB sector textiles.

Employing a regional disaggregation is not possible due to the limited number of observations. This implies losing information on some meaningful differences between countries. We use OECD average for sectoral TFP growth rates relative to the mean for all regions in the model. For the non-OECD regions we would like to use other averages as these regions are generally at a different development stage, but there are no data available.

In WorldScan, the average TFP growth rate is imposed by assumption or derived from the imposed GDP growth rate, see equation (2.18). The sectoral TFP growth rates deviate from the average TFP growth rates. The relative deviation is based on the empirical findings in this section. For the 16-sector version we have divided the simple averages of Table 3.2 by the macro average of 0.87 percent. Based on expert opinions, we have set the relative TFP growth rates in energy and raw materials at the average (at one). Furthermore, we do not believe the negligible growth rates for business services and financial services. We assume that for these sectors TFP growth rates are equal to the growth rate in trade services.

Table 3.3 Sectoral TFP growth relative to the mean

Sector	Growth	Sector	Growth
Agriculture	3.1	Capital goods	2.4
Energy[a]	1.0	Transport	1.6
Other raw materials[a]	1.0	Communication	3.9
Food processing	1.2	Construction[b]	0.3
Other consumption goods	1.8	Trade services	0.8
Paper and publishing	1.1	Financial services[b]	0.3
Chemicals and minerals	3.4	Other business services[b]	0.3
Metals	2.3	Other services	0.3

[a] Average TFP growth is imposed due to missing data.
[b] Relative TFP growth is set equal to that in other services, because underlying data delivered (implausible) negative growth.
Source: Kets and Lejour (2003). Note that numbers larger (smaller) than 1 imply that sectoral TFP grows faster (slower) than average (macro) TFP.

3.3 Research and development decisions

New technologies and better products boost productivity, not only in the innovating sector itself, but also in other sectors. In addition, since the influential paper by Coe and Helpman (1995) it is well established that investment in research and development (R&D) generates international spillovers: firm-specific R&D decisions have often an external effect on productivity in the host country of the firm as well as for the trading partners.[23]

R&D and innovations are important drivers for productivity improvements, but R&D and its implications are not widely modelled in AGE models. This is surprising because R&D decisions have potentially large general equilibrium effects through backward and forward linkages, in particular if R&D improvements also spill over to other sectors.

Recently, researchers have attempted to model some aspects of R&D in global models. Most of them introduced R&D spillovers in AGE models. Examples are Diao *et al.* (1999), and Lejour and Nahuis (2005). Bayoumi *et al.* (1999) have incorporated R&D in the macro-econometric model of the IMF Multimod. Recently, Brécard *et al.* (2004) have modelled R&D in their sectoral econometric model Némésis.

In all these models the R&D decision is not based on optimisation behaviour of firms.

[23] Since then many researchers have studied R&D and R&D spillovers. We do not replicate the literature here. For some recent overviews we refer to Jacobs *et al*. (2002) and Keller (2004).

Recently, we have incorporated the R&D decision of firms in our model based on profit maximisation. We introduce this model extension in this section and also discuss the data issues involved with the modelling of R&D in AGE models. Section 3.4 reviews our modelling of R&D spillovers and the underlying empirics, based on Lejour and Nahuis (2005), and Lejour and Tang (2006). Note that by modelling the R&D stock and its spillovers to productivity we investigate one of the determinants of TFP growth.

The R&D decision

Each period firms decide on their optimal R&D stock. Just as labour and capital, R&D generates value added for the firm. The R&D stock is treated as a capital stock. The basic idea is that a firm invests in R&D each period and that this investment contributes to productivity during several periods. The investments thus contribute to a R&D stock, which depreciates over time. Hence, sectoral R&D expenditures in period t, IR_s, equal the sectoral R&D stock (measured in volume terms) in period t, R_s, minus the stock in period $t-1$, corrected for depreciation:

$$IR_{s,t} = (R_{s,t} - (1-\delta_{RD})R_{s,t-1})\,p_R \tag{3.4}$$

The optimal R&D stock in a sector is derived from cost minimisation, which implies that the marginal product of the sectoral R&D stock equals the user costs of R&D. User costs, p_R, equal the investment price for R&D, p_{RD}, times the sum of the risk-free return on R&D, a risk premium, o_{RD}, and the depreciation rate. We assume that the risk-free return on R&D is equal to the risk-free return on capital, the real interest rate:

$$p_R = p_{RD}\,(r + o_{RD} + \delta_{RD}) \tag{3.5}$$

Note that this expression is analogous to the user costs of capital in equation (2.4). Yet the values of the user costs may differ, because the risk premia and depreciation rates may differ. p_R times the R&D stock is equal to the share of R&D to value added by sector. We assume that the value added nest in the production function is a CES construct of the R&D stock and the CES nesting of capital and labour. This is illustrated in Figure 2.1. The substitution elasticity between R&D and the capital-labour nest is 0.9. This implies that R&D is not a very good substitute for physical and human capital.[24]

R&D is produced by the R&D sector. This is a separate sector in the model. Its production structure is based on the input structure of the R&D sector in the US. This is one of the few countries that explicitly distinguishes a R&D sector in its national accounts. The main input of R&D is high-skilled labour. The R&D sector only produces for domestic firms. Value added of

[24] There are not many applied models which have incorporated the R&D stock, nor are there good estimates of the substitution between R&D and other inputs. Some examples are Den Butter and Wollmer (1996), and Van Bergeijk *et al*. (1997). Both papers assume high complementarity between R&D and physical capital. However, the latter assumes that R&D and human capital are substitutes.

the R&D sector equals the sum of the R&D expenditures of all sectors. We neglect international trade. This is not a restrictive assumption for our current applications of the model. It will be different if issues as international cooperation in R&D or outsourcing of R&D become important.

We are fully aware of the simplifications we have made in modelling R&D. We model one representative R&D sector while in practice R&D is performed by business enterprises, higher education and government research institutes. The inputs in these three sectors for producing R&D will differ, just as their productivity. Other studies, such as DG E&I (2004), analyse the differences between these sectors. WorldScan is not suited to deal with these differences. Moreover, all R&D is performed outside the sectors while in practice business enterprise R&D is often conducted within firms. R&D stocks are also not comparable over sectors as is implied by our modelling. Yet, these simplifications fit in our general analysis of the main effects of R&D on sectoral productivity and economic growth.

Data issues

We calibrate WorldScan on the GTAP database, version 6 (Dimaranan and McDougall, 2005). From this data set we not only derive the demand, production and trade patterns, but also the labour and capital intensity of the different sectors. The incorporation of R&D affects the model and the data. To start with the latter, the GTAP database does not include expenditures on R&D. R&D is part of the other business sector. What is even more important, National Accounts - from which the GTAP data are derived - often consider R&D as expenditures for intermediate goods. R&D is not seen as an investment, as most economists would interpret it, and does not contribute to value added. We do not wish to inflate value added by R&D income.[25] Therefore we subtract R&D income from capital and labour income in the calibration year, so that we calibrate R&D, capital and labour together at value added from the GTAP database.

The output of the R&D sector equals R&D expenditure of firms in an economy. We subtract this output and the corresponding inputs from the GTAP data of the other business services sector in order to stay as close to the database as possible. The R&D depreciation rate is set at 11 percent, following Carson *et al*. (1994). An alternative would be a depreciation rate of 15 percent, which according to Griliches (2000) is the number most often used. However, the empirical base is weak.[26]

R&D activity is concentrated within a few countries. Together Germany, France, the United Kingdom, Japan and the United States spend 90% of all R&D expenditures in the group of 14 OECD countries considered. Most of the R&D expenditures take place in the manufacturing sectors Chemicals, Transport equipment, Electrical equipment, and Other machinery and

[25] The R&D data - as share of national income - are derived from OECD (2003) and UNESCO (1998).

[26] The numbers reflect the private depreciation rate of R&D, the social depreciation rate is much lower.

equipment: these sectors comprise about 85% of total R&D expenditures in manufacturing and 70% of the total economy (see Table 3.4). Nearly 20% of total R&D expenditures take place in services. This is a substantial share, but relatively small compared to the share of services in value added.

Table 3.4 R&D expenditures in 14 OECD countries, 1998

Sector	Expenditures in billion US$	Expenditures as % of total	Expenditures as % of value added
Basis metal	4.1	1.2	2.5
Non-metallic minerals	2.8	0.8	2.1
Chemicals	50.0	15.1	13.7
Electrical equipment	106.0	31.7	19.0
Metal products	3.6	1.1	1.3
Other machinery and equipment	19.5	5.8	5.2
Paper, publishing and printing	3.4	1.0	1.0
Rubber and plastics	4.9	1.5	3.5
Textiles and leather	1.6	0.6	0.9
Transport equipment	61.8	18.5	14.7
Food processing	5.3	1.6	1.3
Total manufacturing	269.5	80.6	7.2
Total services	58.7	17.6	0.4
Total	334.3	100.0	1.7

Source: OECD databases ANBERD and STAN and own calculations.
Numbers do not add to 100, because some sectors are ignored.

3.4 R&D spillovers

Estimated model

Based on the ideas of Coe and Helpman (1995) we incorporate an empirical relation between total factor productivity (TFP) growth and the growth of R&D stocks in the model. We distinguish three types of R&D stocks: the R&D stocks of the own sector, of other sectors in the economy to reflect domestic spillovers, and of foreign sectors to reflect international spillovers. We model the received spillovers from other domestic sectors analogously to Jacobs *et al.* (2002). The growth rate of the spillover stock ($\mathring{S}_j^D$) in sector j depends on the growth rate of the R&D stocks ($\mathring{R}_i$) in the other sectors weighted by the share of domestic intermediate deliveries of these sectors to production in sector j:

$$\mathring{S}_j^D = \sum_{i \neq j} w_{ij}^D \, \mathring{R}_i \tag{3.6}$$

where a single dot above R represents the growth rate and w_{ij}^D represents the share of domestic intermediate deliveries of sector i in the production of sector j. The shares do not add to one because imported intermediate deliveries and primary factor inputs are not weighted in this equation. $\mathring{S}_j^D$ is a weighted aggregate of various growth rates but it grows less fast than the R&D stocks because the weights do not add up to 1. Sector j not only receives spillovers from other sectors in its own country, but also from sectors abroad:

$$\mathring{S}_{jk}^F = \sum_{l \neq k} \sum_i m_{lk} \, w_{ij}^F \, \mathring{R}_{il} \tag{3.7}$$

The variable m_{lk} represents the share of country l in total import of country k and w_{ij}^F represents the share of intermediate deliveries of sector i from other countries in the production of sector j.

Estimation results

The empirical relation between TFP growth and the R&D stocks is based on data of 14 OECD countries and 12 sectors for the period 1980 to 1999.[27] The data are from the ANBERD database of the OECD for the R&D expenditures, and from the STAN data base of the OECD to construct total factor productivity (TFP) growth and value added. The growth of TFP is related to the growth of the own sectoral spillovers, the domestic R&D spillovers from other sectors and the foreign R&D spillovers. The estimated equation reads:

$$\mathring{a}_{sr,t} = \beta_V \, \mathring{R}_{sr,t} + \beta_D \, \mathring{S}_{sr,t}^D + \beta_F \, \mathring{S}_{sr,t}^F + \sum_r D_r + \sum_t D_t + \varepsilon_{sr,t} \tag{3.8}$$

D_r and D_t are country and time dummies, ε is the disturbance term. Table 3.5 presents the estimation results. We have estimated with dynamic OLS, see Funk (2001), and Kao *et al.* (1999), because the OLS estimates can be biased due to the non-stationarity of the time series. As is usual for these estimates we introduce two lags and one lead of the differences of the explanatory variables in the equation.

Table 3.5 R&D spillovers on TFP growth

Coefficient	Parameter estimate	Elasticity (%)
Own sector R&D spillover	0.049 (0.022)	4.9
Domestic sectoral R&D spillover	0.325 (0.107)	7.4
Foreign R&D spillover	0.868 (0.233)	5.6
Total elasticity		18.0

R^2 is 0.183. The number of observations is 2250. The equation is estimated with dynamic OLS using two lags and one lead. The numbers between parentheses are standard errors. Country and time dummies are included but not presented. Data sources are OECD (2003), ANBERD and Stan database. Lejour and Tang (2005) provide more details. Note that we do not use the own sector R&D spillover in WorldScan. The reason is that this effect is captured already by the inclusion of R&D as a factor of production.

[27] The 14 countries are Australia, Canada, Germany, Denmark, Spain, Finland, France, United Kingdom, Italy, Japan, Netherlands, Norway, Sweden, and the United States.

The elasticity for the own sectoral R&D spillovers to TFP growth is low compared to other studies. In his overview of the estimates of the own R&D elasticity Nadiri (1993) concludes that these are in the range of 6% to 42%. Our domestic spillover elasticity equals 7.4% (the weighted average of the share of own intermediate deliveries is 0.226 times the parameter estimate).This result is comparable to Verspagen (1997) who reports elasticities for the domestic spillovers of 2% to 9%, but it is again relatively low compared to the rest of the literature. Jacobs *et al.* (2002) and Keller (1997) find elasticities of about 15%, and Nadiri's overview reports spillover elasticities between 10% and 26%. The foreign spillover elasticity is 5.6% (the weighted average of the share of foreign intermediate deliveries is 0.065). This is comparable to the results of Coe and Helpman (1995). They find an elasticity of TFP to foreign R&D of 6-9%. Jacobs *et al.* (2002) report an elasticity of 12.9%, but that is only valid for the manufacturing sector. For the total economy it is probably much lower because services are R&D extensive.

As a result our total elasticity is about 18%. So a 1 percent change in the global R&D stock leads to a 0.18 percent increase in total factor productivity. The social return on R&D is much higher: every euro spent on R&D world-wide instead of on GDP leads to nearly 0.9 euro extra GDP. This is a rate of return of about 90%.[28] This is close to the upper range of the social rate of return on R&D found by other researchers. Canton *et al.* (2005) conclude that these estimates typically are in the range of 30% to 100%. Jones and Williams (1998) claim that these estimates are conservative because they do not take account of the full dynamic effects of R&D. Griffith *et al.* (2000) estimate for most OECD countries social rates of return on R&D of about 50% or higher.[29]

The model

We incorporate the relation between TFP and R&D stocks and R&D-spillovers in WorldScan, according to equation (3.8). However, that equation only represents the part of TFP growth due to the R&D spillovers. We represent this part by $\mathring{ad}$. The growth rate of this endogenous part of TFP follows from substituting the changes in the R&D stocks and the estimated values for the parameters in equation (3.8).

$$\mathring{ad}_{sr} = \hat{\beta}_V\,\mathring{R}_{sr} + \hat{\beta}_D\,\mathring{S}^D_{sr} + \hat{\beta}_F\,\mathring{S}^F_{sr} \tag{3.9}$$

R&D stocks and R&D spillovers explain only a part of TFP growth in the model. Therefore we use also exogenous TFP growth. So total TFP growth consists of an exogenous and endogenous

[28] The return can easily be calculated from the elasticity, assuming that the effects on TFP growth and GDP growth are the same. Multiplying the elasticity by the GDP level and dividing it by the R&D stock one arrives at the return on R&D.

[29] Note that the estimates are based on a growth equation in which R&D only affects TFP. The R&D stock is no separate input in production as it is in WorldScan. In WorldScan the own R&D stock already delivers a return on its investment. Therefore we assume that the spillover effect of own sectoral R&D on TFP growth is zero. This reduces the elasticity of R&D on TFP due to spillovers to 13%. However, for most countries and sectors the elasticity of private R&D on production in the model is 4% to 5%, such that the total elasticity is still about 18%.

part, the R&D spillovers. The exogenous part consists of three elements, see equation (2.19). TFP growth within a sector thus equals

$$\mathring{a}_{TVA,rs} = (1+\mathring{a}d_{rs})(1+\mathring{a}_{TVA,r})\left(\frac{\bar{a}_{TVA,s}}{\bar{a}_{TVA}}+1\right)-1 \tag{3.10}$$

For the base year, we have derived the R&D stocks for the spillovers according to equation (3.4), (3.6) and (3.7). We have used the OECD data on R&D expenditures to calculate the R&D stocks in equation (3.4). The value of total TFP growth for each sector follows also from the calibration. By inverting equation (3.10), we calculate the exogenous part of TFP growth, $\mathring{a}_{TVA,r}$. In time TFP grows due to an exogenous increase and an endogenous increase in the R&D stocks.

4 Labour and population

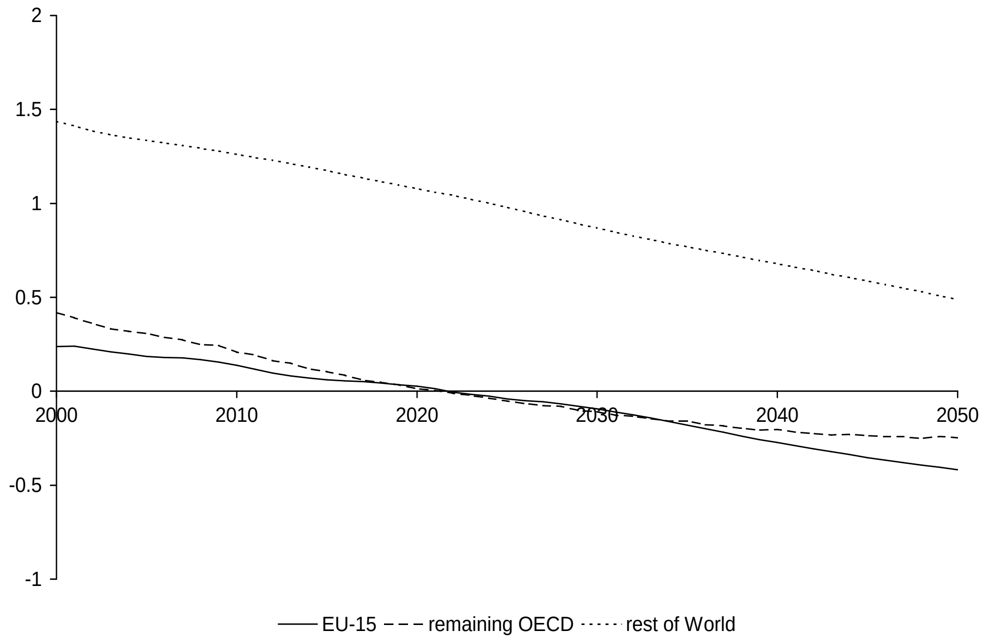
Supplies of skilled and unskilled labour are exogenous in WorldScan. They depend upon demography, participation rates and the share of the high skilled in the total workforce. This chapter describes the mechanisms and some of the details involved in projecting these developments until the year 2050. These projections are prerequisite for the assessment of the impacts of ageing. Population projections for the countries of the EU-15 are taken from Eurostat and for all other countries from the UN. For 24 population cohorts participation rates are projected using time series analysis. The data are a mixture of past observations and ILO-projections up to 2010. Aggregation of the projected rates over cohorts and individual countries yields macro participation rates for specific regions. Projections of skilled labour shares finally yield time series of the skilled and unskilled labour force.

4.1 Population

Population projections are mainly taken from the revision 2002 of the UN World Population Prospects (United Nations, 2004). These consist of alternative demographic projections until 2050 for all countries. The data and projections are provided in considerable detail, showing annual population sizes by gender and 5-year age cohort over the period 1950-2050 at country-level. Of the four projection alternatives available – low, medium, high and constant fertility – we have chosen the medium variant. For the countries of EU-15 we used the baseline projections for the period 1999-2050 of Eurostat (2000).

The developments in projected population sizes are summarised for selected regions in Figure 4.1. Population growth is decreasing everywhere and in most Western European countries the growth rate becomes sooner or later negative, implying a shrinking population. This is already the case now in Central Europe, the Former Soviet Union, and Italy. In Western Europe the reduction in population size will be most pronounced in Germany, Italy and Spain. From 2020 onwards the population will shrink in Spain and Germany, while for the other EU countries this will be the case only after 2040. Population growth remains positive in the United States due to immigration. Population will also continue to increase in Turkey, the Middle East, Latin America and the rest of the World (Asia and Sub-Saharan Africa). Yet, in these regions too population growth is projected to decrease substantially.

Figure 4.1 World population prospect for selected regions, percentage change over previous year, 2000-2050



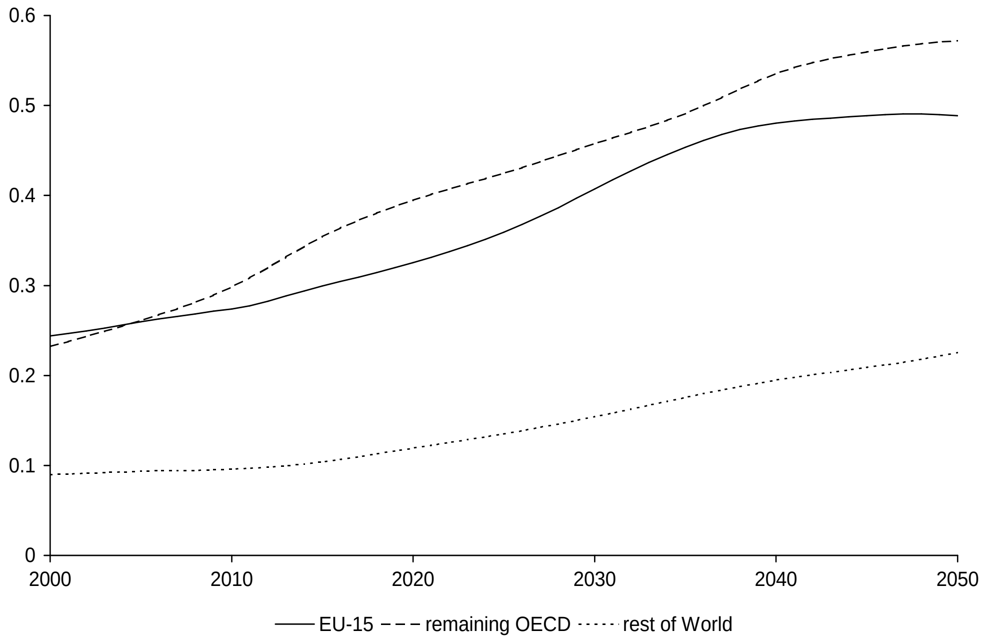
Source: UN World Population Prospects, Eurostat Population Scenarios

Unsurprisingly, because of lower population growth, the share of OECD-countries in global population drops from around 14% in 2000 to a little over 10% in 2050.

Declining growth of the population due to falling birth rates affects the age composition. In particular, the share of elderly people will increase. This is apparent from Figure 4.2 which shows the development of the so-called elderly dependency ratio for selected regions. The ratio is defined as the number of people over 65 divided by the potential labour force, *i.e.* the number of people between 15 and 65.

The elderly dependency ratio increases in all regions. In particular, ageing is a strong trend in Germany, Italy and Spain. In Central Europe ageing rises dramatically after 2030. Ageing is less pronounced in the United States. Even outside the OECD populations will age, although the process will start later and is less striking. An exception is China, where ageing of the population becomes already a pressing problem early in this century (De Groot and Tang (2002)).

Figure 4.2 Elderly dependency ratios for selected regions, 2000-2050



Source: UN World Population Prospects, Eurostat Population Scenarios

4.2 Participation

The labour supply trends in many applications of WorldScan are based upon projected participation rates and projected population developments. Participation rates are not constant in time. They are influenced by several factors. First, higher economic growth enables more young people to attain education for a longer time period and consequently the participation rates in these age cohorts will be pushed downwards. Second, the last decades show that more people retire at a younger age, resulting in a downward trend in participation rates of older age cohorts. Though this trend may be reversed in the future by government policies aiming at alleviation of the ageing problem, such policies are generally not incorporated in the projections. Third, participation rates of women are affected by economic and cultural developments. Fourth, participation is affected by the attractiveness of the social security system (see Roodenburg and van Vuuren, 2004).

Extrapolation approach

Our aim is to extrapolate participation rates until 2050, because some of our scenarios and analyses run up to 2050. Data are available for the years 1950, 1960, 1970, 1980, 1990 and 1995, while ILO projections can be used as a data source for the years 2000 and 2010 (see ILO, 2000). Data and projections are available for both males and females and for 12 age cohorts[30]. For all 87 countries/regions of the GTAP-6 data set (see Dimaranan and McDougall, 2006) we make projections of each of the 24 cohorts before aggregating them to macro participation rates for the regions present in the WorldScan classification.

We extrapolate the current trends in participation rates between 1950 and 2010 until 2050, using an auto-regressive model for the period 1950 to 2010. This model is as follows. First we apply a logit transformation to the participation rates for all sexes, age cohorts and countries/regions

$$y = \log(x/(1-x))$$

in which x represents the participation rate. For those age cohorts which do not participate in the labour market in 2010 such as the age cohorts 10-15 for both sexes in the OECD, we ignore the data in the regressions. We take the first differences of the variable y and estimate a first- or second-order auto-regressive process for all age cohorts, and sexes, pooling the data over regions. The data are pooled for two reasons. First, the trends in participation rates are similar in many regions. Participation rates for people between 10 and 20 years of age are decreasing, because educational attainment increases. Participation rates of elderly also decrease. Second, the time series per region, per sex and age cohort are very short. They consist of 9 or 10 ‘data points’ only. By pooling the observations over regions, the number of observations increases substantially.

The AR(2) regression reads

$$\Delta y_t = \alpha_0 + \alpha_1 \Delta y_{t-1} + \alpha_2 \Delta y_{t-2} + \varepsilon_t$$

in which $\Delta y_t = y_t - y_{t-1}$ represents the first difference of the transformed participation rate per cohort and sex and ε_t represents a disturbance term with zero mean and constant variance.

The regression has been carried out for two country groups. The first consists of 6 regions of developing countries[31], while the other comprises 40 separate countries from OECD, Eastern Europe and the Former Soviet Union (called industrialised countries from now on). We choose these country groups for pooling, since the group members show similar pictures concerning ageing. For nearly all estimated equations the constant term and the coefficient were significant at the 95% level. Only for the cohorts men 20-24 and 30-34 and women 55+ the coefficient was not significant in the group of developing countries. For the industrialised group the estimations for the younger male age-cohorts (until 24) and 65+ did not produce significant coefficients (see Lejour and van Leeuwen (2002) for detailed tables of estimation results).

[30] These are the age cohorts 10-14, 15-19, .. and 65+. The participation rates of the age cohorts 0-4 and 5-9 are ignored because these are negligible; see also ILO (2001).

[31] These regions are Latin America, Sub-Saharan Africa, Middle East & North Africa, China, South-East Asia and South Asia and Rest World.

We did not attempt to improve the estimation results for particular cohorts as an in-depth analysis of labour market participation of the various age cohorts is not our aim. We simply carried out these estimations in order to project participation rates at the macroeconomic level for our scenario studies with WorldScan and the projected participation rates per age cohort and sex are only an intermediate step in that process.

Actual and projected developments are shown in Figure 4.3. In this figure we show the ILO data between 1950 and 1990, the ILO projections for 1990 and 2010 and our projections between 2010 and 2050 in one graph. The trends in participation rates per age cohort from the age cohort 10-14 until the age cohort 65+ are presented in twelve graphs. Each graph shows the participation rates for men and women, for developing as well as for industrialised countries.

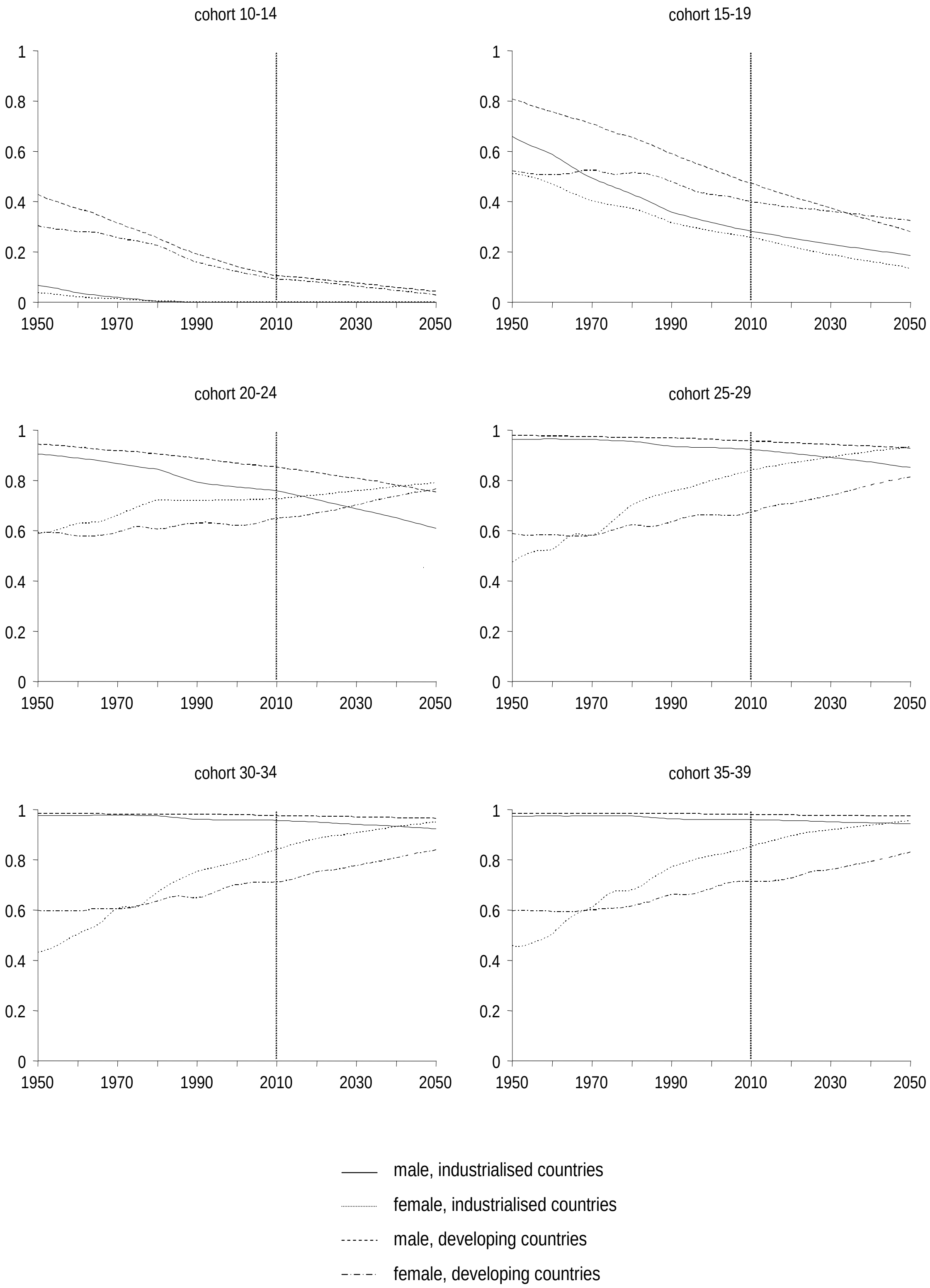
The participation rates in the age cohorts 10-14 and 15-19 decrease over time. In general the participation rates in developing regions are higher than in the industrialised world, but the trend is going downwards. For the age cohort 10-14 participation rates are almost negligible in 2050 for developing regions. This is already the case today in industrialised countries.

In the age cohorts 20-24 to 55-59 labour market participation of women rises while it decreases (slightly) for men. The decrease is substantial in the age cohort 20-24 because of increasing participation in higher education. This tendency also seems to be present in the age cohort 25-29 although to a lesser extent. For the older age cohorts 50-54 and 55-59 male participation rates also decrease substantially, but for the younger age cohorts the decrease is rather modest. For the age cohorts 20-24 to 30-34 the participation rates of women in industrialised countries surpass those of men after 2020. This trend reflects a strong upward trend in labour market participation of women in these countries in our projections. For the older age cohorts female participation rates converge to the male rates of men or slightly exceed them.

For the age cohorts 60-64 and 65+ participation rates of men decrease sharply. Those of women remain constant in time or decrease slightly.

For all age cohorts the participation rates of men in developing countries are higher than those in the more developed countries. For women this pattern only prevails between 1950 and 1980. From 1980 onwards female labour market participation in the cohorts from 20 to 54 is higher in the industrialised countries than in the developing world.

Figure 4.3 Participation rate by age cohort and gender in industrialised and developing countries 1950-2050



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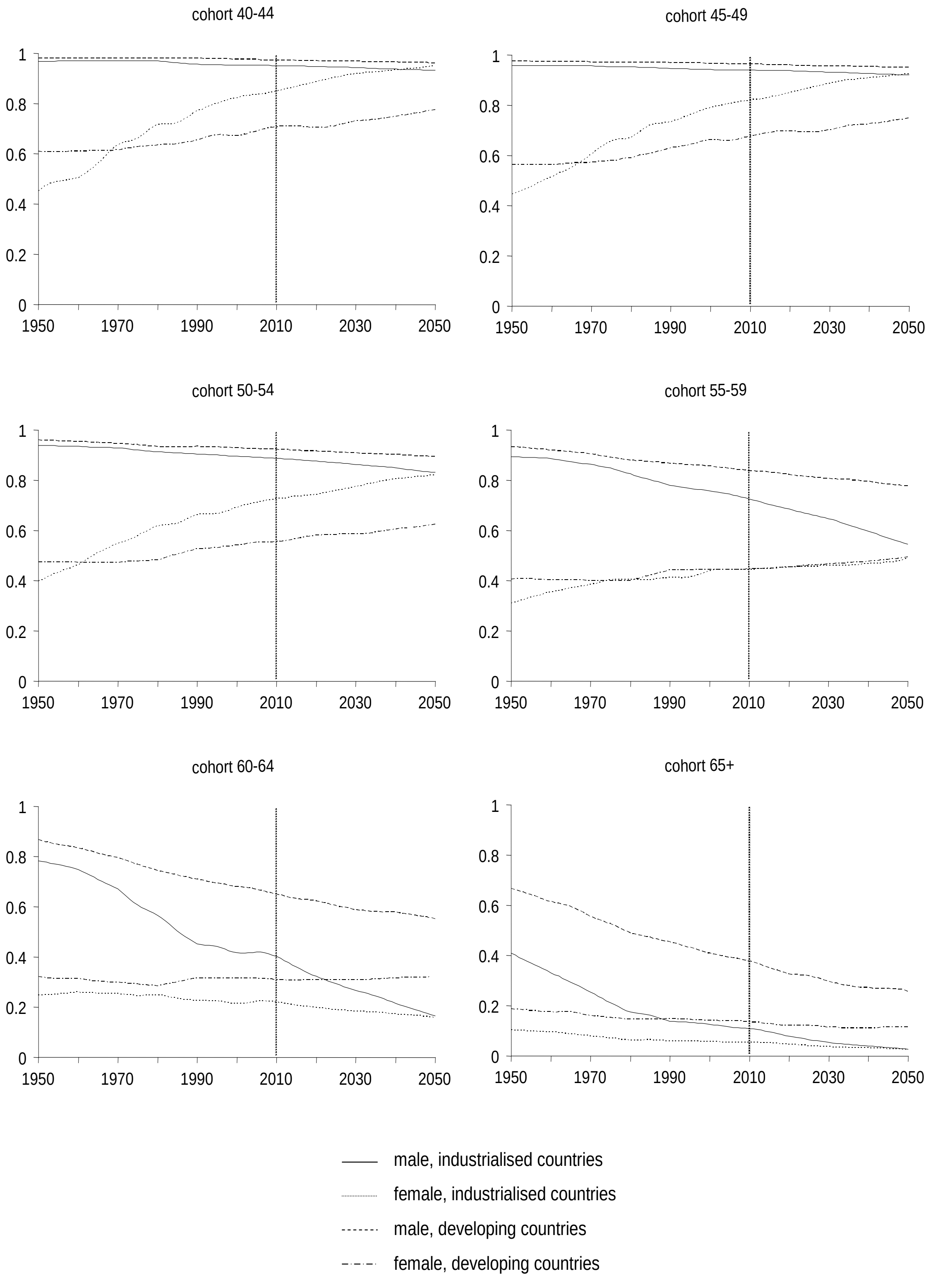
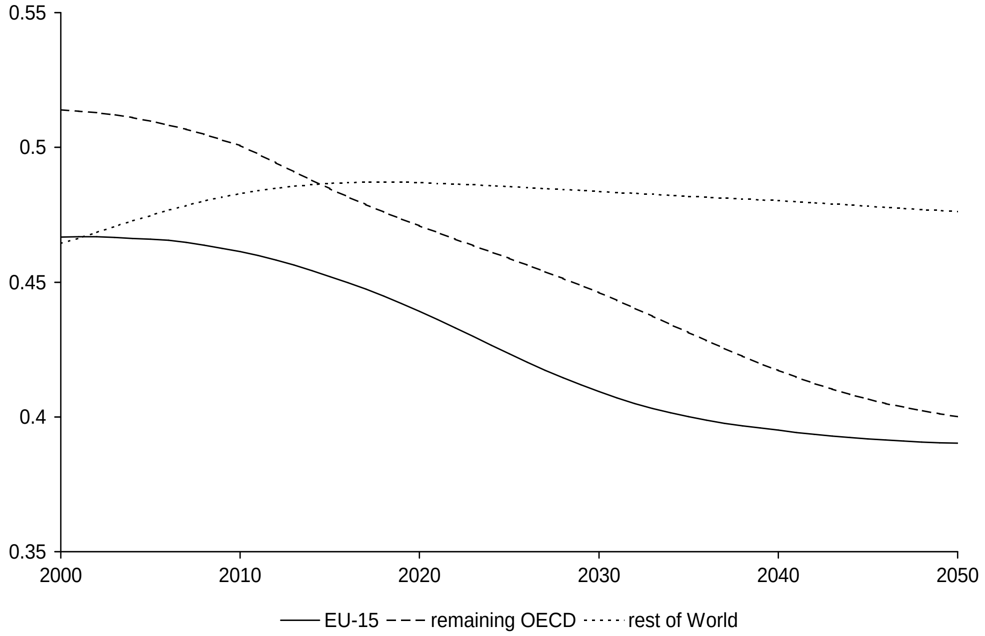

cohort 40-44
cohort 45-49
cohort 50-54
cohort 55-59
cohort 60-64
cohort 65+
0
0.2
0.4
0.6
0.8
1
1950
1970
1990
2010
2030
2050
male, industrialised countries
female, industrialised countries
male, developing countries
female, developing countries

Combining the population projections of section 4.1 with the projected participation rates by age cohort and gender yields the macro participation rates. These are shown in Figure 4.4 for a breakdown of selected regions. The projections are subject to a substantial degree of uncertainty.

Figure 4.4 Macro participation rates for selected regions, 2000-2050

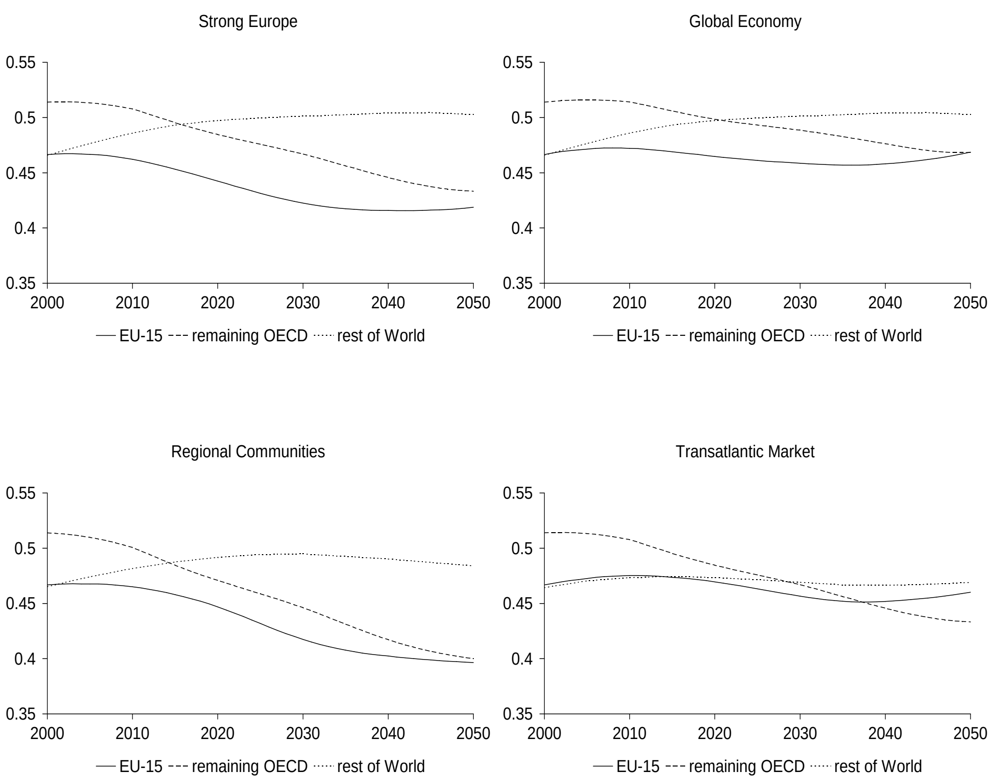


Actual participation rates are influenced by various economic and cultural factors. Our mechanical projections do not explicitly reflect these influences. However, extrapolation of trends seems to be more realistic than just keeping participation rates constant beyond 2010. For example, declining participation rates in the younger age cohorts as has been the case in developed countries - and is the case in many developing countries now - are heavily correlated with economic development. With continuing economic growth it seems more sensible to include this trend in the projections rather than assuming constant participation rates for each age cohort and sex from 2010 onwards.

Figure 4.4 shows that in all regions 45% to 50% of the population participated at the labour market in 2000. In general participation rates decrease until 2050 to a range of 35% to 50% of the population. In several countries of the Rest of the World (notably in the Middle East and Northern Africa) participation rates are very low because women hardly enter the labour market. Nevertheless, in this region participation rates will first increase due to higher participation of women and then decrease because of ageing. In the EU and other OECD participation rates decrease. These follow the pattern of ageing, although mitigated by an increasing labour market participation of women. In Italy, Spain, Central Europe, remaining OECD (including Japan) and the Former Soviet Union, decreasing participation seems to be a larger problem than in the other industrialised countries.

Our simple projections are a far cry from an in-depth analysis of labour market participation of specific age cohorts. First of all, the time horizon of the projections is very long given the time horizon of the data even if the latter include projections of the ILO for the years 2000 and 2010. Second, the estimation method using a first- or second-order auto-regressive process is simple and does not address the possibility of convergence of participation rates either for men and women or for developed and developing countries. Third, any projection could be affected by changes in government policy and endogenous mechanisms. An example is the decline in participation rates of elder age cohorts in the industrialised world. To alleviate the problems of ageing, governments could try to increase these rates. Moreover, employers could invest in keeping the elderly at work if labour becomes increasingly scarce. Hence, induced (policy) measures may prevent the projected declines to materialise.

Figure 4.5 Macro participation rates for selected regions in Four Scenarios for Europe, 2000-2050



Source: Quantifying four scenarios for Europe (2003)

As an illustration of the ways in which alternative policy settings might influence macro-participation rates, we show the rates used for the scenarios of *Quantifying Four Scenarios for Europe* (Lejour, 2003). In the scenarios on the left side of Figure 4.5 (STRONG EUROPE and REGIONAL COMMUNITIES) the emphasis is on equity rather than efficiency. In the scenarios to the right (GLOBAL ECONOMY and TRANSATLANTIC MARKET) the emphasis is just the opposite. Three factors affect participation in these scenarios: population growth, social security systems, and the participation rates of women and the elderly. First, population growth in EU-15 follows the projection scenarios of Eurostat (2000). Population growth is highest in STRONG EUROPE and GLOBAL ECONOMY, lowest in REGIONAL COMMUNITIES and average *(i.e.* according to Eurostats baseline projection) in TRANSATLANTIC MARKETS. Due to ageing a larger share of the population than currently is the case will be older than 65 in all scenarios. This reduces macro participation rates in all scenarios and especially in REGIONAL COMMUNITIES. Second, social security systems are relatively generous in the scenarios with a focus on equity (REGIONAL COMMUNITIES and STRONG EUROPE), affecting participation negatively. In the two other scenarios with a focus on efficiency the low social benefits increase labour-participation rates. Third, though female participation rates are projected to rise at the same pace in all scenarios, participation of the elderly differs. In REGIONAL COMMUNITIES existing rules and policies are assumed to remain in place, hence the elderly will continue to retire early. In STRONG EUROPE early retirement programmes are made less attractive, increasing participation of older people. In TRANSATLANTIC MARKET and GLOBAL ECONOMY people are stimulated to stay employed even after the age of 65. Early retirement schemes are disbandoned and tax and pension schemes are geared to promote working after the age of 65. Due to the influence of these factors, the macro-participation rates in EU-15 are in 2040 similar to those in the year 2000 in the right-hand panels of Figure 4.5, while they are considerably lower in the left-hand panels.

4.3 Labour skills

WorldScan distinguishes low-skilled and high-skilled labour. This is relevant, not only for the analysis of the labour market, but also for the analysis of economic growth. Moreover, it affects specialisation patterns. OECD regions endowed with a relatively high amount of high-skilled labour specialise in the production of high-skilled labour-intensive goods, and regions endowed with relatively much low-skilled labour specialise in low-skilled labour-intensive goods.

Labour can be classified as high- or low skilled according to two methods. The first uses a criterion based on the professional status of employees. Professional workers are classified as high-skilled, and production workers as low-skilled.[32] The second method uses a criterion based

[32] This method is followed in the GTAP database; see Dimaranan and McDougall (2006).

on schooling levels. High-skilled workers are classified as those who completed secondary education. We have used the latter method for two reasons. First, education levels provide a better indication of endowments in regions. Second, pronounced differences between the regional qualities of employment are better described by average education levels than by occupational classification.

The classification of high- and low-skilled workers in a region is based on current and projected stocks of human capital for the different levels of education in a region. Barro and Lee (1993, 1996) have constructed a stock of human capital for every schooling level for about hundred countries using a perpetual inventory method. The four relevant levels are none, primary, secondary, and higher education. For the latter three levels they also distinguish attainment and completion levels. Changes in the number of people who have attained or completed a certain level depend on the mortality rate of that group and the inflow. The inflow is determined by the size of the new age cohort times the enrolment rate for the specific schooling level. The method thus needs data on enrolment rates, age cohorts, and age-specific death rates (see UNESCO (1989)). In this way Barro and Lee (1996) have constructed stocks of human capital for the age category 15-64 between 1960 and 1990. Ahuja and Filmer (1995) have constructed projected stocks of educational attainment of the population aged 6 and over until 2020. They have used projections on enrolment rates, age cohorts and age-specific death rates, as well as the stocks of human capital from Barro and Lee (1993). However, their projections do not include the OECD countries. Furthermore, they only construct projections for attained levels, because projections on drop out rates and by consequence completed levels are not available.

The resulting stocks of human capital raise several questions, given our purpose to classify high- and low-skilled labour. First, the differences in attained levels of education between the United States and most other OECD countries are quite large. The proportion of the population that attained only primary education is much higher in Europe, whereas the attainment in higher education is much lower. Moreover, for most large European economies convergence tendencies to the United States in educational attainment do not show up. Within Europe the differences (in secondary education) are also striking. Attainment in secondary education rose from 1960 to 1990 in Austria by about 40% of the population, while the rise is only 10% in Germany and France.[33]

In our opinion, the implied differences in projected skill levels in these countries are not plausible if they are related to actual differences in skill-intensive production technologies in the OECD. OECD (1997b) supports this reasoning. Hence, it seems reasonable to assume that educational levels are similar within OECD regions. According to the data of Barro and Lee (1996), educational levels in Eastern Europe and the Former Soviet Union are comparable to the

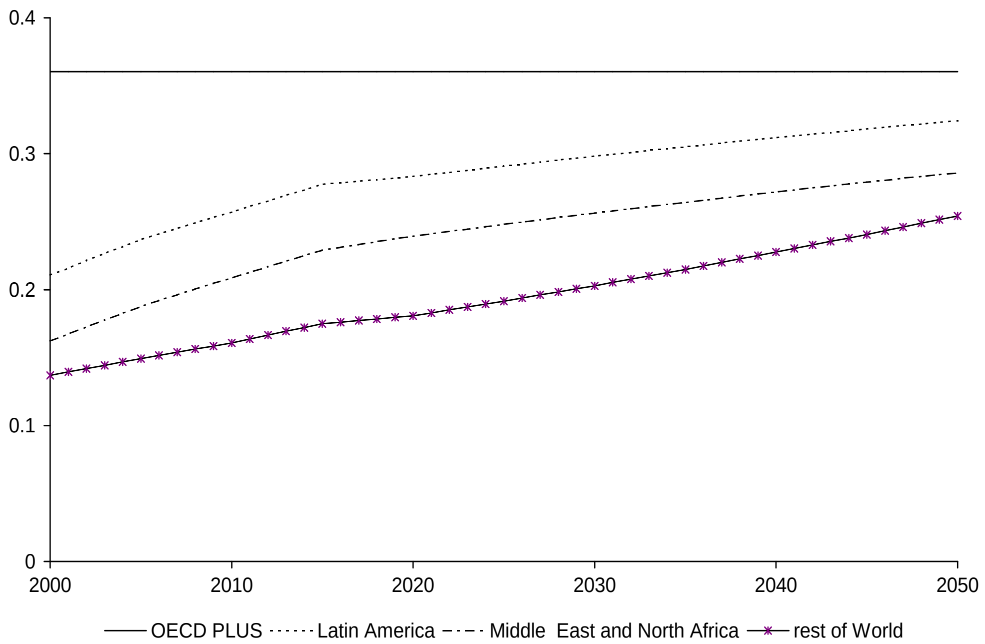
[33] These problems go back to the raw data of UNESCO (1989). Van Leeuwen and Lejour (1998) discuss some of the causes, such as different classifications of education levels and institutional differences.

OECD. We therefore assume for our projections that the stocks of human capital are similar in the OECD, Eastern Europe and the Former Soviet Union.

Besides the problem mentioned above, the projections of Ahuja and Filmer (1995) on human capital include only developing countries, and are not available beyond 2020. For the developed regions and beyond 2020, we have to construct our own projections. Moreover, Ahuja and Filmer (1995) provide projections only for attained levels of education. However, we classify high-skilled workers as those who have completed secondary education or more. The reason is that other classification criteria lead to a very large share of high-skilled workers in the OECD (e.g. if attained secondary education is a criterion) or a negligible share of high-skilled workers in the non-OECD (*e.g.* if attained tertiary education is a criterion).

Figure 4.6 shows our projections until 2050 for the population share that completed secondary education.[34] The figure shows that the projected share of skilled labour for the OECD-countries is kept constant (at 36.1%) and that the relative supply of high-skilled labour in the non-OECD regions will increase. It will, however, take a long time before OECD levels are reached, because many developing countries are a long way from even providing basic education at this moment as the World Bank (1995) points out. Nevertheless, slowly but surely they are getting closer.

Figure 4.6 Share of high-skilled labour in total labour supply for a breakdown of selected countries and regions 2000-2050



Source: Own calculations based on Ahuja and Filmer (1995), and Barro and Lee (1996)

[34] Van Leeuwen and Lejour (1998) extensively discuss the method used.

4.4 The labour market: modelling and applications

Modelling

The preceding sections discussed mainly our projections on population, labour-market participation and skills. These projections are exogenous inputs in WorldScan. This section concentrates on the representation of the labour market in Worldscan. Total labour supply in region r, l^S is a function of the participation rate, lq^S, and the population, pop (measured in millions). The equation reads

$$l_r^S = lq_r^S \, pop_r \tag{4.1}$$

The share of workers per skill type in total labour supply is represented by lq_i^S. Labour supply of high- and low-skilled workers thus reads

$$l_{ir}^S = lq_{ir}^S \, l_r^S \tag{4.2}$$

The unemployment rate is exogenous. In the calibration year unemployment rates are derived from Eurostat and the World Bank. For subsequent years we project the unemployment rates. In general we assume that these rates are constant. However, for some purposes such as scenario studies (Lejour, 2003) we make alternative assumptions. From Eurostat we know the unemployment rates of the various skill groups i, represented by the variable luq_i. The unemployment level of skill group i in region r reads

$$lu_{ir} = luq_{ir} \, l_{ir}^S \tag{4.3}$$

Total unemployment in region r is the sum of he unemployment levels of both skill types.

$$lu_r = \sum_i lu_{ir} \tag{4.4}$$

The overall unemployment rate reads

$$luq_r = \frac{lu_r}{l_r^S} \tag{4.5}$$

The employment level is the difference between labour supply and unemployment

$$l_{ir} = l_{ir}^S - lu_{ir} \tag{4.6}$$

$$l_r = l_r^S - lu_r \tag{4.7}$$

From equation (2.5) we know the demand for high and low-skilled labour in each sector. Aggregating labour demand over all sectors gives total labour demand in a region. Regional labour demand has to be equal to employment for each skill type, as in equation (4.6). Labour demand q_i depends on the wage rate w_i. The equilibrium condition at the labour market thus reads for each skill type

$$q_{ir}\,(w_{ir}) = l_{ir} \tag{4.8}$$

The average wage in a region is the weighted average of the wages per skill type.

$$w_r = \frac{\sum_i w_{ir} \; l_{ir}}{l_r} \tag{4.9}$$

Applications

As in most global general equilibrium models labour markets are described in a very crude way. Because we distinguish two skills types, we are able to analyse the effects of globalisation on the wage distribution.[35] Moreover, we are able to analyse employment shifts between sectors due to structural changes. We also analyse the effects of migration flows. Migration flows themselves are not modelled in WorldScan. Based on work of others, we use (exogenous) migration flows to change population and labour supply in the various regions.[36] We take account of labour-market participation rates of the various groups of migrants and their skill levels. Because population, labour supply and skill projections are exogenous in the model, it is possible to incorporate migration flows in these projections.

The present modelling of the labour market does not permit us to analyse labour-market policies or the effects of social security policies on employment. For that purpose we have to modify the model. Because labour-market policies and social security arrangements vary widely per country, it remains quite a challenge to model these issues in a global general equilibrium model.

[35] Examples are OECD (1997a), Lejour and Tang, (2000), and Nahuis (1999).

[36] Examples are our analyses on European integration. We have incorporated the expected migration flows of the new accession countries and the candidate member Turkey to the older members states to examine the economic effects, see Lejour *et al*. (2004), and Lejour and de Mooij (2005).

5 Savings and capital mobility

This chapter concentrates on the modelling of savings, capital and capital mobility in WorldScan. Section 5.1 discusses the effects of economic growth and the structure of the population on savings. This relation is empirically estimated. Section 5.2 explains the modelling of international capital mobility and section 5.3 discusses the degree of international capital mobility.

5.1 National Savings

Introduction

Ageing is an important phenomenon in Europe and Japan in the coming decades. Although the precise relation between savings and ageing is unclear,[37] the broad pattern of dissaving when young, saving when working and again dissaving when old is fairly robust. It also appears from estimations across countries and over time, which relate countries' savings rates to the age structure of their population. A robust finding is that a higher share of the population between the age of 40 and 65 leads to a higher savings rate, whereas a higher share of the population older than 65 leads to a lower savings rate.

Given the relevance of ageing in Europe, we prefer to model the effects of ageing directly in WorldScan. Therefore we have estimated a relation between savings and demography and incorporated that relation in the model. This is a common procedure in AGE models. Many static AGE models assume an exogenous savings rate (*e.g.* the GTAP model), while other dynamic AGE models also incorporate an estimated savings function (*e.g.* the Linkage model). The inclusion of an exogenous or estimated savings rate deviates from modelling savings derived from welfare-maximising consumers. In a previous version of WorldScan (see CPB, 1999) savings were derived from welfare maximisation. In that version consumers decided over savings and consumption over an infinite time horizon. Savings were not fully determined by intertemporal welfare-maximisation, because the model is solved year by year (recursively) and not over an infinite time horizon. Another disadvantage was that the effects of ageing were less explicitly modelled: the consumption function contained a 'probability of death'variable. For an ageing population this variable will increase, but it is less easy to represent ageing than by incorporating the size of age cohorts in an estimated savings functions, as we will show below.[38]

[37] Canton *et al*. (2004) provide a more extensive discussion on this issue. National savings are defined as private and government savings. Thus dissaving in the life cycle also includes government expenditures.

[38] This section draws heavily on De Groot and Tang (2002) and Canton *et al*. (2004).

Empirical specification

For the estimation of the relationship between savings and the demographic structure of the population, we have used a slightly modified version of the commonly-used methodology developed in Fair and Dominguez (1991) to estimate age-dependent economic decisions such as savings, participation, etc. We estimate the following equation:

$$Sq_{i,t} = \beta_i + \beta_1 g_{i,t} + \sum_{j=1}^{17} \alpha_j c_{ji,t} + \varepsilon_{it} \tag{5.1}$$

where $Sq_{i,t}$ is the average savings rate of country i over the time period from $t-5$ to t, β_i is a series of country-specific fixed effects, $g_{i,t}$ is the growth rate of GDP per capita of country i over the time period from $t-5$ to t, and $c_{ji,t}$ is the fraction of cohort j of the total population in country i at time t. In principle, we could discriminate seventeen five-year cohorts, namely 0-5, 5-10, 10-15, ..., 75-80 and 80 and above. Multi-collinearity among the cohort-size variables complicates the estimation of this equation. There are two ways to deal with the multicollinearity. The first is to put more structure on the estimated parameters α_j by imposing a polynomial constraint on these parameters. Fair and Dominguez (1991) follow this method, and De Groot and Tang (2002) present this also as an alternative. We do not present these results here, because we choose the second method. The second method puts more structure on the parameters by aggregating the five-age cohorts into 4 broad age-groups of 0-25 year, 25-45 year, 45-65 year, and over 65. The estimation results are presented below.

Data

Our data are derived from a variety of sources. Information on the age composition of economies is taken from United Nations (2001). Data on GDP per worker are taken from the Penn World Table (Mark 6.1). Our measure for savings is average Gross Domestic Savings [39] for the five-year periods distinguished in the analysis and is taken from the World Bank (World Development Indicators, 2003). Their data have been aggregated to the mentioned four age-groups.

Regression results

The equations in Table 5.1 use the four aggregated cohorts. Because the population shares of the four groups add up to one by definition, the problem of multi-collinearity among the cohort shares is still present. Therefore we exclude the youngest age-group from the regression. The results are reported for an extensive sample (covering 107 countries) as well as for two restricted samples of only OECD and non-OECD countries.

The growth rate has a positive effect on savings. It is stronger for the OECD countries than for the non-OECD ones. A large share of the age-cohort between 25 and 65 affects savings

[39] The savings consist of consumer, firm and government savings.

Table 5.1 Dependent variable is average domestic savings (% of GDP), pooled cross-section analysis with 5-year periods from 1960 to 2000

Equation	1	2	3
	(Mix, 107 countries)[a]	(OECD, 22 countries)[b]	(Non-OECD, 121 countries)[c]
Growth rate GDP per capita	0.14	0.64***	0.28***
	(1.34)	(3.81)	(3.43)
Share population, 25-45 aged	0.57***	− .09	0.46***
	(4.52)	(− 0.67)	(5.04)
Share population 45-65 aged	0.85***	0.06	0.95***
	(3.82)	(0.31)	(4.57)
Share population above 65	− 0.79***	− 0.55***	− 0.98***
	(− 3.38)	(− 3.28)	(− 5.04)
Adjusted R^2	0.77	0.64	0.68
Number of observations	608	153	637

[a] Mix is OECD and non-OECD countries combined (column (2) and (3)), from which poor non-OECD countries are excluded.
[b] OECD consists of the old members, excluding Mexico, Korea, Turkey, Czech Republic, Slovakia, Poland, Hungary and Germany.
[c] Countries with negative savings rates are excluded from this sample, see de Groot and Tang (2002) for more details.
All equations are estimated using country-specific fixed effects. White heteroskedaticity consistent t-statistics have been reported in parentheses *, ** and *** means significance at, respectively, 10, 5 and 1%.

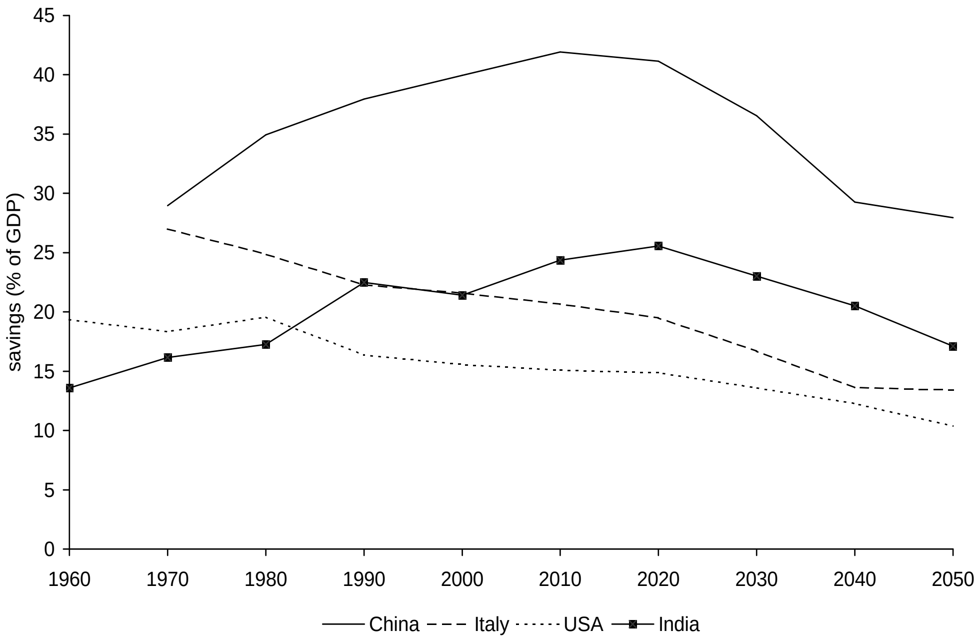
positively in the non-OECD countries. For the OECD this parameter is not statistically significant. Ageing, or a large share of people aged 65 and older reduces savings.

We have used the extensive sample (column (1) in table 5.1) to assess the impact of ageing on savings. By substituting the projected sizes for the age cohorts in the equation and some assumptions on projected GDP growth per worker we have calculated the expected savings rate for various countries. Figure 5.1 presents this pattern for China, India, Italy, and the United States.[40] We have incorporated equation (5.1) in the model. For the OECD countries or regions we use the regression results of column 2 and for the non-OECD countries or regions the results of column 3. To reduce simultaneity in solving WorldScan we use as explanatory variable the GDP growth rate per capita one period lagged. The projections of the population cohorts come from United Nations and Eurostat and are discussed in Chapter 4.

The real interest rate does not affect national savings. In theory there is ambiguity about the sign of this variable. De Groot and Tang (2002) did not find a significant coefficient using the real interest rate as explanatory variable. For the same reason Van der Mensbrugghe (2005) does not incorporate the interest rate in the savings function in the Linkage model. That savings function is based on the empirical work of Loayza *et al.* (2000), where savings are a function of economic growth per capita and the demographic variables. Instead of the population share between 25 and 65 years old, they use the population share between 0 and 25 years. The coefficients for that

[40] This pattern is found for a wide range of alternative specifications. De Groot and Tang (2002) claim that the Fair and Dominguez (1991) specifications yield extreme savings rates for several countries after 2030. This is likely to be caused by the imposed functional form, resulting in relatively poor out-of-sample behaviour. These extreme savings rates after 2030 are the reason to choose for the empirical specification in Table 5.1.

Figure 5.1 Historical national savings rates 1960-2000, and projected rates 2000-2050



explanatory variable are statistically negative for the non-OECD countries, and not significant for the OECD ones. This result confirms the findings of De Groot and Tang (2002).

Equation (5.2) describes the macro savings rate in the model. Savings are expressed as a share of national income. Given the level of national income, Y_r^{NI} for country r, we derive the value of macro consumption, C_r, as the complement. Note that macro consumption also consists of government consumption.

$$C_r = (1 - Sq_r) Y_r^{NI} \quad (5.2)$$

5.2 Capital mobility

Introduction

Capital demand has to be matched by capital supply. In a closed economy, regional savings equal regional investment. We assume that regions are linked not only by trade in goods and services, but also by international capital mobility. This implies that regional savings and investment can diverge. Therefore, only at a global level savings have to be equal to investment. In spite of the integration of regional capital markets, we do not model one international capital market. In the text box it is illustrated that international capital mobility is still far from perfect. The elimination of capital controls and other barriers have stimulated capital mobility, but this is not sufficient to equalise returns on investment internationally.

Imperfect capital mobility

Savings and investment can diverge in integrated capital markets. In the sixties and seventies, capital markets were not heavily integrated, in spite of the elimination of capital controls and other barriers. In a classic paper, Feldstein and Horioka (1980) show that even among industrialised countries capital mobility is limited: changes in the national savings rate ultimately change investment rates by the same amount. For the period 1960-1974, they showed that savings and investment were heavily correlated. However, capital was not as mobile in that period as it is now. Regression analysis by Obstfeld and Rogoff (1996) over the decade 1982-1991 for nearly all OECD countries shows that that correlation is still high, although it is weakening (see also Canton *et al*. 2004). The correlation between savings and investment exists not only in industrial countries, but also in developing countries. However, massive foreign investment flows to countries like China, Indonesia and Brazil have increased the importance of international capital mobility. For the developing world as a whole, the importance of foreign direct investment (FDI) increased during the last two decades (as can be seen in the table). This increase indicates rising capital mobility, in particular for private capital. Another indicator is the value of inward FDI stocks expressed as share of GDP. Worldwide, these shares rose from 4.6% in 1980 to 9.4% in 1994 (see UNCTAD, 1996). These numbers reflect the growing importance of international capital mobility.

Savings and investment in developing countries (as share of GDP), 1973-1994

Period	1973-1980	1981-1990	1990-1994
Domestic savings	25.7	23.1	25.6
Investment	25.7	24.6	27.2
Foreign savings (net)	0.00	− 1.5	− 1.6

Source: OECD (1997a).

The literature provides various explanations for imperfect capital mobility.[41] Apart from restrictions on international trade in capital and goods, asymmetric information is a significant barrier for trade. Gordon and Bovenberg (1996) see asymmetric information between domestic and foreign investors as an obstacle to international capital mobility. Investors usually know more about the prospects of their own economy and about investment opportunities at home, than about those in other countries. The gravity literature on foreign direct investment (FDI) also indicates that capital mobility is not perfect. If capital mobility would be perfect, distance would have no effect on the size of equity flows or foreign direct investment. Table 5.2 shows some estimates presented in CEPR (2002) on the impact of distance on economic interactions in capital markets. The estimates express equity flows and foreign direct investment at different distances, relative to the flows at a distance of 1000 km. We see that distance substantially reduces equity transactions and, to a lesser extend, FDI. Hence, distance matters. Although some information in capital markets can be transmitted digitally, a lot still requires face-to-face contact. Trust is important for many economic decisions and transactions. Face-to-face contact

[41] These are discussed in Canton *et al*. (2004) and more extensively in Obstfeld and Rogoff (1996).

can provide trust where, electronic communication fails to produce that.

Table 5.2 The impact of distance on cross-border capital flows

Distance in km	Equity flows	Foreign direct investment
1000	1.00	1.00
2000	0.55	0.75
4000	0.31	0.56
8000	0.17	0.42

Source: CEPR (2002).

Although capital mobility is not perfect, the increasing importance of FDI suggests that regional capital markets have to be linked. We therefore model regional capital markets in which capital supply comes from various regions. This modelling will be explained below.

Mechanism in WorldScan

Each country uses part of its income Y for consumption C and part for accumulation of capital goods. Savings S in region r is simply a fraction of the level of current income in that region,

$$S_r = Sq_r Y_r^{NI} \tag{5.3}$$

where Sq is the savings rate. The savings rate is a function of the growth rate, and the demographic composition of the population as discussed in section 5.1. In period $t+1$ the stock of supplied capital by region r, $k_{r,t+1}$, is equal of savings in period t and the stock of supplied capital, net of depreciation, δ^K, in the period t.

$$k_{r,t+1} = \frac{S_{r,t}}{p_r^I} + (1-\delta^K)\, k_{r,t} \tag{5.4}$$

δ^K is the depreciation rate which is set at 2.8%.[42] The stock of supplied capital, k_r is expressed in volume terms. Therefore the value of savings has to be divided by p^I, the price of investment goods. The value of the supplied capital stock is equal to the wealth of a region. We define current wealth as

$$W_r = p_r^I\, k_r \tag{5.5}$$

Countries face different interest rates against which they can borrow or lend investment funds. Structural differences in interest rates are assumed to reflect transaction costs. Even though these differences remain, opportunities for arbitrage – taking into account the transaction costs that are involved – are fully exploited. In this sense international capital markets are perfect, but capital mobility is not. This view on the capital market and capital mobility has been strongly advocated

[42] This is the average of sectoral depreciation rates for the Dutch economy, see Meinen et *et al*. (1998).

by Stigler (1963): "*A misallocation of capital is created, not eliminated, if interest rates are reduced to borrowers without a commensurate reduction in the costs of transactions. The situation is exactly comparable to the elimination of geographical differences in the price of a commodity: if prices at two points differ by less than the transportation costs, the movement of goods is uneconomic*." Here, we pursue the analogy between transaction costs in the capital markets and the transportation costs in goods markets.
The stock of supplied capital can be used either in domestic or in foreign production. However, international trade in capital goods is costly. More specifically, exporting and importing capital are subject to (iceberg) transport costs. Only a fraction π_h that an exporter ships from its country h to the global market of capital goods arrives at that market. Similarly, an importer buys more on the global market than will arrive in country b. This is indicated by the variable π_b, which is larger than one.[43] The price for internationally traded capital goods p^K ensures that the global market is in equilibrium:

$$\sum_{r=1}^{R} p^K \pi_r k_r^F = 0 \tag{5.6}$$

where k^F represents the export of capital goods. The exports are positive for an exporting country, $k^F > 0$, and negative for an importing country, $k^F < 0$. Exporters in country h receive

$$Y_r^{NFI} = p^K \pi_r k_r^F \tag{5.7}$$

Y_r^{NFI} represents net foreign income in country r resulting from international capital mobility. For a capital-importing country, net foreign income is negative.

The volume of foreign capital is the difference between the supply of capital and demand in a region.

$$k_r^F = k_r - q_{CPE,r} \tag{5.8}$$

The demand for capital follows from cost minimisation of producers. Demand for capital in region r, $q_{CPE,r}$, is derived in equation (2.8), and supply of capital, k_r, is derived in equation (5.4).

For convenience we assume that households own the capital stock and rent it to domestic and – through the international market of capital goods – foreign producers. By definition wealth is equal to the value of the supplied capital stock in our model. Because all exports of capital have to be matched by imports the value of invested capital has to balance the value of supplied capital globally. At the country level this may differ because of net capital exports or imports.

At the margin households are indifferent in renting capital to domestic or foreign firms. The rental price for domestic producers is the price of investment goods times the sum of the real

[43] Note that in our interpretation the fraction of capital goods that reaches its destination is independent of the transport distance. However, the fraction is region specific. So, it may be related to remoteness.

domestic interest rate r (in terms of the final good), a risk premium and the depreciation rate δ^K, see equation (2.4). It has to be equal to the global price of capital goods net of transport cost.

$$p_{CPE,r} = \left(r_r + o^K + \delta^K\right) p_r^I = p^K \pi_r \qquad (5.9)$$

Given the international transaction costs, π_r, the depreciation rates, risk premia and prices, this equation determines the real rate of interest for every region. Countries will face different real interest rates, because capital mobility is limited. A country with positive foreign assets will have a lower π and lower real interest rate r than a country with net foreign debt. More specifically, the real interest rate differential between countries i and j depends on the net foreign asset positions of these countries and on the relative price of investment goods[44]

$$r_i - r_j = p^K \left(\frac{\pi_I}{p_i^I} - \frac{\pi_j}{p_j^I}\right) \qquad (5.10)$$

5.3 Degree of capital mobility

The transportation or transaction costs are assumed to depend on the volume of the capital flow. The basic idea is that the larger the volume of capital flows the higher the costs. Starting from no capital flows, capital exporters first invest in projects abroad with low transaction costs. These are companies with a clear organisational and financial structure. There is a lot of information publicly available and the screening of foreign companies by the capital exporters is fairly easy and cheap. If the projects with low transaction costs are financed, the capital exporters search for investment opportunities with higher transactions costs. So the larger the volume of international capital flows, the higher are the transaction costs.[45] In mathematical terms, the more capital a country exports, the lower is π_r, and the more capital a country imports, the higher is π_r. More technically, π_r is a negative function of k^F as share of supplied capital in a country,

$$\pi\left(\frac{k^F}{k}\right) > 0\ ,\ \pi'\left(\frac{k^F}{k}\right) < 0\ ,\ \pi\left(0\right) = 1 \qquad (5.11)$$

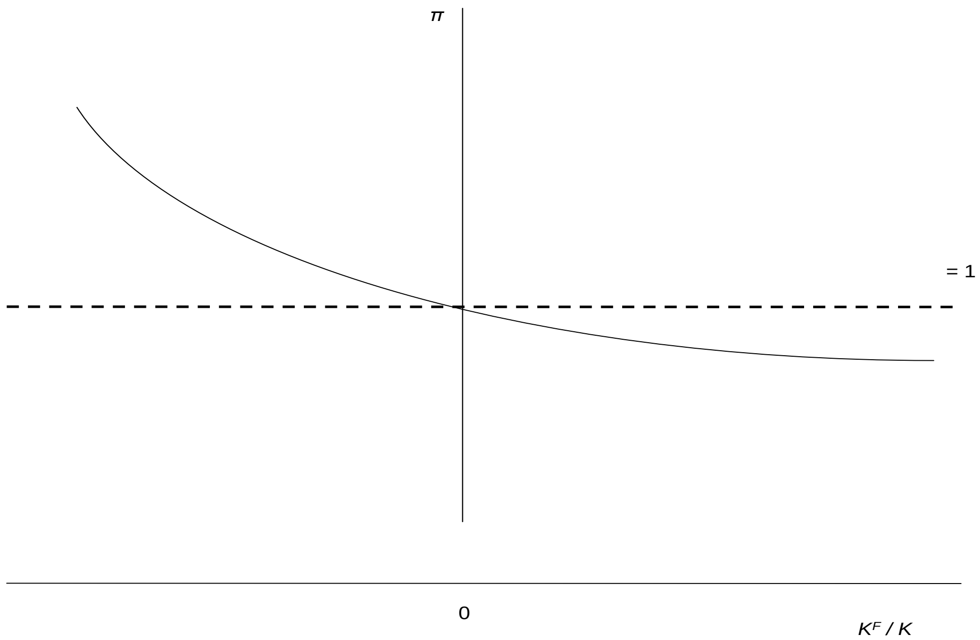
Equation (5.11) implies that if country h exports capital, it will receive only a payment of a share (less than 100%) of the exported capital supply because of the international transaction costs ($\pi < 1$). The international transaction costs for the exporter are thus $(1 - \pi_h)k^F$. If the amount of capital would be traded within a country, the transaction costs are zero ($\pi = 1$). Not only the exporter faces international transaction costs, also the importing country b is subject to these costs. For the importer, $\pi_b > 1$. The international transaction costs are thus $(\pi_b - 1)k^F$. The total

[44] Equation (5.10) is derived from equation (5.9) for country i and j, assuming identical regional risk premia and depreciation rates.

[45] It is possible that capital exporters learn more about the foreign country in which they invest.This could reduce the transaction costs to some extent. We conjecture that the reduction of transaction costs by learning effects will not dominate the increase in transaction costs by search effects for new opportunities on average.

transaction costs for exporter and importer are $(\pi_b - \pi_h)k^F$. Figure 5.2 illustrates the relation between the transaction costs and the net capital flow. Since the aggregate volume of capital flows matters, agents do not take into account the effect of the volume of exported capital on transaction costs.

Figure 5.2 Transaction costs and net capital flows



So far we did not discuss the functional form of equation (5.11), nor its empirical content. The slope of the function in Figure 5.2 represents the inverse of the degree of capital mobility. In the model we assume that function π in equation (5.11) has an exponential form

$$\pi_r = \exp\left(\frac{\theta_r k_r^F}{k_r}\right) \tag{5.12}$$

The parameter θ is assumed to be negative, such that an increase in the net position of foreign capital, k^F, relative to the capital stock increases the international mobility costs of capital as is already indicated by the restrictions of the functional form. In this specification θ determines the degree of international capital mobility. A higher absolute value of θ raises the transaction costs. It is region specific because we want to distinguish the degree of integration of OECD and non-OECD countries on the global capital market. We assume that is it higher for non-OECD countries. As a consequence, transaction costs are the lowest for capital flows between OECD countries, higher for capital flows between OECD and non-OECD countries, and the highest for capital flows between non-OECD countries.

Estimating degree of international capital mobility

De Groot and Tang (2002) have estimated the degree of capital mobility using the data and methodology of Lane and Milesi-Ferreti (2001). Our basic regression explains the real interest rate as a function of the net foreign assets as ratio of GDP and a set of country and time-specific fixed effects.[46] The latter are included to control for period-specific global imbalances on the world capital market. We have estimated the following equation.

$$r_{r,t} = \beta_{0,r,t} + \underset{(-0.13***)}{\beta_1} \frac{CUMCA_{r,t}}{2 + CUMCA_{r,t}} + \underset{(-0.37***)}{\beta_2} EXP_{r,t} + \underset{(0.02*)}{\beta_3} DEBT_{r,t} + \varepsilon_{r,t} \tag{5.13}$$

where r is the real interest rate in country r in period t, and, $CUMCA$ the Cumulative Current Account as a fraction of GDP.[47] EXP is an openness measure (exports as fraction of GDP), and $DEBT$ is government debt. The latter two variables are included to avoid biases on the estimates of β_1, which is our measure of capital market mobility. β_1 is the same variable as θ in equation (5.12). The estimates (reported below in brackets) show that negative cumulative assets exert an upward pressure on the real interest rate. To give a feeling for the size of the effects, we take the Cumulated Current Accounts of the United States and Japan. These are -0.18 and 0.40 respectively. Ceteris paribus, the regression equation predicts that the US will face a 3.5% points higher real interest rate than Japan.

Government debt has a positive effect on the real interest rate, because a higher demand for capital exerts an upward pressure on the real interest rate. The degree of openness has a negative impact on the interest rate. This is driven by the notion that countries that export relatively much have a large capacity to repay debts.

For the non-OECD there are no reliable data. We know that non-OECD countries are on average less integrated at international capital markets than OECD countries. Therefore we assume that the absolute value of the coefficient is higher. Hence the effects of changes in net foreign assets positions on the national real interest rate are larger. We assume that the value of the coefficient is $4 \times (-0.13) = -0.52$.

5.4 Calibration

Three issues are highlighted in this section. The first is the consistency of the National Accounts. The second is the calibration of the initial stock of capital supply, and the third is the calibration of the capital costs.

[46] The data set consist of 21 OECD countries; new OECD members and Luxembourg are excluded.

[47] The choice for our measure for net foreign asset position is driven by the notion that the ratio of foreign to total capital equals $CUMCA_r/(CUMCA_r + \frac{\alpha_r}{(r+\delta)})$ where we assume the second term in the denominator to equal 2. This is based on assumptions that are roughly in line with the data in our model, namely that the capital income share in production, α=0.3, the world interest rate, $\bar{r} = 0.07$ and the depreciation rate, δ=0.08 implying $\frac{\alpha}{(r+\delta)} = 2$. Sensitivity analyses for the latter assumption have been performed and these do not substantially affect the results. Data for net foreign assets as a fraction of GDP ($CUMCA_r$) are available from Lane and Milesi Ferretti (2001).

Consistency of accounts

We have to ensure consistency of our accounts, which are taken from the GTAP-database. We have the accounting identities for GDP, see equation (2.12) and national income, Y_r^{NI}. National income is defined as the value of GDP plus net foreign income.

$$Y_r^{NI} = Y_r^{GDP} + Y_r^{NFI} \tag{5.14}$$

By assuming that investment equals savings in the calibration, net foreign income has to be equal to the difference between the value of exports and imports by definition. The data on exports and imports stem from the GTAP-database. The data on net foreign assets are from Lane and Milesi-Fereti (2002). The latter data determine with the endogenous interest rates, net foreign income. These two data bases are not consistent. By consequence, the accounting relation between net trade and net foreign income will not hold in the calibration. As a way out, we assign the difference between net foreign income and net trade to net foreign income transfers. This calibrated value for the additional foreign income transfer is assumed to be exogenous in the model.

Initial stock of supplied capital

In the calibration model we determine the (starting) stock of capital supply of every region. The stock of capital supply is equal to the demand for capital in a region plus the exported capital stock (see 5.8). The latter information comes from Lane and Milesi-Ferretti (2001), i.e. the net foreign asset position (NFA) of the regions. These NFA's necessarily sum up globally to null. The demand for capital is derived from the GTAP data on capital income. The volume of capital demand depends on the price of capital which is discussed below. The investment prices are equal to one in every region by definition, implying that net foreign incomes from investment sum up globally to zero.

Capital costs

The fraction of net capital exports and the supply of capital determine the transaction costs (see equation (5.12)). Using equation (5.9) we derive the capital costs of every region relative to one region. For that region the level of the capital costs is chosen to comply with a global Solow-growth condition. This means that globally the savings have to meet the demand for investment. Investment equals the demand for capital due to depreciation, and extra demand due to changes in labour supply growth and TFP-growth the next period. The savings come from the GTAP6-database, depreciation is an exogenous variable, and labour supply growth follows from population and labour-market participation projections, see Chapter 4. TFP-growth is derived by targetting GDP per capita growth to a target, see equation (2.18).[48]

[48] Of course we could assume the growth in TFP to be exogenous, but this gives an unstable time-path.

6 Consumption and Welfare

On the basis of their preferences consumers decide how to spend their budget on consumer goods and services. The Linear Expenditure System (LES) is suitable to model this consumption decision, because it combines simplicity with some flexibility. An extension of the GTAP-database provides a sound empirical underpinning for calibration of the LES. The modelling of consumer choice is also important as it enables explicit welfare analyses.

6.1 Sectoral consumption demand system

In the WorldScan model consumers decide how to spend their earned income in three stages. First, income is distributed over consumption (private and government) and savings (see Chapter 5). Second, the income available for consumption is allocated to purchasing consumer goods and services, which will be the focus of this chapter. Third, the purchased consumer goods or services will come from different regions (see Chapter 7).

The major requirement for any empirical valid consumption demand system is non-homogeneity. Homogenous demand systems, like the CES-functions used in Chapter 2 to model the demand for production factors, imply an income elasticity of one; a rise in income of 1% leads to a rise of 1% in expenditure on each input. However, it is a well-known fact from the empirical consumption literature that with rising income the budget share spent on necessary goods becomes smaller, while the share spent on luxury goods becomes larger.[49] This empirical fact compels the use of non-homogenous demand systems for modelling the allocation of consumer demand. From the portfolio of non-homogenous functions, the Linear Expenditure System (LES) is preferred for its simplicity in modelling and interpretation.

The Linear Expenditure System is derived from the maximisation of a Stone-Geary utility function under a linear budget restriction for a consumer c:

$$\max \quad U_c\left(c_{c,1},...c_{c,n}\right) = B\prod_{j=1}^{n}\left(c_{c,j}-\gamma_{c,j}\right)^{\alpha_j} \tag{6.1}$$

$$\text{subject to} \quad \sum_{j=1}^{n} p_j^C c_{c,j} = C_c$$

with $0 < \alpha_j < 1, \sum_j \alpha_j = 1$, and B some positive scaling constant. In this equation $c_{c,j}$ denotes the demand for consumer category j by consumer c, p_j^C the corresponding price and Y_c the total consumption budget of consumer c. This maximisation problem can be solved using the Lagrange method, yielding the Linear Expenditure System of demand equations:

$$c_{c,j} = \gamma_{c,j} + \frac{\alpha_j}{p_j^C}\left(C_c - \sum_{j=1}^{n} p_j^C \gamma_{c,j}\right) \tag{6.2}$$

[49] For some excellent overview articles see Brown *et al.* (1972) and Deaton and Muellbauer (1980).

A positive value for the parameter $\gamma_{c,j}$ allows the interpretation of subsistence level, i.e. the minimal quantity of consumption good j necessary to survive. If all the subsistence levels are satisfied, the remaining budget will be distributed over the consumption goods according to their marginal budget shares α_j. When income per capita is approaching infinity, the LES demand system converges to a Cobb-Douglas demand system. Summing the individual demand equations over the total population yields the aggregated demand equations:

$$c_j = \sum_{c=1}^{pop} c_{c,j} \qquad (6.3)$$

with *pop* being the population size.

6.2 Consumption data

The GTAP-database is used to assign values to the parameters of the Linear Expenditure System. The standard GTAP database contains input-output tables per region and trade data connecting these regions. From this dataset the sectoral consumption shares can be obtained. Besides that, additional consumption data are available from the GTAP database: the elasticity of income per sector and region and the so-called Frisch-parameter per region. Table 6.1 shows these statistics for the OECD and the non-OECD regions and for aggregated consumption categories. The

Table 6.1 Elasticities of income and Frisch parameters for the OECD and Non-OECD

	OECD	non-OECD
Income elasticity		
Food	0.32	0.51
Beverages and Tobacco	0.88	0.90
Clothing and Footwear	0.82	0.86
Gross rents and Fuels	0.97	1.03
Housing apparel	1.04	1.11
Education and Medical care	1.18	1.31
Transport and Communication	1.23	1.33
Recreation	1.32	1.41
Other goods and Services	1.29	1.40
Frisch parameter	− 1.54	− 4.07

Source: GTAP5/6, Dimaranan and McDougall (2002, 2005).

GTAP database[50] derives the income elasticities for the food sectors from the FAO-model and bases the other income elasticities on the study of Theil, Chung and Seale (1989). Table 6.1 reveals that the income elasticity for the necessary goods like food, beverages and clothing is

[50] The values for the income elasticity and the Frisch parameter have not been updated from the GTAP5 version to the GTAP6 version.

below one, while this elasticity for the luxurious services like education, medical services, and transport is above one.

Values for the Frisch parameters are based on the investigation of Lluch *et al.* (1977), who estimated the LES for a large number of regions. This Frisch parameter ω is defined as the income elasticity of the marginal utility[51] of income:

$$\omega = \frac{\partial \log \left(\frac{\mathrm{d}U_c}{\mathrm{d}C_c} \right)}{\partial \log (C_c)} \tag{6.4}$$

It can be shown (Sato, 1972), that for direct additive utility functions like the LES, the Frisch-parameter equals $-1/\sigma^*$, where σ^* is approximately equal to the unweighted mean of all partial Allen-substitution elasticities. Expressed in terms of this 'mean' substitution elasticity σ^*, we find in Table 6.1 for the OECD a value of 0.65 and for the non-OECD a value of 0.25. The higher value of σ^* for the region with higher income per capita (OECD) can be attributed to the relatively lower substitution elasticity of necessary goods compared with luxurious goods. With a higher income per capita, the share of less price sensitive, necessary goods is relatively lower, while the share of the more price sensitive, luxurious goods is relatively higher. For regions with a high income per capita, the LES approaches a Cobb-Douglas demand system and the σ^*-parameter becomes one.

The next section on calibration describes the method that is used to transmit the empirical information on the income elasticities and the Frisch parameter from GTAP to the LES parameters.

6.3 Calibration

The Stone-Geary utility functions contains three unknown parameters: the marginal budget share parameter α, the subsistence parameter γ, and the scaling constant B. This section explains the method used for assigning numerical values to these parameters.

For the elasticity of income of the Linear Expenditure System, the following expression can be derived:

$$\varepsilon_j = \frac{\alpha_j}{Cq_j} \tag{6.5}$$

with Cq_j denoting the budget share of consumption category j. This equation shows that the LES is not a homogenous demand system $(\varepsilon_j \neq 1)$, which is a necessary property for any empirically valid consumption demand system. The marginal budget-share parameter α_j is calibrated by inverting equation 6.5:

$$\alpha_j = Cq_j \varepsilon_j \tag{6.6}$$

[51] To be precise, the utility function is not the one of equation 6.1, but its logarithmic transformation.

Both the budget share Cq_j and the elasticity of income ε_j are known from the GTAP-database.

Another important parameter characterising the LES is the Frisch parameter. The general expression for the Frisch parameter ω from equation 6.4 can be applied to the LES, yielding (e.g. Dervis *et al.*, 1982):

$$\omega = -\frac{C_c}{C_c - \sum p_{jC}\gamma_{c,j}} \tag{6.7}$$

The parameter ω is a monotonic declining function of income per capita C_c, because the total subsistence expenditure $\sum p_j^C \gamma_{c,j}$ is not a function of C_c. Therefore, the 'mean'elasticity of substitution of the LES, being equal to $-1/\omega$, is a monotonic increasing function of C_c, with a limit of 1. Substituting equation (6.2) in the denominator of equation (6.7) enables to solve for the subsistence parameter γ_j:

$$\gamma_{c,j} = \left(Cq_j + \frac{\alpha_j}{\omega}\right)\frac{C_c}{p_j^C} \tag{6.8}$$

This subsistence parameter thus replicates, given a value for ω, the consumption budget-shares in the base year. In the WorldScan model, the calibrated value for γ is assumed constant over time in order to assure a valid welfare analysis.

Finally, the constant B is used to scale the base year price of a unit utility p^{U_c} to one.

$$p^{U_c} = \frac{C_c}{U_c} = \frac{C_c}{B\prod\limits_j (c_j - \gamma_{c,j})^{\alpha_j}} = 1 \tag{6.9}$$

Inverting equation (6.9) to B gives:

$$B = \frac{C_c}{\prod\limits_j (c_j - \gamma_{c,j})^{\alpha_j}} \tag{6.10}$$

6.4 The concordance matrix and consumption taxes

The GTAP6-database contains information on 57 basic sectors. To keep the WorldScan model tractable, it is helpful to reduce this set of basic sectors to a smaller set of aggregated sectors, usually a number between 8 and 16. Basic sectors are subsumed under an aggregated sector based on their similarity from the perspective of the producer. However, in consumption studies considerably different aggregated sectors arise, as table 6.1 shows. Here the similarity of basic sectors is defined from the consumers perspective. Correspondingly, the modelling of a sectoral consumption demand system in WorldScan must also be founded on aggregated consumption categories. This requires information on the relation between the aggregated production sectors and the aggregated consumption categories, which can be derived from the GTAP-database in the form of a concordance matrix. For that purpose, every GTAP basic sector is classified in a more comprehensive producer based aggregated sector and a consumer based aggregated consumption category. This procedure yields for every region a matrix with consumption values for every aggregated producer sector and consumer category combination.This data matrix supplies the weights of the production sectors in the consumption categories for every region. As an example, table 6.2 presents the composition of Gross Rents and Fuels for the United States.

Table 6.2 Composition of the Gross Rents and fuels consumption in the United States (2001)

	Value in bln US$	Share
Coal	0.0	0.00
Gas and gas distribution	6.0	0.01
Electricity	59.0	0.05
Services (Rents)	1025.0	0.94

Source: GTAP6, Dimaranan and McDougall (2005).

In the WorldScan model, the aggregation[52] takes the form of a Cobb-Douglas function:

$$c_j = \prod_s c_{js}^{\lambda_{js}} \qquad \text{with } \sum_s \lambda_{js} = 1 \tag{6.11}$$

where c_j denotes the consumption volume of a consumption category, c_{js} the consumption volume of the sector s used in the aggregation to the consumption category j, and λ_{js} the share of sector s in the aggregation to the consumption category j. The values of λ are obtained from the GTAP-database. For this Cobb-Douglas function, equations are derived connecting the values and prices of the consumption sectors with the consumption categories:

$$C_s = \sum_j \lambda_{js} C_j \tag{6.12}$$

$$p_j^C = \prod_s \left(\frac{p_s^C}{\lambda_{js}} \right)^{\lambda_{js}}$$

The corresponding volumes result simply from dividing values by prices. The first part of equation (6.12) clarifies the choice of Cobb-Douglas aggregation; the weights used for transforming sectoral values into consumption category values are constant. This feature simplifies the analysis of WorldScan results significantly. Notably, the use of Cobb-Douglas implies a substitution elasticity of one, which allows changes in sectoral prices to influence the composition of the sectoral volumes in the consumer categories.

Finally, the tax on consumption t^C is calculated as the difference between consumption in market prices $p^{D,m}$ (before taxation) and in user prices p^C (after taxation), which are both available from the GTAP database:

$$p_s^C = p_s^{D,m} \left(1 + t_s^C \right) \tag{6.13}$$

In the preceding analysis, all prices and values are defined including consumer taxes, i.e. as user prices.

[52] This aggregation can also be interpreted as a Cobb-Douglas production function; the supply by production sectors is used as an input to produce the goods and services in the consumption categories.

6.5 Welfare analysis

Utility gains or losses would be the most natural measure for evaluating welfare change, but utility is only an ordinal concept; statements about welfare changes are limited to more or less welfare, while the magnitude of the differences is meaningless. For this reason, researchers on welfare prefer the cardinal welfare measure of (Hicksian) equivalent variation. This Equivalent Variation EV[53] is defined as the amount of money that should be given to a person in the baseline situation B to attain the welfare level of an alternative situation V. More formally:

$$EV_c = e_c\left(p^C_{1,B},....,p^C_{N,B},U_{c,V}\right) - e_c\left(p^C_{1,B},.....,p^C_{N,B},U_{c,B}\right) \tag{6.14}$$

with the expenditure function $e_c(p^C_1,.....,p^C_N)$ denoting the per capita expenditure necessary to attain utility level U_c at prices $p^C_1,.....,p^C_N$. The equivalent variation as a welfare indicator has some strong points (as in Ebert,1995):

- indicates the direction of welfare changes correctly.
- ranks different situations consistently.
- evaluates changes in money: the expenditure function is in monetary units.
- derives from observable data: consumption prices and volumes (and thus utility level).

In the next section, equations for the expenditure function and the equivalent variation are derived for the Linear Expenditure System.

Static welfare analysis

In order to obtain an expression for the equivalent variation of the LES, we first determine the indirect utility function by substituting the demand equation (6.2) into the direct utility function (6.1):

$$\psi_c\left(p^C_1,.....,p^C_N\right) = B\left(C_c - \sum_j p^C_j \gamma_{c,j}\right)\prod_j\left(\frac{\alpha_j}{p^C_j}\right)^{\alpha_j} = U_c \tag{6.15}$$

Inverting this indirect utility function for C_c, yields the expenditure function $e(p^C_1,.....,p^C_N,U_c)$:

$$e_c\left(p^C_1,.....,p^C_N,U_c\right) = \frac{U_c}{B}\prod_j\left(\frac{p^C_j}{\alpha_j}\right)^{\alpha_j} + \sum_j p^C_j \gamma_{c,j} = C_c \tag{6.16}$$

Substituting this expenditure function in equation (6.14), gives an expression for equivalent variation:

$$EV_c = \frac{U_{c,B} - U_{c,V}}{B}\prod_j\left(\frac{p^C_{j,B}}{\alpha_j}\right)^{\alpha_j} \tag{6.17}$$

which is quite easy to compute.

[53] An alternative welfare measure is the compensating Variation (CV_c), that arises by replacing the baseline prices with the prices of the alternative. We prefer the EV_c measure, because of its consistency in ordering several alternatives.

True consumption price index

Another useful application of equivalent variation and the expenditure function comes from redefining the baseline B and the variant V from the previous section as time periods t and $t+1$. Following Deaton and Muellbauer (1980), the relative change in expenditures in period $t+1$ compared period t is exactly factorised into a volume and a price component:

$$\frac{C_{c,\,t+1}}{C_{c,t}} = \frac{e_C\left(p^C_{1,t},\ldots..,p^C_{N,t},U_{c,\,t+1}\right)}{e_C\left(p^C_{1,t},\ldots..,p^C_{N,t},U_{c,t}\right)} \cdot\cdot \frac{e_C\left(p^C_{1,t+1},\ldots..,p^C_{N,t+1},U_{c,\,t+1}\right)}{e_C\left(p^C_{1,t},\ldots..,p^C_{N,t},U_{c,\,t+1}\right)} \tag{6.18}$$

with the volume index based on the prices in period t (equivalent variation in relative form) and the price index based on the utility level of period $t+1$. This price index is also called a true price index or true cost-of-living index and is incorporated in the WorldScan model to calculate the macro consumption price index:

$$PI^C_T = \prod_{t=1}^{T} \frac{e_C\left(p^C_{1,t+1},\ldots..,p^C_{N,t+1},U_{c,\,t+1}\right)}{e_C\left(p^C_{1,t},\ldots..,p^C_{N,t},U_{c,\,t+1}\right)} \tag{6.19}$$

Dynamic welfare analysis

The static welfare evaluation in the previous sections is limited to current consumption. Important determinants of the welfare of economic agents, like leisure and environmental quality are not taken into account.[54] Also the importance of savings, interpretable as postponed consumption, is neglected. This section on dynamic welfare analysis addresses this last issue.

In the preceding section on static welfare analysis, the welfare of a representative consumer is evaluated at a specific point in time, i.e. by instantaneous equivalent variation. However, for an integral assessment of welfare effects the transition path to this specific point in time can not be neglected. Moreover, the consumption path after this point should also be taken into account. Formulating an explicit inter-temporal utility function that describes the preferences of a representative consumer over time, would solve these problems. However, in the chapter on savings, the use of an inter-temporal utility function was dismissed in favour of a reduced form equation linking savings to demography. WorldScan therefore follows the practice of many economic models; all instantaneous equivalent variations are discounted and added into one lifetime welfare measure:

$$EV_c = \sum_{t=1}^{\infty} \frac{EV_{c,t}}{(1+\rho)^t} \tag{6.20}$$

The discount rate ρ in this equation indicates the preference for short term consumption compared to future consumption. Equation (6.20) takes the utility derived from savings indirectly into account; savings are used to invest in production capacity, resulting in additional

[54] Also not addressed in this discussion are important themes like inter-generational discounting, hyperbolic discounting and discounting under uncertainty (see Caplin and Leahy (2000) and Faber and Hemmersbaugh (1993) for excellent overviews).

future consumption. Notably, this type of welfare analysis is conditional on the exogenous path of the savings rate; policy changes are not allowed to influence the path of the savings rate.

Although the integration of instantaneous equivalent variation in equation (6.20) is over an infinite time horizon, we simulate in practical applications a time path over a finite period length. This issue can be solved in two ways: either by assuming the discount factors, i.e. $1/(1+\rho)^t$, beyond the end year to be approximately zero, or by assuming a steady state growth path after the end year.

The value chosen for the discount factor is quite important, because the resulting lifetime equivalent variation measure strongly depends on it. Two approaches exist in the economic literature (IPCC, 1996): social rate of time preference and opportunity cost of capital.

First, the ‘social rate of time preference’ refers to the rate at which one is willing to forego present consumption for future consumption opportunities. This time preference can be decomposed into a ‘pure time preference’ term (impatience) and the marginal utility of income term. The discount rate will be modest in this case, and tends to be in the range between 0.5% and 3.0%.

Secondly, the opportunity costs of capital refer to the marginal rate of transformation between present and future consumption opportunities or the marginal productivity of capital. A consumer can consume his income directly or bring it to the capital market and receive the next period an income from it equal to the marginal productivity of capital. In general this will give a higher discount rate than in the time preference approach, roughly between 3% and 6% in real terms for long-term, risk-free public investments. This rate of return is also available from WorldScan model simulations (see Chapter 5) and in long-term climate change studies this discount factor is applied.

Summarising, dynamic welfare analysis is an important issue for policy analysis. However, because this analysis contains many complexities and pitfalls, every application of welfare analysis has to be analysed thoroughly.

7 Trade and trade barriers

This chapter presents one of the main characteristics of global AGE models: the modelling of bilateral trade. Section 7.1 derives the Armington demand functions that explain bilateral trade. Section 7.2 presents the formal barriers to trade and the substitution elasticities in the model. Section 7.3 discusses our modelling and estimation of non-tariff barriers.

7.1 The Armington demand equations

Representation of intra-industry flows

An important characteristic of global AGE models is the representation of trade flows between regions. A large share of trade between countries is intra-industry trade, that is to say two-way bilateral trade in similar, but not identical products.[55] These trade flows can not be described in Ricardian or Hecksher-Ohlin models in which trade depends on differences in endowments between countries. Differences in endowments lead to trade flows motivated by specialisation. These trade flows account for only a small part of total trade.

Intra-industry trade can be modelled using the so called Armington assumption.[56] The Armington assumption is widely used in trade models. As far as we know all AGE models use the Armington assumption to calibrate and stimulate bilateral trade. According to this idea, firms in each region produce a unique variety of a particular good. The number of varieties of a particular sector equals the number of regions. Regional varieties are imperfect substitutes. Therefore, firms have monopoly power over their own variety and can choose their price, given demand (see the seminal paper of Dixit and Stiglitz (1977)). Agents derive utility from consuming all varieties of a sector.[57] The volume of demand for a certain category of goods within a region is considered to be a CES (constant elasticity of substitution) composite of all varieties. Total demand in a region consists not only of consumer demand (equation 6.10), but also of investment demand (equation (6.2)) and intermediate demand (equation (2.6)):

$$q_{sb}^{D} = c_{sb} + i_{sb} + q_{sb} \tag{7.1}$$

Given the CES composite for the total demand and the relevant budget restriction, the demand

[55] Most AGE models distinguish several production sectors; some of them are manufacturing sectors, others are service sectors. If we use terms like goods or products, we refer to commodities and services. Commodities include agricultural products, energy and manufacturing products.

[56] See Armington (1969).

[57] Note that consumers also divide their income between savings and consumption, and between the various sectors (see chapters 5 and 6).

for a variety from region h in region b in a certain sector equals[58]

$$q_{hb}^{D} = \alpha_{hb}\, q_{b}^{D} \left(\frac{p_{b}^{D,m}}{p_{hb}^{D,m}} \right)^{\sigma} \tag{7.2}$$

The variable α_{hb} represents the agent's preference in region b for the variety produced in region h. In general, the preference for goods produced in the home country is relatively high. The variable σ represents the substitution elasticity or as it is often called the Armington elasticity. Note, that the specification of equations (7.1) and (7.2) implies that consumers and producers have identical preferences over the varieties for final demand, investment and intermediate demand, respectively. $p_{hb}^{D,m}$ denotes the market price in region b of the good produced in region h. The market price is the user price excluding user taxes like taxes on consumption and intermediates and will be defined later on. $p_{b}^{D,m}$ represents the price index in region b for a specific sector. It is the CES aggregate of the prices of all varieties consumed in region b.

$$p_{b}^{D,m} = \left(\sum_{h} \alpha_{hb} \left(p_{hb}^{D,m} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{7.3}$$

Given the demand functions of equation (7.2), the share of a particular good from region h in region b, Qq_{hb}, reads

$$Qq_{hb}^{D,m} = \alpha_{hb} \left(\frac{p_{b}^{D,m}}{p_{hb}^{D,m}} \right)^{\sigma-1} \tag{7.4}$$

Armington elasticities

The value of the Armington elasticity is central for the analyses of trade and terms-of-trade effects of all kinds of policy applications with AGE models. In the past econometric estimates on substitution of varieties were not satisfactory for using them in AGE models. Quite often they are estimated at more disaggregated levels than the sectors in AGE models. Moreover the estimates are biased downwards because most studies take the price variation as given and ignore differences in quality. If the quality is high, import demand and prices will be relatively high. This leads to lower estimates, see Hertel *et al.* (2003).

Most people feel that these estimated elasticities only represent substitution in the short term, but not in the long term. In the long term the substitution possibilities should be greater. One reason for this conjecture is that AGE models are not capable of representing the acceleration of trade flows the last decades in backtracking exercises. Moreover, trade-liberalisation experiments in AGE models often lead to lower trade increases than occur in practice. These results could be improved by using higher substitution elasticities.

For a long time we have used the substitution elasticities from the econometric work of Hummels (1999) in WorldScan. He used 1994 data from the US, New Zealand, Argentina,

[58] Textbooks, among them Blanchard and Fischer (1989), and Obstfeld and Rogoff (1996), extensively discuss the Dixit-Stiglitz model and the derivation of the demand equations. From here we omit sector subscripts.

Brazil, Chile, and Paraguay. The original database consisted of 15 thousand goods. These were aggregated to 62 goods commodity sectors at the two digit level (excluding services). For 57 of the 62 sectors the estimated elasticity is statistically significant at the 5% level with an average value of 5.6 and for most goods in a range from 3 to 8. Therefore, we have set the elasticities for manufacturing industries, agriculture and raw materials at 5.6. For services we choose an elasticity of 4.0. As far as we know, nobody provides estimates of the latter. It seems reasonable that the substitution possibilities are more limited than for goods but not completely negligible, in particular not for transport and business services. The GTAP model uses an elasticity of 3.8 for all services sectors, and the Dutch macro-econometric model JADE uses an elasticity of 2.65 (CPB, 2003).

The estimates of Hummels (1999) are in general higher than the values in most previous studies. Recently, Hertel *et al*. (2003) used the Hummels data set to estimate new substitution elasticities at the five-digit level. This procedure is motivated by the ideas that aggregation to the two-digit level involves biases for some of the explanatory variables such as tariffs. Moreover, the disaggregated data contain more data and a larger variation in tariff and trade costs. The estimations at a more disaggregated level than Hummels (1999) lead on average to higher estimates. The simple average is 7.0 instead of 5.6.[59] The variation across sectors is large: in agriculture it varies between 2.6 for *other grains products* to 10.1 for *paddy rice*. The largest elasticity of substitution is found for *natural gas*, 34.4. Within manufacturing (excluding *processed food* and *minerals*) it varies from 4.2 for *petrol and coal products* to 8.8 for *electronic equipment*.

We use these results in our new applications of WorldScan including the sectoral variation, see Table 7.1. Hertel *et al*. (2003) present also the confidence intervals of the estimates and the number of observations which give some feeling for the precision of the various sectoral estimates.

Table 7.1 Armington substitution elasticities in WorldScan

Manufacturing sectors	Value	Other sectors	Value
Low technology	6.6	Agriculture	7.3
Medium-low technology	6.6	Energy	7.3
Medium-high technology	7.2	Services	3.8
High technology	8.8		

Source: Hertel *et al.* (2003), and for Services own guess.

[59] Because of these higher substitution elasticities there is less need to distinguish short and long-term Armington elasticities as we did in the past, see CPB (1999). The short-term parameters were calibrated at the lower empirical estimates and we endogenised the preference variables s_{hb} in order to replicate big sweeps in trade patterns in the previous version of the model. The new and higher estimates of substitution elasticities undermine the usefulness of this mechanism. Therefore it has been abandoned.

Calibration

The allocation of sectoral demand over varieties from different regions is based on so-called Armington preferences. According to equation (7.4), the market shares of domestic and foreign producers depend on the preferences and relative prices. In the calibration the market shares are directly derived from the GTAP database. This database provides information on the value of the trade flows and total demand within a region. Based on these data, we calculate the market shares. The market prices are a composite of the exogenous producer price (in the calibration year) and taxes and subsidies. Taxes and subsidies (including trade taxes) are also directly calculated from the GTAP database. The values of the Armington substitution elasticities are derived from other studies (see table (7.1). Based upon this information we calibrate the consumer preferences in equation (7.4) as

$$\alpha_{hb}^{D,m} = Qq_{hb} \left(\frac{p_{hb}^{D,m}}{p_b^{D,m}} \right)^{\sigma - 1} \tag{7.5}$$

Prices

Firms offer their products to their home market at market prices. These are equal to the producer prices (see Chapter 2), raised with production taxes, t_h^Q. Prices of products exported from region h to country b are affected by trading costs. These costs consist of import tariffs, t_{hb}^M, export taxes, t_{hb}^X, non-tariff barriers, t_{hb}^N, and transport costs. Transport costs depend on the transport margins, $\beta_{INT,hb}$ and global transport price, p_{INT}^m.

$$p_{hb}^{D,m} = p_h^S \left(1 + t_h^Q\right) \frac{\left(1 + t_{hb}^X + t_{hb}^M\right)}{\left(1 - t_{hb}^N\right)} + \beta_{INT,hb}\; p_{INT}^m \tag{7.6}$$

$$p_{INT}^m = \left(\sum_h \alpha_{INT,h} \left(p_{TRA,r}^S \left(1 + t_{TRA,r}^Q\right)\right)^{1 - \sigma_{INT}} \right)^{\frac{1}{1 - \sigma_{INT}}} \tag{7.7}$$

The international transport price is an aggregate of all regional transport prices. σ_{INT} is the substitution elasticity for international transport. The market price, $p_b^{D,m}$, in equation (7.3) is thus the price excluding user taxes on consumption, t^C, and intermediate goods, t^F. These taxes are imposed by the importing country and do not discriminate by region of origin: these taxes thus do not affect the choice between goods of different origin. The agent prices for consumption and intermediate goods read

$$p_b^k = p_b^{D,m} \left(1 + t_b^k\right) \qquad k = \text{C,F} \tag{7.8}$$

The transport margins are calibrated using the GTAP database. The database includes CIF-FOB margins for each bilateral trade relation and for each commodity. CIF-FOB margins measure the difference between the value at the importer’s border and the value at the exporter’s border. We interpret this margin as the transport costs between the country of origin and destination. Given the global transport price (equation (7.7)) we calculate the transport margin β_{hb}. We assume that the transport margin is constant in time. For most services it is zero, because there are no CIF-FOB margins available. In some applications – an example is the scenario study, Lejour (2003) – we decrease the transport margins to mimic international trade facilitation.

The import, export, and production tariffs are fixed as a percentage of the relevant prices according to the values in the GTAP database. The non-tariff barriers are also expressed as tax rates. These rates are derived from estimations of gravity equations as will be explained in Section 7.3.

7.2 Formal trade barriers

Import and export tariffs

In our applications on trade policy we introduce various forms of trade liberalisation on a regional and global scale in the scenarios. To give some idea of the protection level, we present at an aggregated level some of the import tariffs in the model.

Table 7.2 Import tariffs in the OECD and non-OECD countries in 1997 (% of import value)

Exporting region	Importing region		
Agriculture/food	OECD	Non-OECD	World
OECD	33.9	30.6	32.2
non-OECD	24.1	32.3	25.7
Manufacturing	OECD	Non-OECD	World
OECD	2.7	9.2	5.5
non-OECD	4.9	12.1	5.8

Source: GTAP database (Dimaranan and McDougal, 2002). Within the OECD, intra EU-15 trade is excluded, and Central and Eastern Europe are classified as OECD. The tariff data are bound rates. Applied rates are in general lower.

Table 7.2 shows that countries impose substantial tariffs in agriculture of about 30% of the import value against world prices.[60] The OECD imposes higher tariffs on imports from the OECD than from imports originating from the non-OECD. One of the reasons is that the OECD imports consist, relatively, of much processed food from other OECD countries, which is subject to higher import tariffs than (basic) agricultural products from non-OECD countries. Export tariffs and subsidies are also significant. The OECD subsidises its agricultural exports, while the developing countries raise export taxes of about 2.5%. The general opinion is that the gains from liberalising agricultural policies could be large, because current trade and production patterns in agriculture are severely distorted due the subsides and taxes.

[60] The world price is defined as the price of a good which has passed the border of the exporting country, but has not passed the border of the importing country. It includes producer taxes and export taxes, but not import tariffs and transport costs.

Table 7.2 shows that OECD countries do not impose significant import tariffs in manufacturing, regardless of whether these are imported from other OECD countries or the developing ones. The non-OECD countries impose tariffs of about 10% of the import prices. At the world level, the average import tariff is much lower because most trade takes place within the OECD. The numbers in table 7.2 are from 1997. Current tariffs are probably lower.

The table also shows that if developing countries export their manufactures, they face higher import tariffs, on average, than OECD countries. WTO (2001) argues that tariffs are relatively high in sectors that are important for developing countries, such as textiles and clothing, leather and other labour-intensive goods. From that perspective, the gains of further trade liberalisation in manufacturing could be relatively large for the developing countries. The recent study of Francois *et al*. (2005) on the welfare effects of the Doha round emphasises this point.

OECD countries do not impose import tariffs at all in the service sectors, and those of the developing countries do not exceed half a percent of the import value. In services, import tariffs have never been important. However, within services non-tariff barriers are a substantial impediment to trade. Section 7.3 concentrates on these barriers.

7.3 Non-tariff Barriers

This section presents [61] the calibration of NTB's in WorldScan. First, we discuss the nature of NTB's and the way NTB's are treated in models. Second, we present the estimation of NTB's in the literature and our method. This method consists of two steps. First, we estimate potential bilateral trade. We interpret the difference between potential trade and actual trade as an indication of the size of NTB's. Second, we calibrate the NTB's in WorldScan based upon the potential trade increase. Finally, we present the size of the NTB's.

Causes of non-tariff barriers

Trade in services is hampered by three types of barriers, ignoring tariffs (Hoekman and Braga, 1997). The first is quotas and prohibitions. An example is landing rights for airplanes. Second, price regulations are an impediment to trade. Airport and tourist taxes, for example, reduce the demand for tourist services. Finally, there is sometimes discriminatory access to distribution networks. For instance, foreign providers are not always granted access to distribution networks. This not only hampers trade, but also reduces competition.

Except for these reasons services trade is also hampered by regulatory barriers. In 2002, the EC launched a report full of anecdotic evidence of regulatory barriers in service trade. These barriers seem persuasive and distort the functioning of the internal market for services within the European Union. Kox and Lejour (2005) show that these barriers hurt service trade substantially.

[61] This section is based on Lejour (2001).

Services trade could nearly triple if differences in regulation between the exporting and importing country are wiped out.

NTB's are not only important in services, but also in manufacturing and agriculture. Various restrictions fall under the heading of non-tariff barriers (NTB) in these sectors, such as anti-dumping and countervailing actions, non-automatic licensing and (voluntary) export restraints. The Uruguay round aimed at reducing these barriers in manufacturing, proved to be fairly successful. Most of the NTB's apply to food processing, beverages and tobacco, and textiles and apparel. NTB's also include intentional and unintentional restrictions on international trade that stem from regulating product characteristics and production methods. Concerns for health, safety, the environment, and consumer protection are legitimate grounds for member states to restrict imports from other member states. These obstacles to trade are often referred to as technical barriers.

Modelling NTB's

Technical barriers can be modelled in several ways. We choose to treat NTB's as import tariffs in the model. This means that the NTB is levied in the importing country at the border. This is quite standard (see Verikios and Zhang (2001)). Then we have to decide whether the NTB's generate income or not. If they contain income, levying NTB's generates revenues for the importing country. So, the barriers are cost-increasing for users and generate income for agents in the importing country directly, because they assist the exporters to overcome the NTB's or for the government. The latter revenues are transferred in a lump-sum fashion to the households in WorldScan. The barriers also generate losses in efficiency. Removing the NTB's thus improves efficiency for the economy as a whole, which may outweigh the loss in revenues generated by the NTB's. In most models NTB's are modelled in this way, see e.g. the FTAP model (Verikios and Zhang (2001), or Li and Zhai (1999)).

The question is to what extent do the NTB's generate income? These rents are not always substantial. For example, if the NTB's reflect risk and uncertainty in trade or technical barriers to trade, then it is clear that these barriers hamper trade but do not generate income. For that reason we model the NTB's without revenue-generating effects. We model the NTB's as 'iceberg' costs.[62] In transporting goods from the exporting to the importing country, the goods partly melt away and so only a fraction of the goods arrives at its destination. This increases the price of the imported good. The market price in the importing country reflects thus the transportation loss due to the NTB's. So, the NTB's raise prices for the users without generating revenues as is modelled in equation (7.6). This way of modelling is quite standard in the economic geography literature (see Krugman (1991)), but not in AGE models.

[62] Note that the costs are proportional to the volume of trade in our model. In other (geography) models the iceberg costs are proportional to distance.

The estimation of NTB’s

The problem of NTB’s whether they appear in services or manufacturing is how to quantify them. Most of the estimates are guesstimates. One well-known source is Hoekman (1995). Hoekman has quantified NTB’s using the commitments to reduce trade barriers of the individual countries for the General Agreement on Trade in Services (GATS). Countries with many commitments are assumed to have high initial trade barriers in certain service sectors. Hoekman has obtained numbers for about 20 service sectors in more than 30 countries. The values of the NTB’s he obtained are considered to be too high by the experts. Nowadays the Productivity Commission (Australia) is very active in quantifying NTB’s. On the basis of regulations in various services sectors the commission tries to quantify non-tariff barriers for specific sectors, like banking, telecommunications, maritime, wholesale and retail distribution, professional services, electricity supply and air passenger transport (see Findlay and Warren, 2000). In general they construct indexes based on the degree of restrictions in a market. Then they use this index in an econometric model to estimate the price effects of the regulation.

Another method is to obtain NTB estimates for an internal market union on the basis of an expected increase in bilateral trade due to the participation within the internal market. The idea is that an internal market such as the EU represents the ideal of no trade barriers due to all its measures to reduce and eliminate trade distortions. We compare this ideal situation with actual trade between countries. Lejour *et al.* (2004b) use gravity equations to estimate the impact of an internal market on trade at a sectoral level. Participating in an internal market is an important stimulus for bilateral trade compared to the situation that one or both countries do not participate in the internal market. The gravity approach is often used for these kind of purposes. Gravity equations explain bilateral trade patterns very well and are often used to forecast trade developments.[63]

Given the difference between potential trade and actual trade (that is equal to the potential trade increase), Lejour *et al*. (2004b) derive the level of NTB’s which hamper this increase in trade. To calibrate the implicit barriers, they translate the potential trade increase into a Samuelson iceberg trade-cost equivalent of the barriers. If they abolish the NTB’s in the model, they arrive at the trade levels that correspond to the predictions from the gravity model. This procedure is explained more extensively below.

Calibration of NTB’s in WorldScan

First, we repeat the standard procedure in calibrating the Armington demand functions. This calibration procedure determines the preferences based on the values of the trade flows and substitution elasticities from the GTAP database, see also equation (7.2). Now these parameters

[63] Anderson and Van Wincoop (2004), Linders (2005) and Nahuis (2004), among others, discuss the origins, theoretical foundations, applications and limitations of the gravity model.

include a superscript $C1$. In particular, for each sector the Armington demand system yields (we drop the sector subscript):

$$q_{hb}^{D} = \alpha_{hb}^{C1}\, q_{b}^{D} \left(\frac{p_{b}^{D,m,0}}{p_{hb}^{D,m,0}} \right)^{\sigma} \tag{7.9}$$

where q_{hb} is the trade from country h to country b and q_b is total demand for the good in country b. Superscript D indicates that a variable is derived directly from the data. Preferences are reflected by s. Prices ($p^{m,0}$) are exogenous because these are determined elsewhere in the calibration procedure. Note that for the time being, we assume that prices do not include NTB's (or more formally, we have set the value of the NTB's at zero). This is indicated with the superscript 0. The price-index p is a function of the (given) prices, see equation (7.3).

Now we take two steps. In the first step (denoted by superscript $C2$), we calculate the preferences required to produce the *ceteris paribus* trade volume predicted by the gravity model:

$$q_{hb}^{G} = \alpha_{hb}^{C2}\, q_{b}^{G} \left(\frac{p_{b}^{D,m,0}}{p_{hb}^{D,m\,0}} \right)^{\sigma} \tag{7.10}$$

where q_{hb}^{G} denotes the potential trade without NTB's. q_{b}^{G} is calculated such that it is consistent with the predicted bilateral trade flows from the gravity equation. This gives us a set of alternative preference parameters α^{C2}, which are consistent with the potential trade flows that would materialise if there where no NTB's.

In the second step, we use the alternative preference parameter ($C2$) to calculate the NTB's. In particular, we re-calibrate the Armington demand system so as to replicate the actual trade data again. For this, we adjust the prices by introducing the NTB, reflecting an iceberg cost:

$$q_{hb}^{D} = \alpha_{hb}^{C2}\, q_{b}^{D} \left(\frac{p_{b}^{D,m}}{p_{hb}^{D,m}} \right)^{\sigma} \tag{7.11}$$

The superscript 0 is dropped reflecting that prices are also affected by the NTB's. To determine the price index in the second calibration step, we use the fact that the NTB is zero for the consumption of domestic goods, i.e.:

$$q_{bb}^{D} = \alpha_{hb}^{C2}\, q_{b}^{D} \left(\frac{p_{b}^{D,m}}{p_{bb}^{D,m}} \right)^{\sigma} \tag{7.12}$$

Equation (7.12) is used to pin down prices. To be more precise, equations (7.11) and (7.12) are solved simultaneously to determine prices.

The level of NTB's

The relevance of a NTB as trade barrier depends on the size of the NTB and on the substitution elasticities in the Armington equations. When the elasticity is low, a reduction of the NTB has smaller effects on trade than when the elasticity is high. Quite often the estimates of NTB's are based implicitly or explicitly upon the substitution elasticities. This is very explicit in our case because we use potential trade increases in the Armington functions in deriving the NTB. We want to ensure that the substitution elasticities used in the calibration are equal to those used in the simulation. This is more easily done for NTB's that are estimated by ourselves than by others. Many estimates in Findlay and Warren (2000) assume (implictly) some degree of substitution between the varieties. If this degree of substitution differs from the one in the model one should corrrect for this difference in order to derive the right trade-hampering effects of the trade barrier.

Table 7.3 presents the NTB levels for various sectors in WorldScan. In some sectors the NTB's are zero, because the gravity equation does not predict an increase in trade due to the EU internal market. Partly, this can be caused by the fact that trade is not affected by the internal market such as for energy and raw materials. It could also be the case that the EU directives and rules are not effectively implemented as is the case for most service sectors.

Table 7.3 Level of NTB's 1997 (% of import value)

Sector	NTB	Sector	NTB
Agriculture	21.7	Capital goods	10.6
Energy	0.0	Transport services	0.6
Raw materials	0.0	Construction	12.6
Consumption goods	9.7	Trade services	22.2
Food processing	14.0	Communication	0.0
Paper, printing, publishing	13.7	Financial services	0.0
Chemicals and minerals	2.5	Business services	17.6
Metals	0.0	Other services	4.8

Source: own calculations, based on Lejour *et al.* (2004) and Nahuis (2004).

From this table we draw two conclusions. The first is that NTB's vary substantially between industries. The second is that the NTB's are relatively high in some sectors compared to tariffs. This suggests large gains from the elimination of NTBs compared to tariffs. The study of Lejour *et al.* (2004) to the accession of the countries in Middle and East Europe to the European Union confirms this result.

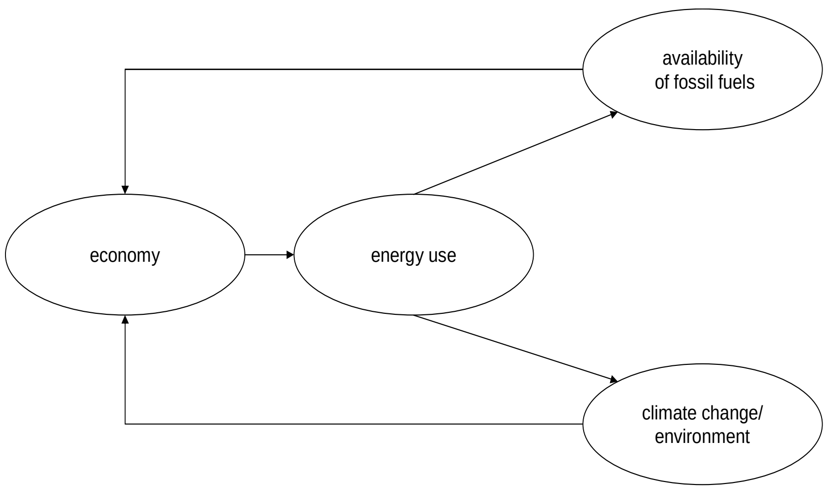
8 Energy and Climate change

In order to address the economic effects of climate change policies, the WorldScan model covers several greenhouse gases: carbon dioxide, methane and nitrous oxide. Energy use, besides being an important aspect of the economy on its own, is also the main source of carbon dioxide emissions. Instruments for emission abatement policies are also available in the model

8.1 Introduction

Energy is one of the keys to economic development.[64] Societies are fuelled by energy and future economic growth will demand an increased availability and use of energy. This ever-growing demand for energy will put an increasing claim on natural resources and the environment. Firstly, oil and gas reserves[65] are expected to become scarce over time, because these natural resources are finite. Secondly, the combustion of fossil fuels leads to emissions of greenhouse gases and evidence is mounting that these emissions result in global warming. Important feedbacks exist on energy use and the economy. Physical disruptions in the supply of energy and large variations in the price of energy affect economic growth significantly. Climate change causes a large range of hazards, like deterioration of biodiversity and increased water stress. Figure 8.1 summarises these relationships between the economy and energy use graphically.

Figure 8.1 Economy, energy and natural resources



The energy version of the WorldScan model distinguishes six energy carriers: coal, petroleum products, gas (including gas distribution), electricity, modern biomass and non-fossil-fuels

[64] This introduction is derived from *Four Futures for Energy Markets and Climate Change* by Bollen *et al.* (2004).

[65] For coal, the process of resource depletion is negligible.

(nuclear, geothermal, solar and wind energy). The demand for these energy carriers derives foremost from the production sectors (70-85%), which use energy as an intermediate input, but also from the households, who consume energy directly. Table 8.1 displays the energy cost shares of production for the OECD and non-OECD countries. Despite the fact that the OECD countries use a larger amount of energy compared to the non-OECD countries, their cost shares for energy use are lower than for the non-OECD countries. The macro energy cost shares of

Table 8.1 Cost shares of energy use by producers for the OECD and Non-OECD (2001)

	OECD	Non-OECD
Coal	0.3	0.9
Gas and gas distribution	0.5	1.2
Petroleum products	1.1	2.0
Oil	1.2	2.1
Biomass	0.1	1.5
Non-fossil fuels	0.3	0.2
Electricity	2.6	3.0
Total	6.1	11.0

Source: Dimaranan and McDougal (2002) and for biomass and non-fossil fuels the IMAGE-TIMER model of the RIVM (2001).

table 8.1 are misinterpreted easily, because large differences exist among sectors: the chemical and basis metal sectors have 30-50% of their production costs made up of energy, while services use relatively little energy (see Bollen, 2004, for more details). Therefore, a shift towards a more service oriented society will lower energy demand.

Table 8.2 gives some data on energy demand of consumers, who use the energy carriers for heating, lightning, and mobility. This table reveals a similar expenditure pattern for the OECD and non-OECD countries.

Table 8.2 Expenditure shares of energy use by consumers for the OECD and non-OECD (2001)

	OECD	Non-OECD
Coal	0.0	0.0
Gas and gas distribution	0.1	0.2
Petroleum products	1.7	1.7
Electricity	1.1	1.1
Total	3.0	3.0

Source: Dimaranan and McDougal (2002).

The production and demand structure of the energy carriers follows the functional specification of the other goods and services sectors (see Chapter 2 and 6). A distinguishing feature of energy use is resource availability. Combustion of fossil fuels involves the depletion of non-renewable resources. At the global level resources for oil and gas might be sufficient to meet future demand. However, at a regional level existing differences between energy demand and supply could be magnified and give rise to large price variations, harming economic growth. Section 8.2 will provide the mathematical specifications of energy supply and demand.

Two developments in energy technology are important: more efficient use of energy due to technological developments and increasing availability of new, economically viable energy carriers, the so-called backstop technologies. Firstly, more efficient conversion techniques in electricity production and more efficient use of energy in final energy services, like transportation and heating, will lead to a decrease of energy demand. Improvements in energy technology cause, besides the diminishing use of primary energy per unit of output (a lower energy intensity), also changes in the energy structure (fuel-switching).

Secondly, backstop energy supply technologies will become increasingly important in the future. The term backstop technology describes an energy source that is not yet commercial, is physically a perfect substitute for an existing energy carrier, and is available in unlimited supply at a constant marginal cost (Nordhaus, 1979). Except for the plutonium breeder nuclear reactor, pure backstop technologies do not exist. The WorldScan model defines non-fossil fuels (nuclear, geothermal, solar and wind energy) as a backstop technology. Modern biomass is another alternative energy carrier used in the model. Energy technology will be discussed further in Section 8.3. The calibration of the energy parameters and the dynamics of energy use form the focus of Section 8.4. Emissions of greenhouse gases and instruments for abatement policies are the focus of Section 8.5 and 8.6, respectively.

8.2 The structure of energy supply and demand

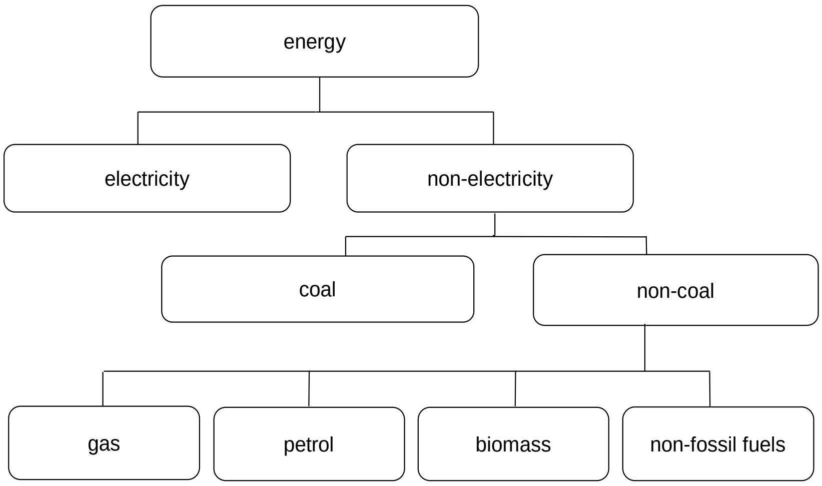
The energy version of WorldScan distinguishes three fossil energy sectors: coal, petroleum products[66] and gas (including gas distribution). Furthermore, electricity is modelled as a separate sector. The production and demand structures of these fossil energy carriers and electricity closely follow the functional specification of the other goods and services sectors, which have already been described in previous chapters. This section presents an overview of the deviations from these general specifications.

[66] Actually, both oil and petroleum products are produced in separate sectors. However, because oil is delivered almost completely to the petroleum sector, no special attention will be given to this energy carrier in this chapter. Oil only plays a minor role as a material input in the production function of the other sectors.

Energy demand

The demand for the energy carriers derives from the production sectors, which use energy as an intermediate input, and from the households, which consume energy directly. This section starts with the description of the energy carriers as inputs in the production process. The energy part of the production tree is modelled as a nested CES-function and is depicted schematically in Figure 8.2. At the top of the energy tree, electricity is separated from non-electrical energy inputs with a

Figure 8.2 Energy disaggregation in the production structure of the WorldScan energy version



substitution elasticity of 0.25. Next, coal is nested separately, because of its use for base-load capacity in electric power plants, while the other energy sources are used for the peak-load (Bollen, 2004). A substitution elasticity of 0.7 between coal and the non-coal energy inputs is assumed. Finally, the lowest level of the energy nest is formed by petroleum products, gas plus gas distribution, biomass and non-fossil fuels with a substitution parameter of 0.5.

The equations for the demand of energy by consumers correspond exactly to the general consumption equations from Chapter 6. The sectors coal, gas and electricity belong to the consumption category Gross Rents and Fuels (heating) and the sector petroleum to Other Goods and Services (mobility).

Unit of measurement

The unit of measurement for values in the WorldScan model is US$. General equilibrium models only determine relative prices, with some arbitrary price fixed (at one). The unit of the volume levels is likewise arbitrary. However, the volume of fossil fuels needs to be expressed in physical units, because of the direct relation between the energy content of a fossil fuel and the amount of carbon dioxide emissions. The energy database of GTAP, GTAP-E (Dimaranan and McDougall, 2002, Chapter 17), fulfils this requirement. This database expresses the demand (intermediate plus final) for coal, petroleum products and gas in megatonnes of oil equivalents

(Mtoe), making these volumes comparable on the basis of their energy content. More details on these physical units are given in the box below.

Units, dimensions and definitions: energy

Concerning energy, a confusing number of definitions and dimensions circulates. Generally, coal is measured in tons, gas in cubic meters and petroleum products in barrels. The WorldScan model expresses the volume of energy demand in megatonnes of oil equivalents (Mtoe), with 1 tonne being equal to 10^3 kg. Dimaranan and McDougall (2002, Chapter 17) give a useful table with conversion factors for different energy products. Another unit often used to express the caloric value of energy products, is joules (J). The relation between tonnes of oil equivalents and joules is: 1 toe = 41.868 10^9J. Because of the large magnitude of these numbers, some unfamiliar shortcut notations are used: kilo (k) = 10^3, mega (M) = 10^6, giga (G) = 10^9, tera (T) = 10^{12}, peta (P) = 10^{15} and exa (E) = 10^{18}. The price of energy in the WorldScan model is defined as energy value in billion US$ divided by energy volume in megatonnes of oil equivalents, and therefore expressed in the unit 1000 US$ / toe.

Energy supply and resource depletion

One feature that distinguishes the production of energy carriers from the production of other goods and services is the depletion of the fixed factor. This fuel specific fixed factor is necessary for the retrieval , i.e. production, of coal, oil and gas.[67] This fixed factor is limited in size and will decrease in time as a result of depletion. Scarcity of the fixed factor will raise the price of the produced fossil fuel. Rising prices lower the demand for these fuels and thus diminish the use of energy in the future.

The modelling of the resource depletion roughly follows the approach of the EPPA model (Babiker *et al.*, 2001):

$$q_{FIX,s,t} = q_{FIX,s,t-1}\left(1 - \frac{q^S_{s,t}}{S_{FIX,s,t}}\right) \qquad s = \text{COL,OIL,GAS} \tag{8.1}$$

with $S_{FIX,s}$ denoting the available stock of fossil fuel reserves and q^S_s the quantity of fossil fuel actually produced in a year. Both variables are expressed in megatonnes of oil equivalents, while the volume of the fixed factor used in the production function, $q_{FIX,s}$, is expressed in some arbitrary unit. The time subscripts t and t-1 show the dynamic nature of this process, although its nature is quite mechanical; scarcity does not increase the stock of retrievable resources. The data on the coal and oil reserves also come from the EPPA model (Babiker *et al.*, 2001). These reserves include identified, undiscovered and currently uneconomic recoverable resources. For simulation over periods of 50 years or more, this broad definition is appropriate. For gas, WorldScan uses data from the IEA/OECD-publication (2002), because this source provides more recent measurements and contains specific information on European countries. Table 8.3 shows the base year values for the coal, oil and gas reserves of some regions.

[67] The importance of the fixed factor is negligible in the sector petroleum products. However, as the production of petroleum products largely depends on the input of oil, depletion of oil will indirectly influence the demand for petroleum products.

Table 8.3 Coal, oil and gas reserves per region in Mtoe

Region	Coal[a] 1995	Oil[a] 1995	Gas[b] 2000
United States	1 266 754	23 645	4 738
Pacific OECD	747 074	59 709	3 100
Western Europe	379 269	7 667	4 496
Eastern Europe	646 979	1 433	711
Former Soviet Union	3 941 533	126 582	55 949
Middle East and North Africa	236 518	259 633	59 408
Latin America	24 648	47 132	7 783
Rest of the World	1 132 195	29 687	3 205

[a] Source: EPPA model (Babiker *et al*, 2001, p. 36).
[b] Source: IEA/OECD publication: Natural Gas Information (2002, table 23).

8.3 Energy technologies

Two developments in energy technology are important: increasing availability of new, economically viable energy sources, the so-called backstop technologies, and more efficient use of energy due to technological developments.

Alternative and backstop energy technologies

The demand for biomass and non-fossil fuels originates in the WorldScan model completely from the production sectors, because households do not use these energy sources directly. These inputs are situated in the lowest nest of the energy tree, as is shown in figure 8.2. Therefore, the input of biomass and non-fossil fuel is a direct substitute for gas and petroleum products with a substitution parameter of 0.5.

The production of biomass takes place in the agricultural sector and the production of non-fossil fuels in the service sectors. By having the service sector, with its infinite supply elasticity, produce the non-fossil fuels, we create a kind of backstop technology in the WorldScan model.

The user price of biomass is based on the market price and input tax of the agricultural sector. Similarly, the user price of non-fossil fuels derives from the prices and taxes of the service sector. Equation (8.2) summarises these assumptions:

$$\begin{aligned} p_{BIO} &= p^{D,m}_{AGR}\,(1+t^{F}_{AGR}) \\ p_{NFF} &= p^{D,m}_{SRV}\,(1+t^{F}_{SRV}) \end{aligned} \tag{8.2}$$

with t^F denoting the tax on inputs in the production, $p^{D,m}$ the market demand price and p the user demand price.

Energy-specific efficiency index

Due to energy-specific technological progress, the same output can be produced with less energy input. A fuel-specific efficiency index captures this development. As an example of the necessary modifications for the introduction of an efficiency index, we give the equations of the production function for the bottom level of the energy inputs (Total Non-Coal): gas (GAS), petroleum products (PTR), biomass (BIO) and non-fossil fuels (NFF). Similar specifications apply to the nests with Coal and Electricity. Output maximisation under a cost restriction with energy-specific efficiency indices becomes:

$$\begin{aligned} &\max \quad q_{TNC} = CES(A_{GAS}q_{GAS},\ A_{PTR}q_{PTR},\ A_{BIO}q_{BIO},\ A_{NFF}q_{NFF};\ \rho_{TNC}) \\ &\text{subject to } \textstyle\sum_f q_f p_f = C_{TNC} \qquad f = \text{GAS,PTR,BIO,NFF} \end{aligned} \tag{8.3}$$

with CES denoting a constant elasticity of substitution function (see also Chapter 2) and A_f being the efficiency index for a specific fuel. This index equals one in the base year. The parameter ρ_{TNC} can be converted into the more familiar substitution parameter: $\sigma_{TNC} = 1/(1-\rho_{TNC})$. Expressed in efficiency volumes and prices, the above optimisation problem becomes:

$$\begin{aligned} &\max \quad q_{TNC} = CES(\tilde{q}_{GAS},\ \tilde{q}_{PTR},\ \tilde{q}_{BIO},\ \tilde{q}_{NFF};\ \rho_{TNC}) \\ &\text{subject to } \textstyle\sum_f q_f p_f = \sum_f \left(A_f q_f\right)\left(\dfrac{p_f}{A_f}\right) = \sum_f \tilde{q}_f \tilde{p}_f = C_{TNC} \end{aligned} \tag{8.4}$$

where the tilde denotes volumes and prices in efficiency units. The equation for the unit price of q_{TNC} becomes:

$$p_{TNC} = \left(\sum_f \alpha_f \tilde{p}_f^{1-\sigma_{TNC}}\right)^{\frac{1}{1-\sigma_{TNC}}} \tag{8.5}$$

and the equation for the factor demand in efficiency units is:

$$\tilde{q}_f = \alpha_f q_{TNC} \left(\frac{p_{TNC}}{\tilde{p}_f}\right)^{\sigma_{TNC}} \tag{8.6}$$

Converting this equation back into conventional units gives:

$$q_f = A_f^{\ \sigma_{TNC}-1} \alpha_f q_{TNC} \left(\frac{p_{TNC}}{p_f}\right)^{\sigma_{TNC}} \tag{8.7}$$

In the WorldScan model, values for the efficiency index A_f are specified either exogenously or calibrated dynamically to exogenous developments of energy use. This last approach will be explained further in Section 8.4.

8.4 Calibration of energy demand and supply

The calibration of the energy demand and supply functions follows the calibration procedures for the other sectors. The general equations for the calibration of the production parameters are provided in section 2.1 and for the consumption equations in section 6.2 . The GTAP-database (Dimaranan and McDougall, 2002) supplies the data necessary to calibrate the parameters for the energy sectors. Additionally, the cost share data for biomass and non-fossil fuels derive from the IMAGE-TIMER model of the RIVM (2001). This section focusses on two issues that are specific for the energy sectors: calibration of the supply elasticities and dynamic calibration.

Supply elasticities

The supply elasticity is defined as the relative change of output q in response to a relative change of the output price p, i.e. $\eta = \partial \ln q / \partial \ln p$. For every production sector the following expression can be derived, linking the supply elasticity η_s to the upper nest substitution parameter ($\sigma_{TIN,s}$) of a CES production function (Babiker *et al.*, 2001, p.33):

$$\eta_s = \frac{1 - Qq_{FIX,s}}{Qq_{FIX,s}} \sigma_{TIN,s} \tag{8.8}$$

with $Qq_{FIX,s}$ denoting the cost share for the fixed factor. The inverse of equation (8.8) transforms the supply elasticities into regional specific substitution elasticities, depending on the share of the fixed factor in production costs. Most sectors in WorldScan have a very small cost share for the fixed factor, and consequently supply elasticities approaching infinity. However, GTAP provides substantial cost shares for the fixed factor of the fossil-fuel sectors. These cost shares imply upward-sloping supply curves for the fossil fuel sectors, which is consistent with empirical evidence. The WorldScan model assumes values of 20, 5, and 5 for the supply elasticity of the coal, oil and gas sector, respectively. There is no hard empirical evidence on these values, so performing a sensitivity analysis with these parameters will be useful.

Dynamic calibration of energy use

Energy intensity, i.e. the energy use per unit GDP, generally declines in WorlScan due to changes in sector structure (e.g. a more service intensive economy) and rising energy prices (e.g. carbon taxes, resource depletion). These changes in energy intensity are modest, however, compared to the exogenous developments in energy markets required by studies on climate change (e.g. IPCC, 2001). Therefore, WorldScan needs a tool for targetting the energy intensity per energy carrier. The energy-specific efficiency index from Section 8.3, reflecting developments in energy technology, proves to be a suitable tool.

On the production side of the economy, the fuel specific efficiency index is used to calibrate the exogenously imposed developments in energy use for every energy carrier. More formally expressed:

$$q_{ff}^{D}\left(A_{ff}\right) = \bar{q}_{ff}^{D} \qquad ff = \text{GAS,PTR,COL,BIO,NFF} \tag{8.9}$$

with $\bar{q}^{D}$ denoting the imposed energy use in a region and q^{D} the endogenous energy use in WorldScan as a function of the efficiency index A_{ff}. This energy efficiency index is calibrated homogeneously over sectors for every energy input. A higher energy efficiency index directly results in a lower demand for energy inputs (see equation (8.7)). However, the rise in energy efficiency also makes the production price decline, especially in the energy intensive sectors. As a consequence, the demand for energy intensive products will rise, as will the demand for energy inputs. This opposite effect is particularly strong, because no costs are attached to the development and acquisition of energy technology in WorldScan. The calibrated energy efficiency indices should therefore be interpreted with some caution. Primarily, they serve as a method to mimic energy developments in WorldScan for a specific baseline.

According to the GTAP-E database, 15 - 30% of energy demand comes from consumers. This percentage is substantial and therefore households bear part of the energy reduction. In WorldScan, the fossil fuels coal and gas belong to the consumption category Gross Rents and Fuels (heating) and the fossil fuel petroleum to Other Goods and Services (mobility). This mapping from production sectors s to consumption categories c is defined by the weights $\lambda_{s,c}$, which are derived for the base year from the GTAP-database (see equation (6.11) and (6.12) for details). As a first step, we assume that these base year weights change with the growth rate of the exogenous fuel intensity targets:

$$\lambda_{s,GRF,t} = \lambda_{s,GRF,tb} \frac{\left(\overline{q}^{D}_{s,t}/\overline{y}^{GDP}_{t}\right)}{\left(\overline{q}^{D}_{s,tb}/\overline{y}^{GDP}_{tb}\right)} \qquad s = \text{COL,GAS} \tag{8.10}$$

$$\lambda_{s,OGS,t} = \lambda_{s,OGS,tb} \frac{\left(\overline{q}^{D}_{s,t}/\overline{y}^{GDP}_{t}\right)}{\left(\overline{q}^{D}_{s,tb}/\overline{y}^{GDP}_{tb}\right)} \qquad s = \text{PTR}$$

with $\overline{q}^{D}_{s}/\overline{y}^{GDP}$ denoting the target fuel intensity and tb the subscript for the base year. Consequently, a reduction in fuel intensity is paralleled by a reduction in the mapping weights $\lambda_{s,c}$. Smaller weights imply that less fuel is needed to 'produce' a unit of the consumer categories Gross Rents and Fuels, and Other Goods and Services, which can be interpreted as a technological improvement in energy efficiency for households. In the next step, the restriction of adding up to one is enforced on these weights:

$$\lambda^{*}_{s,c} = \frac{\lambda_{s,c}}{\sum_{s} \lambda_{s,c}} \qquad c = \text{GRF,OGS} \tag{8.11}$$

Equation (8.10) and (8.11) describe a simple update rule, and more sophisticated rules are available in WorldScan, but this specification illustrates the calibration procedure adequately.

8.5 Emissions of greenhouse gases

Several anthropogenic greenhouse gases contribute to global warming. The Kyoto Protocol (1997) distinguishes six of these greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and a group of three fluorinated gases. These fluorinated gases are not incorporated in WorldScan as their volumes are negligibly small. The greenhouse gases methane and nitrous oxide are homogeneous enough to be aggregated into one category, called the non-CO_2 greenhouse gases. In this Chapter, carbon dioxide is discussed seperately from the non-CO_2 gases, due to the large differences in modelling strategy. The box below describes the procedure for making these different greenhouse gases comparable. This section first outlines the equations and data for CO_2 emissions, and then continues with the discussion on non-CO_2 emissions.

Units, dimensions and definitions: greenhouse gas emissions

The Kyoto Protocol covers six different greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three F-gases (HFC, PFC and SF_6). The emissions targets in the Kyoto protocol apply to the aggregate of these six gases. These gases differ in their Global Warming Potential (GWP), i.e. their effect on radiative forcing. The GWP of a greenhouse gas is defined as the ratio of the cumulative radiative forcing that would result from the emissions of one kilogram of that gas to that from emission of one kilogram of carbon dioxide over a period of time (usually 100 years). The table below presents the GWPs of the different gases. Emissions volumes are thus commonly expressed in carbon dioxide equivalents: the metric volume times the GWP. Carbon dioxide equivalents can easily be converted to carbon equivalents by multiplying the carbon dioxide equivalents by 12/44 (the ratio of the molecular weight of carbon to carbon dioxide). The WorldScan model measures emissions in gigatons of carbon (GtC). In the WorldScan model the emissions price is defined as emissions reduction costs in billion US $ divided by emissions volume in GtC, and therefore expressed in the unit US$ / tC. To give an impression of the magnitude of this emissions price: the enforcement of the Kyoto protocol induces emissions prices between 0 and 150 US$ / tC, depending on the region, coalition, scenario, etc. (Bollen *et al.*, 2000).

Kyoto greenhouse gases, Global Warming Potential and main emission sources [a]

Greenhouse gas	GWP[b]	Emission sources
CO_2	1	Combustion of fossil fuels (coal, oil and gas)
CH_4	21	Cattle and manure, rice, natural gas, waste and fuel losses/leakage
N_2O	310	Agricultural soils, fertilizer and industrial production (adipic and nitric acid)
HFC_s [a]	140-11 700	Air conditioning and foam blowing
PFC_s [a]	6 200-9 200	Aluminium and semiconductors
SF_6	23 900	Magnesium, semiconductors and electrical switchgear

[a] Source: IPCC (2001).
[b] Differences in global warming potential exist across regions due to the composition of the F-gases.

Carbon dioxide emissions

Carbon dioxide emissions contribute most to global warming, and stem from land use (burning wood and biomass), industrial production (e.g. cement production) and most importantly the combustion of fossil fuels for energy production and consumption. This combustion of fossil fuels comprises about three-quarter of the total emissions, and this share is expected to increase over time (Bollen *et al.*, 2004). Therefore, in WorldScan the modelling of carbon dioxide emissions is restricted to emissions caused by fuel combustion.

The quantity of carbon dioxide emissions, q^{EM}, equals the product of the volume of fossil fuels used in production and consumption, q^{D}, and the emission factor EM^{F}, i.e. the emissions per unit fossil fuel combustion:

$$q^{EM}_{ff,sr,t} = EM^{F}_{ff}\; q^{D}_{ff,sr,t} \qquad ff = \text{COL,PTR,GAS,BIO,NFF} \tag{8.12}$$

Consequently, reducing CO_2 greenhouse gas emissions is possible either by using less energy or by substituting more carbon emitting fuels for less emitting ones.[68] The emission factor in equation (8.12) only contains the subscript ff, which implies that CO_2 emissions relate to energy use in a fixed proportion, depending only on the fuel used. This emission factor for CO_2 greenhouse gases is exogenous in the WorldScan model and table 8.4 displays the values of this emission factor. Table 8.4 additionally reveals, that coal emits the highest amount of carbon per unit energy use and the use of biomass and non-fossil fuels does not contribute to carbon emissions.

Table 8.4 Factors converting energy use (Mtoe) into carbon emissions (GtC)

	Emission factor *1000
Coal	1.00
Petroleum products	0.82
Gas and gas distribution	0.58
Biomass	0.00
Non-fossil fuels	0.00

A useful tool for decomposing carbon emissions is the so-called Kaya-identity (1990). This identity is discussed in a separate box below.

[68] The possibility of reducing emission by carbon sequestration is not yet included in the WorldScan model.

The Kaya identity

A useful tool for decomposing the CO_2 emissions, is the Kaya-identity (1990):

$$q^{EM} = pop \frac{y^{GDP}}{pop} \frac{q^{EN}}{y^{GDP}} \frac{q^{EM}}{q^{EN}}$$

where the emissions volume due to CO_2 greenhouse gases is factorised into population, gross domestic product per capita, energy intensity and carbon intensity. The next table gives a Kaya characterisation of the aggregated regions used in the Bollen *et al.* (2004^b).

Decomposition of CO_2 emissions according to the Kaya identity (2000)[a]

	Population (mln)	GDP (bln US$)	Energy (Mtoe)	Emissions (GtC)	Income/cap (US$cp)	E-intensity (USA=100)	C-intensity (USA=100)
United States	283	8 991	2 150	1.63	31 770	100	100
European Union	543	9 188	1 670	1.21	16 921	76	96
Russia	292	601	605	0.58	2 073	587	90
Rest Annex I	192	6 048	850	0.63	31 498	59	98
Annex I	1 310	24 832	5 520	4.05	18 955	93	97
Middle East	315	792	480	0.35	2 515	253	96
Latin America	514	2 056	520	0.36	3 999	106	91
Rest non-Annex I	3 917	4 077	1 041	1.70	1 039	204	113
Non-Annex I	4 746	6 925	3 000	2.40	1 459	181	106
Global	6 056	31 756	8 520	6.45	5 244	112	100

[a] Source: Bollen *et al.* (2004^b).

This multiplicative equation is conveniently rewritable in the form of relative changes (denoted by a 0 superscript):

$$(q^{EM})^0 = pop^0 + \left(\frac{y^{GDP}}{pop}\right)^0 + \left(\frac{q^{EN}}{y^{GDP}}\right)^0 + \left(\frac{q^{EM}}{q^{EN}}\right)^0$$

This additive form is quite suitable for analysing a policy shock: are the changes in emissions due to changes in economic growth, or changes in energy intensity of the economy, or is fuel switching taking place (carbon intensity)?

Methane and nitrous oxide emissions

The emissions of methane and nitrous oxide result from specific production processes.[69] Table 8.5 details the linkages between emission source, type of emissions, gas, and WorldScan production sector. Although most of the non-CO_2 greenhouse gases are covered in this table, a minor share is ignored: WorldScan does not account for emissions from landfills, sewage and

[69] This section is an abstract from the paper by Kets and Verweij (2005).

wood burning. These non-CO_2 emissions not accounted for in WorldScan amount to roughly 27% of all non-CO_2 related emissions in 2000.

Table 8.5 Non-CO_2 emission and corresponding WorldScan sectors

Emission source	Type	Gases	WorldScan sector (abbreviation)
Paddy rice	Land use	CH_4	Rice cultivation (pds)
Manure, enteric fermentation and animal waste	Land use	CH_4,N_2O	Livestock (liv)
Losses/leakage in coal production and transport	Energy	CH_4	Coal production (col)
Losses/leakage in oil production and transport	Energy	CH_4	Oil production (oil)
Losses/leakage in gas production and distribution	Energy	CH_4	Gas production and distribution (gas)
Fertilizer use	Land use	N_2O	Inputs of chemicals in agricultural sectors
Production of adipic and nitric acid	Industry	N_2O	Production of chemicals (pdr)

Data for non-CO_2 greenhouse gas emission are provided by the RIVM(2001). Table 8.6 presents a breakdown of these non-CO_2 emissions data fore some regions and emission sources. The sectoral composition of the emissions varies considerably over regions. Most notable, emissions from rice cultivation are only important in the WorldScan region Rest of World. The importance of emissions from the production of nitric and adipic acid and leakages in coal and gas production also varies strongly over regions. These non-CO_2 greenhouse gases account for a considerable share of the total emissions (CO_2 plus non-CO_2), ranging from roughly 15% in the USA, the Rest of OECD and the EU-15 countries to even 40% in Latin America.

Table 8.6 Regional and sectoral composition of non-CO_2 emissions (%) in WorldScan, 1997[a]

	USA	EU-15	Former Soviet Union	Eastern Europe	Rest OECD	Middle East	Latin America	Rest of World	World
Livestock	30	42	22	30	53	33	82	43	43
Paddy rice	1	0	1	0	5	3	2	24	11
Leakages coal	25	7	6	37	6	0	1	11	11
Leakages oil	3	1	4	1	2	12	4	1	3
Leakages gas	23	7	62	11	17	41	3	3	15
Fertilizer use	13	27	5	11	12	8	7	17	14
Adipic and nitric acid	6	16	1	11	6	1	1	1	3
Non-CO_2 gases[b]	14	14	25	20	13	22	41	31	23

[a] The share of the different sources is calculated relative to the total non-CO_2 emissions of non-CO_2 sources (weighted by their GWP) included in the model.
[b] The share of non-CO_2 gases is defined relative to the sum of the non-CO_2 and CO_2 emissions.
Source: WorldScan based on RIVM (2001).

WorldScan specifies non-CO_2 greenhouse gas emissions as the product of two distinct components: the production level and the emission factor, i.e. the emissions per unit of output:

$$q^{EM}_{sr,t} = EM^{F}_{sr,t}\, q^{S}_{sr,t} \tag{8.13}$$

with q^{EM} denoting the emissions volume, EM^{F} the emission factor and q^{S} the production level of the emission source. The subscripts s, r and t refer to the emission sector, region and time, respectively. Equation (8.13) for non-CO_2 emissions parallels equation (8.12) for CO_2 emissions. However, both the emission source and the emission factor contain some important differences between CO_2 and non-CO_2 emissions. Firstly, the CO_2 emissions are linked directly to the energy inputs in the production process by means of a fixed emission factor. By contrast, the emissions from a non-CO_2 emission source are influenced by a myriad of factors, which cannot be modelled explicitly in WorldScan. For example, emissions from paddy rice are influenced by nutrient, cultivar type and irrigation method (see e.g. Burniaux, 2000). Therefore, the emission factors for non-CO_2 are variable [70], and thus serve as catch-all variables. Secondly, the non-CO_2 emission per sector varies over time and over regions, while for CO_2 it is fixed for every sector.[71] WorldScan distinguishes two types of changes in emission factors: not climate policy related, exogenous changes, and climate policy related, endogenous changes. This first category of changes in emission factors is not prompted by some desire to decrease emissions, but stem from other considerations, such as technological developments, cost reduction and changes in lifestyle. For instance, farmers can decide to have more cows instead of sheep, thus affecting the emission factor of livestock-related sources. The reduction of the emission factors brought about by these autonomous changes is called Autonomous Emission Efficiency Improvement (AEEI). WorldScan derives the data for this AEEI from external sources, like the IMAGE SRES scenarios (RIVM, 2001). The second category of changes in emission factors will be the focus of the next chapter.

8.6 Climate policies

Given the large hazards of climate change due to greenhouse gas emissions, policy makers are induced to take action. An important instrument in controlling greenhouse gas emissions is the emission price. Before the introduction of a climate policy, emittants face zero costs for their greenhouse gas emissions. With the introduction of climate policy in the form of a carbon emission price, emittants are charged for their emissions. For carbon dioxide related emission, the emission price causes a rise in the user price of fossil fuels, and consequently a fall in the demand for fossil fuels by producers and consumers, resulting in less emissions. For non-CO_2

[70] There is one exception to this way of modelling emissions of non-CO2 greenhouse gases. Emissions from fertilizer use are treated similar to CO2 emissions, i.e. emissions are in fixed proportion to fertilizer input in agricultural sectors, and are not linked to any output level.

[71] Of course, the average emission intensity of CO_2 emitting sectors can vary both over regions and over time, as a result of a change in the input mix.

greenhouse gases, the emission price raises the output price for the emission sectors, leading to a reduced demand for these emission sectors, again resulting in fewer greenhouse gas emissions. Because the emission price is an instrument to reduce the greenhouse gas emissions to a predetermined target level, it is endogenous in the WorldScan model. However, for expositional reasons, this Chapter starts from taking the carbon emission price as exogenously given. The modelling of the emission price is treated separately for CO_2 and non-CO_2 greenhouse gases.

Taxing carbon dioxide emissions

Producers and consumers have to pay a price p^{EM} (in US$ / tCeq) for the greenhouse gas emissions resulting from fossil fuel use. The revenues of this emissions price R_{ff}^{EM} are returned to the regional households in a lump-sum fashion.

$$R_{ff}^{EM} = p^{EM} q_{ff}^{EM} = p^{EM} EM_{ff}^{F}\, q_{ff}^{D}, \qquad ff = \text{COL,GAS,PTR} \tag{8.14}$$

The emission factor EM^F in equation (8.14) is fuel-specific, but the emissions price p^{EM} is not. The emission factor differs according to the carbon content of the fuels; dirty coal becomes more expensive than cleaner natural gas (see also table 8.6). Fuel alternatives like biomass and non-fossil fuels emit no carbon dioxide and therefore the emissions payments R^{EM} are zero. The influence of the emissions price on the fuel price (and indirectly on the fuel demand) becomes more clear by redefining the emissions price as an ad valorem tax rate, i.e. a mark-up on the market price of fossil fuels. This emissions tax rate t^{EM} is expressed as:

$$t_{ff}^{EM} = \frac{R_{ff}^{EM}}{q_{ff}^{D}\, p_{ff}^{D,m}} = \frac{p^{EM} EM_{ff}^{F}}{p_{ff}^{D,m}} \tag{8.15}$$

The emission tax rate depends on the magnitude of the emission factor EM^F: the tax rate will be higher for fuels with a higher carbon intensity. This differs from the emissions price p^{EM}, which does not depend on the specific fuel.

The composition of the user price, i.e. the actual price producers (p) and consumers (p^C) have to pay for the use of economic goods, thus becomes:

$$\begin{aligned} p_{ff} &= p_{ff}^{D,m}\left(1 + t_{ff}^{EM} + t_{ff}^{F}\right) \\ p_{ff}^{C} &= p_{ff}^{D,m}\left(1 + t_{ff}^{EM} + t_{ff}^{C}\right) \end{aligned} \tag{8.16}$$

The market price for fossil fuels $p^{D,m}$ is equal for producers and consumers. Equation (8.16) conveys, that this market price for fossil fuels is modified for producers by two taxes: a general tax on inputs of the production process t^F, and a tax on carbon emissions t^{EM}. For consumers this becomes: a general tax on consumption t^C, and a tax on carbon emissions t^{EM}.[72]
Introducing a carbon emissions price (or equivalently a carbon tax), causing a rise in the user price of fossil fuels, has four major consequences:

[72] Thus, consumers bear part of the consequences of climate policies directly.

- The demand for energy by producers and consumers falls, resulting in a lower energy intensity for a region with a carbon tax.
- Fuel switching to lower carbon intensive energy carriers. A shift will take place from coal to natural gas, biomass and non-fossil fuels. The carbon intensity of a region will decrease.
- Sector specialisation in favour of energy extensive sectors. Due to the introduction of a carbon tax, the production costs of the energy intensive sectors will rise relatively to the energy extensive sectors. The demand of producers and consumers will therefore shift towards more energy extensive products.
- For regions with no carbon tax or a modest one, energy intensive products will become relatively cheaper relatively to regions with a substantial carbon tax. Consequently, the energy intensive sectors in these regions are likely to expand. This effect is called carbon leakage: regions with a carbon tax will lower their carbon emissions, but other regions with a smaller tax will increase their carbon emissions.

Taxing methane and nitrous oxide emissions

The equations for the tax on carbon dioxide emissions have their close analogue in a tax on methane and nitrous oxide emissions. For fertilizer use the tax is levied on the input of this emission source in the agricultural sectors, so the equations (8.14)-(8.16) are still appropriate. For the other non-CO_2 emitting sources the situation is somewhat different, because emissions are linked to the overall production process. Producers have to pay a price p^{EM} (in US$ / tCeq) for these non-CO_2 greenhouse gas emissions. The receipts of this emissions price R_s^{EM}, which are also additional production costs for the firm, are refunded to the regional households in a lump-sum fashion:

$$C_s^{EM} = R_s^{EM} = p^{EM} q_s^{EM} = p^{EM} EM_s^F q_{TIN,s} \qquad s = \text{PDR,LIV,COL,OIL,CRP} \tag{8.17}$$

with C^{EM} denoting the cost of non-CO_2 greenhouse gas emissions for the firms. Similarly to the method used for CO_2, this emissions price is transformed into an ad valorem tax rate:

$$t_s^{EM} = \frac{C_s^{EM}}{q_{TIN,s}\ p_s^S} = \frac{p^{EM} EM_s^F}{p_s^S} \tag{8.18}$$

with p^S being the agent price for producers, i.e. the output price of production before taxation. The equation for the market price of the production output then becomes:

$$p_s^{S,m} = p_s^S \left(1 + t_s^Q + t_s^{EM}\right) = p_{TIN,s} \left(1 + \mu\right) \left(1 + t_s^Q + t_s^{EM}\right) \tag{8.19}$$

The unit production cost p_{TIN} is augmented by a profit mark-up μ(exogenous), a general tax on the output t^Q of sector s, and an emissions tax t^{EM} based on the carbon equivalence content of the produced emissions.

The major consequence of the emissions tax on methane and nitrous oxide is a shift in sector structure: the demand of producers and consumers for these taxed products will decrease in

favour of non-taxed products. Thus, the agricultural sectors, the energy sectors and the chemical sectors will decrease in size. Furthermore, foreign sectors with lower or no emissions taxes will see their market share increase.
So far, the treatment of taxing carbon dioxide emissions and taxing methane plus nitrous oxide emissions are quite similar. However, the tax on non-CO_2 emissions also triggers technological change in the WorldScan model,[73] which will be the subject of the next section.

Induced technological change

Lowering the emissions factor of production for methane and nitrous oxide can not only be realised by autonomous developments, but also by induced technological change (ITC). This emission factor is represented in WorldScan by:

$$EM^F = EM^F_{tb}\ (1-r) \qquad \text{with } r = r_A + r_{ITC} \tag{8.20}$$

with EM^F_{tb} the emission factor in the base year. The reduction r is the sum of the autonomous reduction r_A and the endogenous reduction due to climate policy (i.e. imposing an emission price) r_{ITC}.

Technological emissions reduction introduces the possibility of decreasing the cost of emissions for firms. However, this emissions reduction stemming from induced technological change does not come for free. Total Factor Productivity (TFP) of sectors emitting non-CO_2 greenhouse gases will be lowered as a result of diverting part of the production resources to emissions abatement. The firm thus needs to decide how many resources to use on abatement: q^{ITC}. Generally, it will be optimal to abate part of the emissions, paying the emissions tax over the remainder. The optimum abatement level follows from profit maximisation.[74] In this case, the profit-function of the firm without ITC from Chapter 2:

$$\Pi = p^S\, q_{TIN} - p_{TIN}\, q_{TIN} \tag{8.21}$$

becomes for the firm with ITC:

$$\begin{aligned} \Pi &= p^S\, q_{TIN} - p_{TIN}\left(q_{TIN} + q^{ITC}_{TIN}\right) - p^{EM} EM^F\,(1-r)\left(q_{TIN} + q^{ITC}_{TIN}\right) \\ &= p^S\, A(r)\, q^{ACT}_{TIN} - p_{TIN}\, q^{ACT}_{TIN} - p^{EM} EM^F\,(1-r)\, q^{ACT}_{TIN} \\ &\quad \text{with} \quad q^{ACT}_{TIN} = q_{TIN} + q^{ITC}_{TIN} \quad \text{and} \quad A(r) = \frac{q_{TIN}}{q^{ACT}_{TIN}} \end{aligned} \tag{8.22}$$

with q^{ACT} defined as the activity level that equals the resources used for production plus resources used for abatement and A denoting the productivity index. When $r_{ITC} = 0$ the resources diverted to emissions abatement are zero and consequently $q^{ACT} = q$ and $A = 1$. We

[73] Equivalently for CO2 greenhouse gases, energy technology could be modelled as a function of the emission tax. However, this option is not available in WorldScan at this moment.

[74] More details on the derivation can be found in Kets and Verweij (2005).

assume that productivity is a decreasing and concave function of the emissions reduction r_{ITC} : the more resources are diverted to abatement, the less output is available for sale. The first-order condition for the optimal reduction reads:

$$\frac{\partial \Pi}{\partial r_{ITC}} = p^{S} A' \, q^{ACT}_{TIN} + p^{EM} EM^{F}_{tb} \, q^{ACT}_{TIN} = 0 \tag{8.23}$$

The firm chooses the optimal abatement level, maximising its profits. We assume free entry and thus zero profits, and postulate a particular simple form for p^{EM}:

$$p^{EM}(r_{ITC}) = \frac{\delta \, r_{ITC}}{(\varepsilon - r_A) - r_{ITC}} \qquad \text{for } \; 0 \leq r_{ITC} < \varepsilon - r_A \tag{8.24}$$

with ε denoting the technical limit to the possible emissions reduction and δ the speed of convergence to that limit. Combining the equations (8.22) to (8.24) yields a differential equation for the productivity index A as a function of r_{ITC}. Solving this equation gives the following expression [75] for the productivity index:

$$A(r_{ITC}) = \varsigma \, \left(-\phi \, (r_{ITC})^2 + \lambda \, r_{ITC} + (\varepsilon - r_A) \; p_{TIN} \right)^{\frac{1}{2}} \left(\frac{\eta + 2 \, \phi \, r_{ITC} - \lambda}{\eta - 2 \, \phi \, r_{ITC} + \lambda} \right)^{-\frac{\lambda}{2\eta}} \tag{8.25}$$
$$\text{with } \phi \; = \delta \, EM^{F}; \qquad \lambda = \phi \; (1 - r_A) - p_{TIN} \qquad \eta = (4 \, \phi \; p_{TIN} \, (\varepsilon - r_A) + \lambda^2)^{\frac{1}{2}}$$

with ς a constant of integration following from the constraint $A(0) = 1$. This constant of integration assures that the productivity index A equals 1 for the case of no tax on emissions. For positive emissions taxes, A will be lower than one. Firms can thus choose between paying the emissions tax and investing in pollution control (accepting a lower productivity).

Incorporating equation (8.25) in the WorldScan model requires the specification of values for the technical limit parameter ε and the speed of convergence parameter δ. Bottom up marginal abatement cost curves (MAC) from engineering studies[76] provide the necessary information. These MAC-curves contain the cost of abating the next incremental ton of greenhouse gas (expressed in US $ per unit mass of carbon equivalents) for each level of overall abatement. A MAC-curve is derived by ordering abatement opportunities by cost from low to high, and plotting the total abatement volume of each option. The dots in the left panel of Figure 8.3 provide an example of this bottom up information.

In order to estimate values for the parameters ε and δ, we regressed equation (8.24) to the data points of the MAC-curve. The left panel of Figure 8.3 shows this fitted equation for a particular set of bottom up MAC-data (leakages from coal mining, USA). As an illustration, the right panel graphs the corresponding productivity function A calculated from equation (8.25). In table 8.7 the estimated parameters are presented. An important consequence of the estimated

[75] This expression for A is quite complex, but simplicity lies in the underlying differential equation.

[76] All bottom up MAC curves are taken from the EPA (2003) (using the base energy price scenario, assuming a 5% discount rate and a zero tax rate), except for the MAC curves for paddy rice and fertilizer use, which are taken from Brown *et al.* (1999).

Figure 8.3 Data points and fit of a bottom up MAC curve and the corresponding productivity loss function

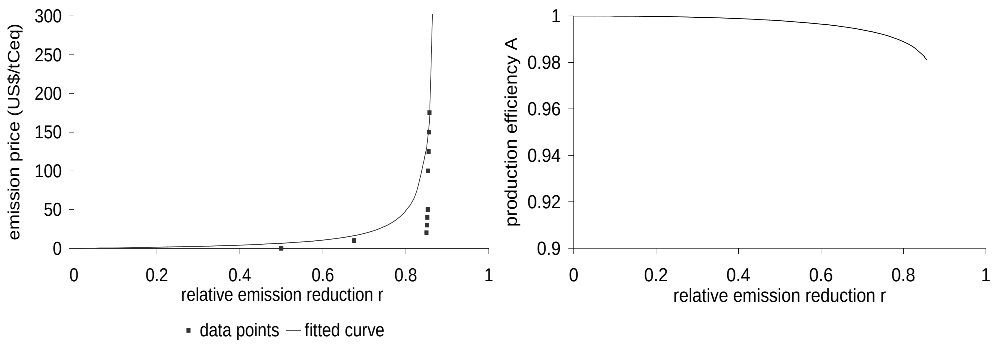


Table 8.7 Fit of the technical reduction limit ε and the speed of concergence δ for bottom up MAC curves

	Paddy rice	Leakages coal	Leakages oil	Leakages gas	Adipic and nitric acid production
ε-parameter					
Europe-15	.57	.52	1.00	.49	.92
USA	.57	.88	.21	.56	.92
Rest OECD	.57	.76	.29	.55	.92
Eastern Europe	.57	.73	1.00	1.00	.92
FSU	.57	.61	.38	.43	1.00
Middle East	.57	.86	.43	.60	1.00
Latin America	.57	1.00	.35	.59	1.00
Rest of World	.57	.80	.32	.53	.92
δ-parameter					
Europe-15	23.2	0.1	5.5	10.0	.05
USA	23.2	5.1	12.2	139.0	.05
Rest OECD	23.2	2.2	13.2	132.0	.05
Eastern Europe	23.2	0.1	1.8	142.0	.05
FSU	23.2	3.0	12.2	15.0	1.00
Middle East	23.2	0.1	5.5	119.0	1.00
Latin America	23.2	1.0	5.5	64.0	1.00
Rest of World	23.2	0.6	10.5	63.0	.05

parameters concerns the availability of large reduction possibilities at fairly low abatement costs. Thus, due to induced technological changes non-CO_2 greenhouse gases offer, compared to CO_2 gases, relatively cheap reduction options. The right panel of Figure 8.3 also examplifies these cheap options; productivity has only fallen about 3% at the reduction potential.

Several things can be noticed about this parameterisation. Firstly, as emissions are also reduced in the baseline through autonomous efficiency improvement, these reductions from AEEI have to be subtracted from the MAC-curves, as these options are no longer available. Therefore, given the specification used in equation (8.24), the MAC-curve intersects the x-axis ($p^{EM} = 0$) at the point where $r = r_A$. As the reduction share through AEEI generally increases over time, the corresponding MAC curve will shift to the right. In the long run, this development decreases the importance of reductions through Induced Technological Change.

Secondly, the set of MAC-data points from engineering studies suggests the availability of negative cost abatement options.[77] However, we assume that only positive costs for the no-regret options are left after subtraction of the autonomous reductions. The non-adoption of these options in the baseline indicates that the costs are positive in practice. One explanation is, that transaction costs may not have been fully accounted for, so that abatement options with negative costs actually present net positive costs. Also, some actors may not be aware of the existence of negative cost options, as the returns are likely to be small in the baseline. Acquiring this information also represents a form of costs, which is in general not included in MAC-curves.

A third issue concerns the limit to emissions reduction for an infinite emissions price. Two possible views exist in the literature on emissions. On the one hand, one could argue that even in the limit of infinite costs only a fixed fraction of the emissions can be abated. On the other hand, one could also argue that the introduction of climate policy will stimulate the development of new abatement options, as in Hyman *et al.* (2002).[78] However, the shape of the MAC-curve is then hard to predict, because the curvature of the MAC-curves for lower emissions prices is also likely to change. WorldScan adopts the conservative approach by assuming a fixed reduction potential. For the short run this seems a reasonable approach, but in the long run this assumption needs to be examined carefully by sensitivity analysis.

Emissions targets and permit trade

In the preceding Sections, equations were derived relating the emissions volume to an exogenous emissions price (tax). This approach might be useful for some issues, but in general the climate policies researcher faces another issue: how large is the emissions price that is necessary to meet an imposed emissions volume target? For instance, the Kyoto protocol commits the countries of the European Union to reduce their emissions volume of greenhouse gases in 2008-2012 to approximately 8 % below the 1990 level. This policy goal is implemented by targeting the emissions level using the emissions price as instrument. It is useful to distinguish two cases: one with permit trade between regions and one without.

In the first case, without emissions trade, regions have to meet their individual targets $\bar{q}^{EM}$ domestically:

$$\sum_g q_{g,r}^{EM}\left(p_r^{EM}\right) = \bar{q}_r^{EM} \qquad g = CO_2\,,\ nonCO_2 \tag{8.26}$$

[77] Negative cost options denote that emission reductions go hand in hand with overall efficiency improvement, leading to negative net costs. A well-known example is the capture and sale of methane in natural gas production. It is commonly assumed that these ‘no regret’ options are not implemented in the absence of climate policy because of transaction costs and so on.

[78] The bottom-up MAC curves only use currently existing abatement technologies or technologies which are incremental improvements on current technologies.

This implicit equation describes a quantity restriction on the regional emissions price, p^{EM}, making this emission price endogenous.

In the second case, regions again face an emissions target in the form of a limited number of emissions permits restricting greenhouse gas emissions to a certain level. In contrast to the first case, regions are allowed to buy and sell these permits on an international permit market. The overall emissions target of the abatement coalition will thus be reached, but individual regions can adjust their reduction efforts through trade in emissions permits. The economic appraisal for a region is: is it more cost efficient to buy permits or to abate pollution. As there exist large differences across regions in marginal costs of abatement, and therefore in the emissions price in the without trade situation, trade will be beneficiary for the welfare of all participating regions compared to a unilateral reduction policy. The implicit equation for the coalition emissions price is:

$$\sum_g \sum_r q_{g,r}^{EM}\left(p^{EM}\right) = \bar{q}^{EM} \qquad g = CO_2\,,\ nonCO_2 \tag{8.27}$$

For the participating regions in the abatement coalition, one emissions target $\bar{q}^{EM}$ and one uniform emissions price p^{EM} exist. However, regions differ in their reduction emission level q^{EM} due to differences in energy use, technology, sectoral structure, taxes, etc. Marginal abatement costs differentials make it efficient to trade emission rights; regions with higher marginal costs will purchase emission rights, while regions with lower marginal costs will sell them, [79] eventually eradicating the differences in marginal costs and emission price.

Furthermore, we have to add the income generated by trade in permits Y^{EM} to the definition of national income from Chapter 2:

$$Y_r^{EM} = \left(\bar{q}_r^{EM} - \sum_g q_{g,r}^{EM}\right) p^{EM} \tag{8.28}$$

For exporters of emissions permits, this income will be positive, while for importers it will be negative.

Until now, we assumed that every region of the abatement coalition exactly meets its emissions targets, whether it is by domestic reduction or by buying emissions permits. However, under the Kyoto protocol, the Former Soviet Union has such a large excess of emissions rights, that a mechanism for the banking of this so called ‘hot air’ has to be modelled. The textbox gives a description of this phenomenon.

This Chapter provides the information necessary to evaluate the effects of climate policies in WorldScan. In recent years, many studies have been conducted with this so called climate version of WorldScan. For instance: Winners and losers of Kyoto (Bollen *et al.*, 2000), and Four

[79] The degree of emission reduction a region needs to achieve affects the costs of reduction, which rise more sharply as targets become more rigorous and reductions more severe. This abatement curve varies across regions, specially the steepness of the curve.

Hot air in Russia

Emissions in Russia (and all other countries of the Former Soviet Union, FSU) dropped dramatically as a result of the economic transformation in the 1990's. Since assigned amounts, according to the Kyoto protocol, were based on 1990 levels of emissions, Russia is blessed with a large excess supply of emissions permits (hot air). This excess supply can be sold on the international market for emissions permits. Russia could decide to 'bank' the excess rights from the early years and 'use' them in later periods. In fact any country could use this strategy, but it wouldn't be profitable to them due to the modest excess of permits. In this way, the pain from serious abatement in later years can be alleviated at the cost of forsaken income from the export of emissions rights in the early years. This all depends on whether assigned amounts for Russia are indeed based on Kyoto targets, whether banking over a longer period is allowed for and on the permit price. The permit price depends on the market power selling parties can exercise. In our analysis we do not assume full intertemporal optimisation over the whole period. Instead, it is assumed that Russia optimises permit sales and passes its unused rights to the post-Kyoto period. In the first budget period of the Kyoto Protocol (2008-2012), countries from the FSU are the only suppliers. Maximising the profits from permit sales implies a banking rate b_{FSU} of 80%. The total amount of emissions rights banked in the first budget period B_{FSU} is determined by the next equation:

$$B_{FSU} = \sum_{t=2008}^{2012} b_{FSU}\ (\bar{q}^{EM}_{FSU,t} - q^{EM}_{FSU,t})$$

These banked emissions right are not sold in the first budget period, so a correction on the equation for income from permit trade Y^{EM}_{FSU} has to be made in this period:

$$Y^{EM}_{FSU,t} = (1 - b_{FSU}) \left(\bar{q}^{EM}_{FSU,t} - \sum_{g} q^{EM}_{g,FSU,t} \right) p^{EM}_{t}, \qquad t = 2008 - 2012$$

After the first budget period, more regions with hot air enter the market. Permit prices can be expected to stay low till emissions at a global level have risen significantly (from 2025 onwards).

futures for energy markets and climate change (Bollen *et al.*, 2004). Section 9.3 will elaborate on these applications.

9 Recent model applications

The usefulness of the modelling work on WorldScan derives from the policy-oriented analyses thus made possible. Recent applications highlighted in this chapter include long-term scenario studies, assessments of the impacts of EU-accessions and analyses of climate change policies.

9.1 Scenario studies

WorldScan was originally built for CPB's long-run scenario study 'Scanning the future' (CPB, 1992). Later on it was used in other scenario studies such as 'The World in 2020: towards a new global age' (OECD, 1992a) and in scenario analyses for the IPCC, the United Nations Intergovernmental Panel on Climate Change (Nakicenovic and Swart, 2000). Hence, a considerable part of the modelling work described in this publication – notably the sectoral desaggregation of TFP growth, the projection of labour supply, the redesign of consumer demand systems and the coverage of greenhouse gas emissions – was motivated by the desire to improve the usefulness of the model for scenario analyses.

Our most recent scenario studies are 'Four Futures of Europe' (De Mooij and Tang, 2003, and Lejour, 2003) and its companion 'Four Futures of Energy Markets and Climate Change' (Bollen, Manders and Mulder, 2004). The aim of these studies is to provide alternative baselines that can be used as a suitable background scenario for policy analysis in subsequent research. The 'Four Futures' studies elaborate on policy challenges that the European Union and the member states themselves will face during the coming decades in view of a number of social and international trends.

These scenarios serve two purposes. First, they provide a structure for discussing the uncertain future of Europe in a comprehensive and internally consistent framework. In this way, the scenarios may yield early warnings to policy makers about particular challenges in the future, *e.g.* with respect to necessary reforms of the public sector and the need for effective international cooperation. Second, the scenarios serve as a tool for policy analyses with a long-term character. Examples are environmental policy, infrastructure, energy, spatial issues and ageing. In particular, one can make a cost-benefit analysis of particular policy measures by thinking through their implications in each of the four scenarios.

Four Futures of Europe

As a tool for analysing these questions four alternative scenarios on the future of Europe are developed. It is hard to predict how the European Union and its members states will look like ten years from now, let alone twenty or thirty years ahead. Yet, policy makers must take decisions today that have long-lasting consequences, for example about infrastructure projects, welfare state reforms, and a transfer of control to international organisations.

The alternative scenarios depend on two groups of "key uncertainties". The first concerns international cooperation: to what extent are nation states willing and able to cooperate within international organisations like the WTO and the European Union? The second key uncertainty concerns national institutions: to what extent will the mix of public and private responsibilities change? Combining the two key uncertainties leads to four different scenarios:

- STRONG EUROPE
  Reforming the process of EU decision-making lays the foundation for a successful, strong European Union. The enlargement is a success and integration proceeds further, both geographically, economically and politically. Europe is the driving force behind broad international cooperation – not only in the area of trade, but also in other areas such as climate change and poverty reduction. European countries maintain social cohesion through public institutions, accepting that this course limits the possibilities of improving economic efficiency. Nevertheless, they cannot prevent that some groups in society lose (in relative terms). The reason is that governments respond to the growing pressure on the public sector by undertaking selective reforms in the labour market, social security and public production. Combined with early measures to accommodate the effects of ageing, this policy helps to maintain a stable and growing economy.

- GLOBAL ECONOMY
  Economic integration is broad and global. As countries find it in their mutual interest, the new WTO round succeeds and economic integration in an enlarging European Union intensifies. Closer cooperation in non-trade areas is not feasible; international organisations in these areas cannot overcome the problem of conflicting interests and freeriding. The problem of climate change intensifies. National institutions become increasingly based on private initiatives and market-based solutions. European governments concentrate on their core tasks, such as the provision of pure public goods and the protection of property rights. They engage less in income redistribution (not only between rich and poor but also between young and old) and public insurance. Incomes become more unequal, but grow relatively fast on average. Besides, social-economic mobility is high.

- TRANSATLANTIC MARKET
  Countries are reluctant to give up their sovereignty. Reforms of EU decision making fail. Instead, the European Union redirects her attention to the United States; they agree upon transatlantic economic integration. This yields welfare gains on both sides of the Atlantic. This, however, sharpens the distinction between the club of rich countries and the group of developing countries. Following social preferences for individual freedom and diversity, European countries limit the role of the state and rely more on market exchange. This boosts technology-driven

growth. At the same time, it increases inequality. The heritage of a large public sector in European countries is not easily dissolved. New markets, e.g. for education and social insurance, lack transparency and competition. The elderly dominate political markets. In this scenario, they effectively oppose comprehensive reforms of the pay-as-you-go systems in continental Europe.

- REGIONAL COMMUNITIES
  The European Union cannot adequately cope with the Eastern enlargement and fails to reform her institutions. As an alternative, a core of rich European countries emerges. More generally, the world is fragmented into a number of trade blocks, and multilateral cooperation is modest. European countries rely on collective arrangements to maintain an equitable distribution of welfare and to control local environmental problems. At the same time, governments in this scenario are unsuccessful in modernizing welfare-state arrangements. A strong lobby of vested interests blocks reforms in various areas. Together with an expanding public sector, this development puts a severe strain on European economies.

This broad spectrum of possible futures for Europe has been quantified with WorldScan by suitable variation of the exogenous variables (see Lejour, 2003). For instance, the extent of economic integration is quantified by adjusting trade barriers (chapter 7) and the extent of capital mobility (chapter 5), while the growth implied by (de-)emphasising considerations of efficiency is achieved by adapting technology parameters (chapters 2 and 3) and labour participation rates (chapter 4). Thus, through comprehensive experiments the key features and trends of the scenarios were shaped within an internally consistent framework. The quantitative range of possible economic futures that results from this is quite broad. Hence, impacts of specific policies are likely to depend upon the specific future that is chosen as a background for the analysis.

Four Futures of Energy Markets and Climate Change

As a sequel to the Four Futures of Europe study the uncertain developments of energy and climate systems have been analysed against the background of the four alternative scenarios. The main conclusions are that in the next decades global reserves of oil and natural gas will probably be sufficient to meet the growing demand. Hence there is no need to worry about a looming depletion of natural energy resources. The use of fossil energy carriers will, however, induce climate change because of the emissions of greenhouse gases.

In order to mitigate the global increase of temperature, greenhouse gas emissions should be reduced. Developing countries should contribute to that effort. On the one hand they will become the major emitters in the near future, on the other hand it is in the developing countries that low-cost abatement options abound. To keep costs manageable, all low-cost options need to be exploited. The improvement of energy-efficiency turns out to be the most efficient option to reduce emissions, followed by fuel-switching. The role of coal will diminish, but with large reduction targets even the share of natural gas will come under pressure. Carbon capture and storage and biological sequestration are projected to play a limited role. Exploiting alternative sources of energy is important. In STRONG EUROPE the share of non-fossil fuels (biomass, nuclear, wind, sun and hydropower) is projected to increase to almost 25%, compared to 6% in 2000. The costs of abating global warming depend on the stringency of the target and on the economic growth in the underlying scenario. In STRONG EUROPE the global GDP-loss in 2040 is projected to be less than 2% under a global cap-and-trade policy that is thought to be compatible with the EU-objective to limit global warming to 2^0 Celsius in this century. In this setting EU-15 would face climate change abatement costs that are somewhat higher than 2% of GDP.

WorldScan's energy and climate change version (chapter 8) has been used to analyse the future developments of energy and climate systems. If international coalitions to abate global warming are incomplete, carbon-leakage may occur, *i.e.*energy-intensive sectors may move to regions where CO_2-emissions are less penalised. Here, WorldScan's implementation of imperfect international capital mobility (chapter 5), is not unimportant as it tends to reduce carbon-leakage (see Bollen *et al.*, 2002).

9.2 Assessing the benefits of EU-accession

The accession of new member states in the EU inspired the work on non-tariff trade-barriers. One study explores the economic consequences of the enlargement of the European Union with countries from Central and Eastern Europe (Lejour *et al.*, 2004). Using gravity equations at the sectoral level the authors estimate the impacts of EU-membership on trade. Industrywise, this impact is (partly) modelled as a pre-accession non-tariff barrier for the candidate members (chapter 7). Hence, the study covers integration aspects that go beyond the reduction of formal trade barriers, assessing the full impacts of accession to the internal market. The results suggest that the candidate member states will gain substantially from accession to the internal market - consumption could increase by about 7.8% in the new member states , although some sectors in these countries will shrink. Most EU countries will experience small welfare increases. The internal market effects appear to be large compared to the economic effects of removing formal trade barriers and migration.

Similarly, in another study the impacts of the possible Turkish accession to the European Union are explored (Lejour and De Mooij, 2005). Three main changes are associated with Turkish membership: (i) accession to the internal European Market; (ii) institutional reforms in Turkey triggered by the requirements for EU-membership; and (iii) migration in response to the free movement of workers. Overall, the macroeconomic implications for EU countries are small but positive. This is caused by cheaper imports and the benefits from trade creation. Dutch exports, for instance, increase by around 20% (550 million euro). Turkey experiences larger economic gains than the EU: consumption per capita is estimated to rise by about 4% as a result of accession to the internal market and free movement of labour. If Turkey would succeed in reforming its domestic institutions in response to EU-membership, economic growth in Turkey could increase more. In particular, tentative estimates suggest that consumption per capita in Turkey could then rise by an additional 9%. These benefits would spill over to the EU, implying - for instance - an increase of Dutch exports to Turkey with another 1.8 billion euro.

9.3 Climate change policies

WorldScan has widely been used to analyse the consequences of climate change policies, often in close collaboration with the Netherlands Environmental Assessment Agency (MNP). A joint study assesses the economic impacts of implementing the Kyoto Protocol (Bollen *et al*., 2000). The options to prevent parties from postponing abatement actions are explored as well (Bollen *et al*., 2001). It turns out that moderate fines on exceeding abatement targets will suffice to ensure early action in the first Kyoto budget period. Another study analyses the sectoral relocation effects of climate change policies (Bollen *et al*., 2002). It addresses the fear that climate change policies will have a negative impact on economies and, particularly, will hurt energy-intensive sectors. Although the energy-intensive sector will have to carry a considerable part of the burden, the costs need not be large, depending on the implementation strategy.

In the aftermath of the scenario study on four futures for energy and climate change, several other studies were conducted that essentially convey the same message. For instance, Bollen, Manders and Veenendaal (2004) analyse the macroeconomic impacts of a climate policy that aims to reduce emissions of greenhouse gases of industrialised nations with 30% below 1990 levels in 2020. Such an effort is consistent with the European Union’s policy target to limit the increase of average world temperature to 2˚C in this century. The economic consequences of such a climate policy may vary widely. Against the background of the GLOBAL ECONOMY scenario the economic loss to the Netherlands is assessed as 0.8% of national income in 2020, provided that all countries implement the climate policy and efficient international emissions markets are in place. However, if developing countries do not join the abatement coalition, and only industrialised nations are engaged in abating global warming, the costs to the Netherlands may rise to 4.8% of national income. The costs depend of course on economic growth in the underlying scenario. In a scenario with a global abatement coalition and moderate economic growth (STRONG EUROPE), these costs will amount to 0.2% of national income.

A sequel to this report provides an analysis of additional scenarios over and above the 30% reduction case (Bollen, Manders and Veenendaal, 2005). In this way, policy makers are provided with a broader spectrum of alternative post-Kyoto policy scenarios and their implications. The policy options analysed are: coalitions with (much) less than global coverage, restrictions on emissions trading, full versus limited use of the Clean Development Mechanism (CDM), and less ambitious aims, reflected by raising caps or imposing fixed and relatively small carbon taxes. Alternative tradeoffs between abatement costs and abatement efforts are analysed in this context. Abatement costs in the benchmark case of a global coalition and unrestricted trade are relatively modest. Costs will rise considerably with smaller coalitions. A smaller coalition will induce migration of energy-intensive activities to non-participating countries. CDM will lower abatement costs in incomplete coalitions. However, seizing CDM opportunities will reduce emissions only in part due to domestic leakage in developing countries. Though carbon tax systems may be as effective in reducing emissions as cap-and-trade systems the compliance costs for participating countries may be quite different.

The studies referred to above focus on the abatement of CO_2 emissions only. Efficiency gains may be achieved when emissions of the other greenhouse gases are reduced *in tandem*. Hence, WorldScan has been adapted to include two other important greenhouse gases as well: methane and nitrous oxide (see chapter 8). The analysis of Kets and Verweij (2005) shows that a multi-gas abatement strategy can offer considerable efficiency gains because marginal abatement cost for the different emission sources are widely diverging. Their approach is consistent with bottom-up information on reduction possibilities for non-CO_2 greenhouse gases while it allows for general equilibrium effects and intergas interactions. Though the impacts of including non-CO_2 greenhouse gases are rather limited at the regional level, the sectoral impacts may be important. A considerable part of the burden of greenhouse abatement tends to be shifted to the agricultural sectors. Reductions of non-CO_2 gases could be especially important for countries like China and India.

9.4 Conclusion

The usefulness of the modelling work on WorldScan derives from the policy-oriented analyses thus made possible. As many of these are of a long term nature the availability of economic background scenarios is of prime importance. After all, impact assessments of specific policies may well differ with the choice of the economic background scenario. Originally, the development of WorldScan started from a desire to develop such scenarios within a consistent framework. In recent years WorldScan has again been deployed in scenario development, focussing on Europe and the trade-offs between equity and efficiency.

Against the background of alternative future developments many international policy issues have been addressed. Appendix C provides a reference listing of WorldScan policy studies that appeared since 2000. The analyses made with WorldScan in the past few years addressed EU-accession, trade policy issues, R&D spillovers and climate change policy impacts from an EU-perspective. In conducting international economic policy analyses we benefited considerably from WorldScan’s consistent, detailed and globally comprehensive view on economic trends and developments.

Today, policy coverage is being extended towards addressing internal market EU-policy and Lisbon policy issues as well. Examples are the assessment of the impacts of the EU Services Directive (de Bruijn *et al.*, 2006) and the 'what if'analysis of meeting some of the Lisbon targets (Gelauff and Lejour, 2006), in particular with respect to labour market participation, R&D expenditure, human capital, reduction of the administrative burden and liberalisation of the internal market for services. Our research agenda points to deeper analyses of these European issues. Hence, WorldScan is likely to be further adapted to meet the requirements that these policy questions pose. In order to improve the analysis of the internal market for services the model has already been extended with imperfect competition and increasing returns to scale (de Bruijn, 2006) while work is underway to also introduce foreign direct investments as a vehicle for the provision of services abroad. In view of the Lisbon agenda, an obvious other extension would be to endogenise the decision to participate in the labour market and to explain the equilibrium level of unemployment. Hence, as long as new policy questions are coming up that can be clarified within a general equilibrium framework, using and explaining WorldScan will continue to be a revolving challenge.

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Appendix A WorldScan equations for the core version

Labour market

Labour supply

$$l_r^S = lq_r^S\ pop_r \tag{A.1}$$

$$l_{i,r}^S = lq_{i,r}^S\ l_r^S \tag{A.2}$$

Unemployment

$$lu_{ir} = luq_{ir}\ l_{ir}^S \tag{A.3}$$

$$lu_r = \sum_i lu_{i,r} \tag{A.4}$$

$$luq_r = \frac{lu_r}{l_r^S} \tag{A.5}$$

Employment

$$l_{ir} = (1 - luq_{ir})\ l_{ir}^S \tag{A.6}$$

$$l_r = (1 - luq_r)\ l_r^S \tag{A.7}$$

Wages

$$w_{ir} = \frac{Q_{ir}}{l_{ir}} \tag{A.8}$$

$$w_r = \frac{\sum_i w_{ir}\ l_{ir}}{l_r} \tag{A.9}$$

Production

Factor cost prices

$$p_{ir} = w_{ir} \tag{A.10}$$

$$p_{LAB,sr} = \prod_i \left(\frac{p_{ir}}{\alpha_{isr}}\right)^{\alpha_{isr}} \tag{A.11}$$

$$p_{CPE,sr} = p_{CPE,r} \tag{A.12}$$

$$p_{FIX,sr} = \frac{Q_{FIX,sr}}{q_{FIX,sr}} \tag{A.13}$$

$$pe_{fsr} = \frac{p_{fsr}}{a_{fsr}} \qquad f\text{=all inputs} \tag{A.14}$$

$$p_{\,TIN,sr} = \left(\sum_f \alpha_{fsr}\ pe_{fsr}{}^{1-\sigma_{TIN,s}}\right)^{\frac{1}{1-\sigma_{TIN,s}}} \qquad f = \text{TIR,FIX} \tag{A.15}$$

$$pe_{\,TIR,sr} = \left(\sum_f \alpha_{fsr}\ pe_{fsr}{}^{1-\sigma_{TIR,s}}\right)^{\frac{1}{1-\sigma_{TIR,s}}} \qquad f = \text{TEV,TIM} \tag{A.16}$$

$$pe_{\,TEV,sr} = \left(\sum_f \alpha_{fsr}\ pe_{fsr}{}^{1-\sigma_{TEV,s}}\right)^{\frac{1}{1-\sigma_{TEV,s}}} \qquad f = \text{TVA,TEN} \tag{A.17}$$

$$pe_{\,TIM,sr} = \left(\sum_f \alpha_{fsr}\ pe_{fsr}{}^{1-\sigma_{TIM,s}}\right)^{\frac{1}{1-\sigma_{TIM,r}}} \qquad f = \text{all material inputs} \tag{A.18}$$

$$p_{\,TVA,sr} = \left(\sum_f \alpha_{fsr}\ pe_{fsr}{}^{1-\sigma_{TVA,s}}\right)^{\frac{1}{1-\sigma_{TVA,s}}} \qquad f = \text{LAB,CPE} \tag{A.19}$$

$$pe_{\,TVA,sr} = \frac{p_{TVA,sr}}{a_{TVA,sr}} \tag{A.20}$$

$$pe_{\,TEN,sr} = pe_{ENG,sr} \tag{A.21}$$

Technology and efficiency improvements

$$\mathring{y}^{GDP}_{c,r} = \left(\frac{y^{GDP}_{c,r}}{y^{GDP}_{c,r,\,t-1}} - 1\right) 100 \tag{A.22}$$

$$\mathring{a}_{TVA,r} = G(\mathring{y}^{GDP}_{c,r} = \hat{y}^{GDP}_{c,r}) \tag{A.23}$$

$$\mathring{a}_{TVA,sr} = \left(\mathring{a}_{TVA,r} + 1\right)\left(\bar{\mathring{a}}_{TVA,sr} + 1\right) - 1 \tag{A.24}$$

$$a_{TVA,sr} = a_{TVA,sr,\,t-1}\left(1 + \mathring{a}_{TVA,sr}\right) \tag{A.25}$$

Inputs and costs

$$Q_{TIN,sr} = p_{TIN,sr}\ q_{TIN,sr} \tag{A.26}$$

$$Q_{fsr} = Q_{TIN,sr}\ \alpha_{fsr} \left(\frac{p_{TIN,sr}}{pe_{fsr}}\right)^{\sigma_{TIN,s}-1} \quad f = \text{FIX,TIR} \tag{A.27}$$

$$Q_{fsr} = Q_{TIR,sr}\ \alpha_{fsr} \left(\frac{pe_{TIR,sr}}{pe_{fsr}}\right)^{\sigma_{TIR,s}-1} \quad f = \text{TEV,TIM} \tag{A.28}$$

$$Q_{fsr} = Q_{TEV,sr}\ \alpha_{fsr} \left(\frac{pe_{TEV,sr}}{pe_{fsr}}\right)^{\sigma_{TEV,s}-1} \quad f = \text{TVA,TEN} \tag{A.29}$$

$$Q_{fsr} = Q_{TIM,sr}\ \alpha_{fsr} \left(\frac{pe_{TIM,sr}}{pe_{fsr}}\right)^{\sigma_{TIM,s}-1} \quad f = \text{all intermediate inputs} \tag{A.30}$$

$$Q_{fsr} = Q_{TVA,sr}\ \alpha_{fsr} \left(\frac{pe_{TVA,sr}}{pe_{fsr}}\right)^{\sigma_{TVA,s}-1} \quad f = \text{LAB,CPE} \tag{A.31}$$

$$Q_{isr} = Q_{LAB,sr}\ \alpha_{isr} \tag{A.32}$$

$$Q_{CPE,r} = \sum_s Q_{CPE,sr} \tag{A.33}$$

$$q_{CPE,r} = \frac{Q_{CPE,r}}{p_{CPE,r}} \tag{A.34}$$

$$Q_{ENG,sr} = Q_{TEN,sr} \tag{A.35}$$

$$q_{fsr} = \frac{Q_{fsr}}{p_{fsr}} \quad f = \text{all inputs} \tag{A.36}$$

$$q_{FIX,sr} = q_{FIX,sr,\,t-1} \tag{A.37}$$

$$Q_{fr} = \sum_s Q_{fsr} \quad f = \text{all intermediate inputs} \tag{A.38}$$

Capacity

$$q^S_{sr} = q^D_{sr} \tag{A.39}$$

$$Q^S_{sr} = q^S_{sr}\ p^S_{sr} \tag{A.40}$$

$$Q^S_r = \sum_s Q^S_{sr} \tag{A.41}$$

Income

$$Y_{sr}^{VA} = Q_{sr}^{S} - \sum_f Q_{fsr} \qquad f = \text{all intermediate inputs} \tag{A.42}$$

$$Y_r^{VA} = \sum_s Y_{sr}^{VA} \tag{A.43}$$

$$Y_r^{GDP} = Y_r^{VA} + T_r \tag{A.44}$$

$$Y_r^{EXP} = C_r + I_r + X_r - M_r \tag{A.45}$$

$$y_r^{GDP} = \frac{\left(c_r \; p_{r,t-1}^{C} + i_r \; p_{r,t-1}^{I} + x_r \; p_{r,t-1}^{X} - m_r \; p_{r,t-1}^{M}\right)}{p_{r,t-1}^{GDP}} \tag{A.46}$$

$$Y_r^{NI} = Y_r^{GDP} + Y_r^{NFI} + Y_r^{TRF} \tag{A.47}$$

$$y_r^{TRF} = \frac{Y_r^{TRF}}{p_r^{C}} \tag{A.48}$$

$$y_r^{NI} = \frac{\left(c_r \; p_{r,t-1}^{C} + i_r \; p_{r,t-1}^{I} + x_r \; p_{r,t-1}^{X} - m_r \; p_{r,t-1}^{M} + y_r^{NFI} \; p_{r,t-1}^{NFI} + y_r^{TRF} \; p_{r,t-1}^{C}\right)}{p_{r,t-1}^{NI}} \tag{A.49}$$

$$p_r^{NI} = \frac{Y_r^{NI}}{y_r^{NI}} \tag{A.50}$$

$$y_{c,r}^{GDP} = 1000 \left(\frac{y_r^{GDP}}{pop_r}\right) \tag{A.51}$$

Consumption

Macro consumption

$$C_r = (1 - Sq_r)\, Y_r^{NI} \tag{A.52}$$

$$C_{c,r} = \frac{C_r}{pop_r} \tag{A.53}$$

$$U_{c,r} = B_r \prod_j (c_{c,jr} - \gamma_{c,jr})^{\alpha_{jr}} \tag{A.54}$$

$$U_r = U_{c,r} \; pop_r \tag{A.55}$$

$$c_r = \frac{C_r}{p_r^{C}} \tag{A.56}$$

$$c_{c,r} = \frac{c_r}{pop_r} \tag{A.57}$$

Sectoral consumption

$$Cq^{MIN}_{c,jr} = \frac{p^C_{jr}\ \gamma_{c,jr}}{C_{c,r}} \quad \text{(A.58)}$$

$$Cq^{MIN}_{c,r} = \sum_j Cq^{MIN}_{c,jr} \quad \text{(A.59)}$$

$$Cq_{jr} = Cq^{MIN}_{c,jr} + \alpha_{jr}\left(1 - Cq^{MIN}_{c,r}\right) \quad \text{(A.60)}$$

$$C_{jr} = Cq_{jr}\ C_r \quad \text{(A.61)}$$

$$c_{jr} = \frac{C_{jr}}{p^C_{jr}} \quad \text{(A.62)}$$

$$c_{c,jr} = \frac{c_{jr}}{pop_r} \quad \text{(A.63)}$$

$$C_{sr} = \sum_j \lambda_{jsr}\ C_{jr} \quad \text{(A.64)}$$

$$c_{sr} = \frac{C_{sr}}{p^C_{sr}} \quad \text{(A.65)}$$

Savings and Investments

Savings

$$S_r = Sq_r\ Y^{NI}_r \quad \text{(A.66)}$$

$$yl^{GDP}_r = 1000\left(\frac{y^{GDP}_r}{l_r}\right) \quad \text{(A.67)}$$

$$\mathring{yl}^{GDP}_r = \left(\frac{yl^{GDP}_r}{yl^{GDP}_{r,t-1}} - 1\right)100 \quad \text{(A.68)}$$

$$\Delta\mathring{yl}^{GDP}_r = \left(\mathring{yl}^{GDP}_r - \mathring{yl}^{GDP}_{r,t-1}\right)0.01 \quad \text{(A.69)}$$

$$\Delta Sq_r = \beta_{1,r}\ \Delta\mathring{yl}^{GDP}_{r,t-1} + \lambda_{1,r}\ \Delta pop_{45-,r} + \lambda_{2,r}\ \Delta pop_{65-,r} + \lambda_{3,r}\ \Delta pop_{65+,r} \quad \text{(A.70)}$$

$$Sq_r = Sq_{r,t-1} + \Delta Sq_r \quad \text{(A.71)}$$

Investment demand

$$i_r = k^E_r - (1 - \delta^K)\,k_r \quad \text{(A.72)}$$

$$I_r = i_r\ p^I_r \quad \text{(A.73)}$$

$$I_{sr} = \alpha^I_{sr}\ I_r \quad \text{(A.74)}$$

Capital markets

$$k_{r,t} = k^{E}_{r,t-1} \qquad (A.75)$$

$$k^{F}_{r} = k_r - q_{CPE,r} \qquad (A.76)$$

$$kq^{F}_{r} = \frac{k^{F}_{r}}{k_r} \qquad (A.77)$$

$$k^{E}_{r} = (1-\delta^{K})\, k_r + \left(\frac{S_r}{p^{I}_{r}}\right) \qquad (A.78)$$

$$W_r = k_r \; p^{I}_{r} \qquad (A.79)$$

$$p_{CPE,n} = G\left(\sum_{r} p^{K}\; \pi_r \; k^{F}_{r} = 0\right) \qquad n\text{= numerair region} \qquad (A.80)$$

$$\pi_r = \exp\left(\theta_r \; kq^{F}_{r}\right) \qquad (A.81)$$

$$p^{K} = \frac{p_{CPE,n}}{\pi_n} \qquad (A.82)$$

$$p_{CPE,o} = p^{K}_{w}\; \pi_o \qquad o\text{= non-numerair regions} \qquad (A.83)$$

$$r_r = \left(\frac{p_{CPE,r}}{p^{I}_{r}}\right) - \delta^{K} - o_r \qquad (A.84)$$

$$p^{NFI}_{r} = p_{CPE,r} \qquad (A.85)$$

$$y^{NFI}_{r} = k^{F}_{r} \qquad (A.86)$$

$$Y^{NFI}_{r} = y^{NFI}_{r}\; p^{NFI}_{r} \qquad (A.87)$$

Trade

Sectoral demand

$$Q_{sb}^{D,m} = \frac{C_{sb}}{\left(1+t_{sb}^{C}\right)} + \frac{I_{sb}}{\left(1+t_{sb}^{I}\right)} + \frac{Q_{sb}}{\left(1+t_{sb}^{F}\right)} \tag{A.88}$$

$$Qq_{\;shb}^{\;D} = \alpha_{shb} \left(\frac{p_{sb}^{D,m}}{p_{shb}^{D,m}} \right)^{(\sigma_s - 1)} \tag{A.89}$$

$$q_{shb}^{D} = \frac{Qq_{\;shb}^{\;D}\, Q_{sb}^{D,m}}{p_{shb}^{D,m}} \tag{A.90}$$

$$q_{sh}^{D} = \sum_{b} \frac{q_{shb}^{D}}{\left(1-t_{shb}^{N}\right)} \qquad s \neq \text{TRA} \tag{A.91}$$

$$q_{\;TRA,h}^{\;D} = \sum_{b} \frac{q_{\;TRA,hb}^{\;D}}{\left(1-t_{\;TRA,hb}^{\;N}\right)} + q_{\;INT,h}^{\;D} \tag{A.92}$$

Demand for international transport services

$$q_{\;INT,sb}^{\;D} = \sum_{h \neq b} \beta_{INT,shb}\, q_{shb}^{D} \tag{A.93}$$

$$q_{\;INT,b}^{\;D} = \sum_{s} q_{\;INT,sb}^{\;D} \tag{A.94}$$

$$Q_{INT}^{D} = p_{INT}^{m} \sum_{b} q_{\;INT,b}^{\;D} \tag{A.95}$$

$$\alpha_{INT,h,t} = Qq_{\;INT,h,t-1}^{\;D} \tag{A.96}$$

$$Qq_{\;INT,h}^{\;D} = \alpha_{INT,h} \left(\frac{p_{\;TRA,hh}^{\;D,m}}{p_{INT}^{m}} \right)^{1-\sigma_{INT}} \tag{A.97}$$

$$q_{\;INT,h}^{\;D} = \frac{Qq_{\;INT,h}^{\;D}\, Q_{INT}^{D}}{p_{\;TRA,hh}^{\;D,m}} \tag{A.98}$$

Import and export

$$x_{sh} = \sum_{b\neq h} \frac{q^D_{shb}}{\left(1-t^N_{shb}\right)} \tag{A.99}$$

$$X_{sh} = \sum_{b\neq h} q^D_{shb}\ p^S_{sh}\left(1+t^Q_{sh}\right)\left(\frac{1+t^X_{shb}}{1-t^N_{shb}}\right) \tag{A.100}$$

$$p^X_{sh} = \frac{X_{sh}}{x_{sh}} \tag{A.101}$$

$$M_{sb} = \sum_{h\neq b} q^D_{shb}\ p^S_{sh}\left(1+t^Q_{sh}\right)\left(\frac{1+t^X_{shb}}{1-t^N_{shb}}\right) \tag{A.102}$$

$$m_{sb} = \sum_{h\neq b} q^D_{shb}\ p^S_{sh,t-1}\left(1+t^Q_{sh}\right)\left(\frac{1+t^X_{shb}}{1-t^N_{shb}}\right)/p^M_{sb,t-1} \tag{A.103}$$

$$p^M_{sb} = \frac{M_{sb}}{m_{sb}} \tag{A.104}$$

$$x_{INT,h} = q^D_{INT,h} \tag{A.105}$$

$$p^X_{INT,h} = p^{D,m}_{TRA,hh} \tag{A.106}$$

$$X_{INT,h} = x_{INT,h}\ p^X_{INT,h} \tag{A.107}$$

$$m_{INT,b} = q^D_{INT,h} \tag{A.108}$$

$$p^M_{INT,b} = p^m_{INT} \tag{A.109}$$

$$M_{INT,b} = m_{INT,b}\ p^M_{INT,b} \tag{A.110}$$

$$X_h = \sum_{s,INT} X_{sh} \tag{A.111}$$

$$x_h = \sum_{s,INT} \frac{x_{sh}\ p^X_{sh,t-1}}{p^X_{h,t-1}} \tag{A.112}$$

$$p^X_h = \frac{X_h}{x_h} \tag{A.113}$$

$$M_b = \sum_{s,INT} M_{sb} \tag{A.114}$$

$$m_b = \sum_{s,INT} \frac{m_{sb}\ p^M_{sb,t-1}}{p^M_{b,t-1}} \tag{A.115}$$

$$p^M_b = \frac{M_b}{m_b} \tag{A.116}$$

Prices

$$p^S_{sr} = p_{TIN,sr}\left(1+\frac{\mu_S}{\sigma_{sr}-1}\right) \quad (A.117)$$

$$p^m_{INT} = \left(\sum_h \alpha_{INT,h}\left(p^S_{TRA,r}\left(1+t^Q_{TRA,r}\right)\right)^{1-\sigma_{INT}}\right)^{\frac{1}{1-\sigma_{INT}}} \quad (A.118)$$

$$p^{D,m}_{shb} = p^S_{sh}\left(1+t^Q_{sh}\right)\frac{\left(1+t^X_{shb}+t^M_{shb}\right)}{\left(1-t^N_{shb}\right)} + \beta_{INT,shb}\, p^m_{INT} \quad (A.119)$$

$$p^{D,m}_{sb} = \left(\sum_h \alpha_{shb}\left(p^{D,m}_{shb}\right)^{1-\sigma_S}\right)^{\frac{1}{1-\sigma_S}} \quad (A.120)$$

$$p^C_{sr} = p^{D,m}_{sr}\left(1+t_{sr}{}^C\right) \quad (A.121)$$

$$p^I_{sr} = p^{D,m}_{sr}\left(1+t_{sr}{}^I\right) \quad (A.122)$$

$$p_{fr} = p^{D,m}_{fr}\left(1+t_{fr}{}^F\right) \qquad f = \text{all material inputs} \quad (A.123)$$

$$p^C_{jr} = \prod_s\left(\frac{p^C_{sr}}{\lambda_{jsr}}\right)^{\lambda_{jsr}} \quad (A.124)$$

$$ph^C_r = \prod_j\left(\frac{p^C_{jr}}{\alpha_{jr}}\right)^{\alpha_{jr}} \quad (A.125)$$

$$\mathring{p}^C_{c,r} = 100\left(\left(\frac{U_{c,r,t-1}}{B_r}\right)ph^C_r + Cq^{MIN}_{c,r}\,C_{c,r} - C_{c,r,t-1}\right)/C_{c,r,t-1} \quad (A.126)$$

$$\mathring{p}^C_r = \mathring{p}^C_{c,r} \quad (A.127)$$

$$p^C_r = p^C_{r,t-1}\left(1+.01\,\mathring{p}^C_r\right) \quad (A.128)$$

$$p^I_r = \prod_s\left(p^I_{sr}\right)^{\alpha^I_{sr}} \quad (A.129)$$

Taxes

$$T^X_{sh} = \sum_b t^X_{shb}\,p^S_{sh}\left(1+t^Q_{sh}\right)\frac{Q_{shb}}{\left(1-t^N_{shb}\right)} \quad (A.130)$$

$$T^X_r = \sum_s T^X_{sr} \quad (A.131)$$

$$T^M_{sb} = \sum_h t^M_{shb}\,p^S_{sh}\left(1+t^Q_{sh}\right)\frac{Q_{shb}}{\left(1-t^N_{shb}\right)} \quad (A.132)$$

$$T^M_r = \sum_s T^M_{sr} \quad (A.133)$$

$$T^C_r = \sum_s \frac{t^C_{sr}\,C_{sr}}{\left(1+t^C_{sr}\right)} \quad (A.134)$$

$$T^I_r = \sum_s \frac{t^I_{sr}\,I_{sr}}{\left(1+t^I_{sr}\right)} \quad (A.135)$$

$$T^F_r = \sum_f \frac{t^F_{fr}\,Q_{fr}}{\left(1+t^F_{fr}\right)} \quad (A.136)$$

$$T^Q_r = \sum_s t^Q_{sr}\,Q^S_{sr} \quad (A.137)$$

$$T_r = T^X_r + T^M_r + T^C_r + T^I_r + T^F_r + T^Q_r \quad (A.138)$$

List of variables

Subscripts

r	region
b	region of destination
h	region of origin
s	sector
j	consumption category
f	input in production
i	labour input (low skilled and high skilled)
c	per capita
$t-1$	previous year

Superscripts

C	consumption
I	investment
X	exports
M	imports
F	intermediates (or foreign for capital markets)
Q	production output
D	demand
S	supply
E	expectations
K	capital services
m	in market prices

Labour market

pop_r	population (in millions, exogenous)
lsq_r	participation rate is labour supply as share of total population (exogenous)
lsq_{ir}	share of skill type in total labour supply (exogenous)
luq_{ir}	share of unemployed per skill type (exogenous)
l_r^S	total labour supply (in millions)
l_{ir}^S	labour supply of skill group i (in millions)
lu_{ir}	number of unemployed per skill type (in millions)
lu_r	total number of unemployed (in millions)
luq_r	share of unemployed in total labour supply
l_{ir}	employment level per skill type (in millions)
l_r	total employment (in millions)

w_r	average wage
w_{ir}	wages per skill type i

Production

α_{fsr}	cost share parameter for input f in sector s of region r
σ_{fs}	substitution parameter for nest f of sector s
p_{ir}	price of labour per skill type i
$p_{LAB,sr}$	price of labour
$p_{CPE,sr}$	price (user costs) of capital
$p_{FIX,sr}$	price for fixed factor
$q_{FIX,sr}$	supply volume for fixed factor
$Q_{FIX,sr}$	demand value for fixed factor
pe_{fsr}	effective costprice of input f
$p_{TIN,sr}$	costprice of total output
$pe_{TIR,sr}$	effective costprice TIR
$pe_{TIM,sr}$	effective costprice intermediate goods
$pe_{TEV,sr}$	effective costprice TEV
$p_{TVA,sr}$	costprice value added
$pe_{TVA,sr}$	effective costprice value added
pe_{TEN}	effective costprice energy goods
$y_{c,r}^{GDP}$	GDP per capita
$a_{TVA,rs}$	technology index of value added for sector s in region r
a_{fsr}	efficiency index of input f for sector s in region r
$\mathring{y}_{c,r}^{GDP}$	relative change in per capita GDP
$\hat{y}_{c,r}^{GDP}$	target for relative change in per capita GDP (exogenous)
$\mathring{a}_{TVA,r}$	relative change in technology level in region r
$\mathring{a}_{TVA,sr}$	relative change in technology level for sector s in region r
$\bar{\mathring{a}}_{TVA,sr}$	exogenous component of relative change in technology level for sector s in region r
Q_{fsr}	costs (value) of using input f in sector s
q_{fsr}	volume of input f used in sector s
$Q_{CPE,r}$	macro demand value for capital goods
$q_{CPE,r}$	macro demand volume for capital goods
q_{sr}^S	output volume supplied by producers in sector s
Q_{sr}^S	output value supplied by producers in sector s
Q_r^S	macro output value supplied by producers
Q_{fr}	macro value of demand for intermediate input f

Income

Y_r^{TRF}	value of secondary net foreign income transfers (exogenous)
y_r^{TRF}	volume of secondary net foreign income transfers
Y_{sr}^{VA}	sectoral value of value added
Y_r^{VA}	macro value of value added
Y_r^{GDP}	macro value of GDP
Y_r^{EXP}	macro value of final expenditures
y_r^{GDP}	macro volume of GDP
Y_r^{NI}	value of national income
y_r^{NI}	volume of national income
p_r^{NI}	price of national income
$y_{c,r}^{GDP}$	macro volume of GDP per capita

Consumption

α_{jr}	marginal budget-share parameter
$\gamma_{c,jr}$	subsistence parameter
B_r	scale parameter for the utility function
λ_{jsr}	share-parameter for the value of sector s used in consumption category c
C_r	macro consumption value
$C_{c,r}$	macro consumption per capita value
U_r	macro utility level
$U_{c,r}$	macro utility per capita level
c_r	macro consumption volume
$c_{c,r}$	macro consumption volume per capita
$Cq_{c,jr}^{MIN}$	share subsistence consumption of consumption category j in macro consumption value per capita
$Cq_{c,r}^{MIN}$	share subsistence consumption in macro consumption value per capita
Cq_{jr}	share consumption value of consumption category j
C_{jr}	consumption value of consumption category j
c_{jr}	consumption volume of consumption category j
$c_{c,jr}$	consumption volume of consumption category j per capita
C_{sr}	consumption value of sector s
c_{sr}	consumption volume of sector s

Savings and Investment

$\beta_{1,r}$	parameter for effect growth rate of GDP volume per employed worker on the savingsquote
$\lambda_{1,r}$	parameter for effect age cohort 25-45 on savingsquote

$\lambda_{2,r}$	parameter for effect age cohort 45-65 on savingsquote
$\lambda_{3,r}$	parameter for effect age cohort 65+ on savingsquote
$\Delta pop_{45-,r}$	difference in size age cohort 25-45 (exogenous)
$\Delta pop_{65-,r}$	difference in size age cohort 45-65 (exogenous)
$\Delta pop_{65+,r}$	difference in size age cohort 65+ (exogenous)
S_r	macro savings value
yl_r^{GDP}	GDP volume per employed worker
$\mathring{yl}_r^{GDP}$	growth rate of GDP volume per employed worker
$\Delta \mathring{yl}_r^{GDP}$	difference in the growth rate of GDP volume per employed worker
ΔSq_r	difference in savingsquote
Sq_r	savingsquote
δ^K	depreciation rate parameter for the capital stock
α_{sr}^I	share parameter for investment goods from sector s
i_r	macro investment volume
I_r	macro investment value
I_{rs}	macro demand value for investment goods from sector s
θ_r	parameter for sensitivity net foreign asset position on captal price
o_r	risk premium (exogenous)
$k_{r,t}$	volume of capital supply
k_r^F	volume of net foreign assets
kq_r^F	ratio of volume of net foreign assets to capital supply
k_r^E	volume of capital supply in the next period
W_r	wealth value
$p_{CPE,r}$	regional rental rate (user costs of capital)
π_r	international transportation costs
p^K	world rental rate
r_r	real interest rate
p_r^{NFI}	price of primary net foreign income transfers
y_r^{NFI}	volume of primary net foreign income transfers
Y_r^{NFI}	value of primary net foreign income transfers

Trade

α_{shb}	share parameters for the Armington equation
σ_s	substitution parameter for the sector s in the Armington equations
σ_{INT}	substitution parameter for the sector international services
$Q_{sb}^{D,m}$	demand value (in market prices) by region b for sector s
Qq_{shb}^D	share of region h in the demand value by region b for sector s
q_{shb}^D	demand volume by region b for sector s produced in region h

q^D_{sh} demand volume for sector s produced in region h

$q^D_{TRA,h}$ demand volume for transport services produced in region h

$q^D_{INT,sb}$ demand volume by sectors in region b for international transport services

$q^D_{INT,b}$ macro demand volume in region b for international transport services

Q^D_{INT} value of international transport services on the world market

$\alpha_{INT,h}$ share-'parameter' of region h in the demand for international transport services

$Qq^D_{INT,h}$ share of region h in the demand value for international transport services

$q^D_{INT,h}$ volume of international transport services produced in region h

x_{sh} sectoral export volume from region h

X_{sh} sectoral export value from region h

p^X_{sh} sectoral export price from region h

M_{sb} sectoral import value to region b

m_{sb} sectoral import volume to region b

p^M_{sb} sectoral import price to region b

$x_{INT,h}$ export volume of international trade services from region h

$p^X_{INT,h}$ export price of international trade services from region h

$X_{INT,h}$ export value of international trade services from region h

$m_{INT,b}$ import volume of international trade services to region b

$p^M_{INT,b}$ import price of international trade services to region b

$M_{INT,b}$ import value of international trade services to region b

X_h macro export value from region h

x_h macro export volume from region h

p^X_h macro export price from region h

M_b macro import value to region b

m_b macro import volume to region b

p^M_b macro import price to region b

Prices

μ_s profit markup scaling-factor per sector

p^S_{sr} producer (supply)price for sector s

p^m_{INT} market producer price for international transport services on the world market

$p^{D,m}_{shb}$ market price demand in region b for goods and services from sector s from region h

$p^{D,m}_{sb}$ market price demand in region b for goods and services from sector s

p^C_{sr} consumer price for sector s

p^I_{sr} investors price for sector s

p_{fr} user price for intermediate f

p^C_{jr} consumer price for consumption category j

ph^C_r help variable with a macro consumer price

$\mathring{p}^{C}_{c,r}$ relative change in macro consumption (utility) price per capita

$\mathring{p}^{C}_{r}$ relative change in macro consumption price

p^{C}_{r} macro consumption price

p^{I}_{r} macro investment price

Taxes

t^{X}_{shb} tax rate in region *b* on exports of sector *s* to region *b* (exogenous)

t^{M}_{shb} tax rate in region *b* on imports of sector *s* from region *h* (exogenous)

t^{N}_{shb} non-trade barrier for sector *s* imports in region *b* from region *h* (exogenous)

t^{C}_{sr} tax rate on consumption per sector (exogenous)

t^{I}_{sr} tax rate on investment per sector (exogenous)

t^{F}_{fr} tax rate on intermediate goods (exogenous)

t^{Q}_{sr} tax rate on production per sector (exogenous)

T^{X}_{sh} sectoral incidence export taxes per region *h*

T^{M}_{sb} sectoral incidence import taxes per region *b*

T^{X}_{r} regional incidence export taxes

T^{M}_{r} regional incidence import taxes

T^{C}_{r} regional incidence consumption taxes

T^{I}_{r} regional incidence investment taxes

T^{F}_{r} regional incidence intermediate good taxes

T^{Q}_{r} regional incidence production taxes

T_{r} total tax income

Appendix B Country and sector classifications

At the most detailed level WorldScan may distinguish the GTAP sectors presented in Table B.1 and the countries and regions presented in Table B.2.

Table B.1 Sector classifiication

Number	Code	Description	Number	Code	Description
1	PDR	Paddy Rice	30	LUM	Wood products
2	WHT	Wheat	31	PPP	Paper products, publishing
3	GRO	Cereal grains nec	32	P_C	Petroleum, coal products
4	V_F	Vegetables, fruits, nuts	33	CRP	Chemical, rubber, plastic products
5	OSD	Oil seeds	34	NMM	Mineral products nec
6	C_B	Sugar cane, sugar beet	35	I_S	Ferous metals
7	PFB	Plant-based fibres	36	NFM	Metals nec
8	OCR	Crops nec	37	FMP	Metal products
9	CTL	Bovine cattle, sheep, goats, horses	38	MVH	Motor vehicles and parts
10	OAP	Animal products nec	39	OTN	Transport equipment nec
11	RMK	Raw milk	49	ELE	Electronic equipment
12	WOL	Wool, silk-worm cocoons	41	OME	Machinery and equipment nec
13	FRS	Foretry	42	OMF	Manufacure, distribution
14	FSH	Fishing	43	ELY	Electricity
15	COA	Coal	44	GDT	Gas manufacture, distribution
16	OIL	Oil	45	WTR	Water
17	GAS	Gas	46	CNS	Construction
18	OMN	Minerals nec	47	TRD	Trade
19	CMT	Bovine meat products	48	OTP	Transport nec
20	OMT	Meat products nec	49	WTP	Water transport
21	VOL	Vegetable oils and fats	50	ATP	Air transport
22	MIL	Dairy products	51	CMN	Communication
23	PCR	Processed rice	52	OFI	Financial services nec
24	SGR	Sugar	53	ISR	Insurance
25	OFD	Food products nec	54	OBS	Other business services
26	B_T	Beverages and tobacco products	55	ROS	Recreational and other services
27	TEX	Textiles	56	OSG	Public Administration, education, etc.
28	WAP	Wearing apparel	57	DWE	Dwellings
29	LEA	Leather products			

Source: GTAP-6 database.

Table B.2 Country classificiation

Number	Code	Description	Number	Code	Description
1	AUS	Australia	45	IRL	Ireland
2	NZL	New Zealand	46	ITA	Italy
3	XOZ	Rest of Oceania	47	LUX	Luxembourg
4	CHN	China	48	NLD	The Netherlands
5	HKG	Hong Kong	49	PRT	Portugal
6	JPN	Japan	50	ESP	Spain
7	KOR	Korea	51	SWE	Sweden
8	TWN	Taiwan	52	CHE	Switzerland
9	XEA	Rest of East Asia	53	XEF	Rest of EFTA
10	IDN	Indonesia	54	XER	Rest of Europe
11	MYS	Malaysia	55	ALB	Albania
12	PHL	Philippines	56	BGR	Bulgaria
13	SGP	Singapore	57	HRV	Croatia
14	THA	Thailand	58	CYP	Cyprus
15	VNM	Vietnam	59	CZE	Czech Republic
16	XSE	Rest of Southeast Asia	60	HUN	Hungary
17	BGD	Bangladesh	61	MLT	Malta
18	IND	India	62	POL	Poland
19	LKA	Sri Lanka	63	ROM	Romania
20	XSA	Rest of South Asia	64	SVK	Slovakia
21	CAN	Canada	65	SVN	Slovenia
22	USA	United States	66	EST	Estonia
23	MEX	Mexico	67	LVA	Latvia
24	XNA	Rest of North America	68	LTU	Lithuania
25	COL	Colombia	69	RUS	Russian Federation
26	PER	Peru	70	XSU	Rest of Former Soviet Union
27	VEN	Venezuela	71	TUR	Turkey
28	XAP	Rest of Andean Pact	72	XME	Rest of Middle East
29	ARG	Argentina	73	MAR	Morocco
30	BRA	Brazil	74	TUN	Tunesia
31	CHL	Chile	75	XNF	Rest of North Africa
32	URY	Uruguay	76	BWA	Botswana
33	XSM	Rest of South America	77	ZAF	South Africa
34	XCA	Central America	78	XSC	Rest of South African Customs Union
35	XFA	Rest of FTAA	79	MWI	Malawi
36	XCB	Rest of Caribbean	80	MOZ	Mozambique
37	AUT	Austria	81	TZA	Tanzania
38	BEL	Belgium	82	ZMB	Zambia
39	DNK	Denmark	83	ZWE	Zimbabwe
40	FIN	Finland	84	XSD	Rest of SADC
41	FRA	France	85	MDG	Madagascar
42	DEU	Germany	86	UGA	uganda
43	GBR	United kingdom	87	XSS	Rest of Sub Saharan Africa
44	GRC	Greece			

Source: GTAP-6 database.

The classifications used in the Four Futures scenario studies are as follows

Table B.3 Regional concordance between WorldScan and GTAP in Four Futures scenarios

Germany	
France	
United Kingdom	
The Netherlands	
BLU	Belgium, Luxembourg
Italy	
Spain	
Rest EU	Sweden, Denmark, Finland, Ireland, Austria, Portugal, Greece,
Central Europe	Poland, Hungary, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia
Former Soviet Union	Russion Federation, Rest of Former Union
Turkey	
United States	
Rest OECD	Japan, Australia, New Zealand, Canada, Switzerland, Rest of EFTA
Latin America and Caribbean	Mexico, Argentina, Brazil, Chile, Uruguay, Venezuela, Colombia, Peru, Rest of Anean Pact, Rest of South America, Central America, Rest of FTAA Rest of Caribbean
Middle East and North Africa	Rest of Middle East, Morocco, Tunisia, Rest of north Africa
Rest World	Rest of North America, Estonia, Lavtia, Lithuania, Albania, Croatia, Cyprus, Malta Rest of Europe, Botswana, South Africa, Rest of South African Customs Union, Malawi Mozambique, Tanzania, Zambia, Zimbabwe. Rest of SADC, Madagascar, Uganda Rest of Sub Saharan Africa, Rest of Oceania, China, Hong Kong, Korea, Taiwan Rest of East Asia, Indonesia, Mlaysia, Philippines, Singapore, Thailand, Vietnam Rest of Southeast Asia, Bangladesh, India, Sri Lanka, Rest of South Asia

Table B.4 Sectoral concordance between WorldScan and GTAP in Four Futures scenarios

Agriculture	Paddy rice, Wheat, Grains, Cereal grains, Non grain crops, Vegetables, Oil seeds Sugar cane Plant-based fibres, Crops, Bovine cattle, Animal products, Raw milk Wool, Forestry, Fisheries
Energy	Refined Petrol and Coal, Gas, Coal, Electricity
Other raw materials	Oil, Minerals
Food processing	Processed rice, Meat products, Vetetable oils, Dairy products, Sugar, Other food products, Beverages and tobacco
Consumption goods	Textile, Wearing Apparel, Leather products, Wood products, Other manufacturing
Printing, paper and publishing	Printing, paper and publishing
Chemicals and minerals	Chemicals, Rubber and Plastics, Mineral Products
Metals	Nonferrous Minerals, Ferrous Minerals
Capital goods	Fabricated Metal Products, Machinery and Equipment, Other Transport Industries Motor Vehicles and parts, Electronic equipment
Transport services	Water, Air and oter transport
Trade services	Trade services
Communication	Communication
Construction	Construction
Financial services	Insurance, Other financial services
Other business services	Other business services
Other services	Gas manufacturing and distribution, Water, Recreational services, Government services

Appendix C Recent WorldScan policy applications

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