

An economy model for GISMO

DART-PBL technical documentation

Background Studies

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Netherlands Environmental Assessment Agency

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© Netherlands Environmental Assessment Agency (PBL), may 2009
PBL publication number 550025003

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Summary

An economy model for GISMO

The Global Integrated Sustainability Model (GISMO), developed at the Netherlands Environmental Assessment Agency (PBL), is a platform for analysing the complexity of sustainable development and human well-being with regards to the three sustainability domains: People, Planet, and Profit (PPP). The economic structure of the GISMO1.0 model is the International Futures model, developed at the University of Denver. To better address price behaviour in the model, the Computable General Equilibrium (CGE) model DART, developed by the Kiel Institute for the World Economy, was included in the GISMO framework and integrated with the International Futures model. The DART model is tuned to the needs of the GISMO project, and is further referred to as DART-PBL. This report provides an overview of the main changes and additions to the original DART model. The changes and additions include: 1) region and sector aggregation compatible with the GISMO framework; 2) human capital accumulation based on demographics, educational attainment and health level to better address human well-being; 3) introduction of a Linear Expenditure System to distinguish between basic and luxury consumption; 4) adjusted savings to take into account different saving patterns of a changing population structure; 5) heterogenic land prices linked with the IMAGE framework to address land scarcity and environmental impacts; and 6) partial labour mobility between agricultural and non-agricultural sectors, to assess changes in income distribution.

Keywords: Economy modelling, Computable General Equilibrium model (CGE), DART, Technical documentation

Rapport in het kort

Een economiemodel voor GISMO

Het Global Integrated Sustainability Model (GISMO), ontwikkeld door het Planbureau voor de Leefomgeving (PBL), is een platform van modellen dat bedoeld is om duurzame ontwikkelingsvraagstukken te analyseren. Het maakt daarbij gebruik van de drie duurzaamheidsdomeinen: People, Planet, Profit (PPP). De economische structuur van GISMO1.0 is het International Futures model, ontwikkeld door de University of Denver. Om prijswerking in het model beter te kunnen beschrijven is het Computable General Equilibrium (CGE) model DART, ontwikkeld door het Kiel Institute for the World Economy, geïntegreerd met het International Futures model. Het DART model is aangepast aan de behoeften van het GISMO project en wordt verder aangeduid als DART-PBL. Dit rapport geeft een overzicht van de belangrijkste aanpassingen en toevoegingen ten opzichte van het originele DART model. Deze aanpassingen en toevoegingen bestaan uit: 1) een regio- en sectorindeling die aansluit bij GISMO; 2) accumulatie van menselijk kapitaal gebaseerd op ontwikkelingen in demografie, onderwijs en gezondheid; 3) introductie van een Linear Expenditure System dat onderscheid maakt tussen basis- en luxe-consumptie; 4) aangepast spaargedrag dat rekening houdt met een veranderende leeftijdsstructuur; 5) introductie van heterogene landprijzen gekoppeld aan het IMAGE model om zo het effect van landschaarste en milieuveranderingen op voedselprijzen te kunnen beschrijven; en 6) partiële mobiliteit van arbeid tussen landbouw- en niet-landbouwgerelateerde sectoren om veranderingen in inkomensverdelingen te kunnen analyseren.

Trefwoorden: Economische modelering, Computable General Equilibrium model (CGE), DART, technische documentatie, GISMO

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Introduction



The Global Integrated Sustainability Model (GISMO), developed at the Netherlands Environmental Assessment Agency (PBL), is a platform for analysing the complexity of sustainable development and human well-being with regards to the three sustainability domains: People, Planet, and Profit (PPP) (Hilderink and Lucas, 2008). The economic structure of the GISMO1.0 model is the International Futures model (Hughes and Hillebrand, 2006), developed at the University of Denver. To better address price behaviour in the model the Computable General Equilibrium (CGE) model DART, developed by the Kiel Institute for the World Economy (IfW), was included in the GISMO framework and integrated with the International Futures model. DART replaces the economic core of IFs economy with respect to production, consumption and international trade, retaining the poverty module and the established links with government budget allocation and expenditures in education and health services. The DART model is tuned to the needs of the GISMO project and is further referred to as DART-PBL. The main purpose of this report is to give an overview of the main changes and additions to the original DART model (Klepper *et al.*, 2003).

1.1 CGE in brief

CGE models (or Applied General Equilibrium (AEG) models) are based on a well-funded, microeconomic framework, and describe the entire economy (Shoven and Whalley, 1992; Ginsburgh and Keyzer, 1997; Conrad, 1999; Dellink, 2005; Ignaciuk, 2006). They have become standard tools for analysing different policy instruments on the budgetary, environmental and trade terrains, as they allow to predict changes in, for example, prices, output and welfare, resulting from a change of policy; and, given this policy change, consumer behaviour and information on technology (Hertel *et al.*, 2006).

CGE models consist of a set of 'economic agents' (consumers, producers, (often) government), each of which demands and supplies commodities or 'goods'. Agents are assumed to behave rationally. Each agent solves its own optimization problem. Firms are grouped together into production sectors. Households are grouped into household groups, and when all households behave identically, they are aggregated into one representative consumer. Mostly, producers operate under constant returns to scale and full competition, and maximise profits, subject to their production technologies, for given

prices¹. Consumers maximise their relative satisfaction from, or desirability of, consumption of various goods and services (utility), subject to their budget constraints.

There are three main conditions that a CGE model has to meet: those of (i) zero profits, (ii) income, and (iii) market clearance. The essence of CGE models is that prices of all goods are determined within the model, such that all the conditions are met, simultaneously.

The *zero profit condition* means that the value of output has to equal the value of all input. If companies operate under full competition, they will never be able to reap any excess profits². In the case of imperfect competition, profits are also counted as input.

The second condition is the *income condition*. Households maximise their utility, subject to a budget constraint, against given prices and given initial endowments. The income condition means that, in a static model, their expenditures (consumption and savings) cannot exceed their income. In dynamic models, a temporal budget deficit/surplus is possible, because of intertemporal borrowing. Households receive their income as payments for the supply of endowments (labor and capital) and from tax revenues.

The economy is in equilibrium if all agents can satisfy their demand for, or supply of goods, given a set of (relative) market prices common to all agents. In other words, total demand (by consumers, firms and government plus exports) must equal total supply, on all markets (domestically produced plus imports)³. For the primary production factors, the demand for, for example, capital, labour, and land, has to

1 It is also possible to model imperfect competition and increasing returns to scale – e.g. oligopoly with a small number of firms and homogeneous goods, or monopolistic competition models with a large number of firms producing differentiated goods.

2 When firms can obtain any profits, it will induce a new firm to compete on that market (in the absence of entry barriers). Then the total supply of produced goods will increase, which leads to price reductions. Lower prices will then decrease profits for both existing and new companies. This process continues until the excess profits equal zero.

3 If excess demand exists, the price of goods can be increased: this leads to an increase in supply and, thus, a decrease in demand. Eventually, an equilibrium price emerges, whereby supply equals demand. The exact opposite occurs, when an excess supply exists. To achieve equilibrium for several markets, simultaneously, a more elaborate procedure is needed, because of the interactions between markets (Dellink, 2005).

equal the endowments. This is referred to as *market clearance condition*. Equilibrium is attained through adjusting the relative prices. The resulting prices are called equilibrium prices.

CGE models are based on principles of input-output models, where substitution is allowed, and prices are determined within the model. CGE models can be seen as a system of non-linear equations, which can be solved, simultaneously. The economy can be described in the CGE model as a set of balances: for every demand there is a supply. This implies that all financial flows in the model are closed. In an open economy, because of international trade, the flow of physical goods is not closed, but the condition under which the trade deficit is exactly matched by domestic consumers' budget deficit implies that financial flows are also closed in an open economy specification. This feature of closed (financial) flows is often referred to as a fully closed economy cycle, and is a major distinction between CGE models and partial equilibrium models, in which such closure is not necessarily imposed. In a CGE model, not only the direct policy effects on companies and households are taken into account, but also the indirect effects. These indirect effects are caused by changes in the behaviour of companies and households, and imply that a policy that influences one market will also have an impact on other markets (Dellink, 2005).

The main advantages of the CGE format are: (i) it describes the whole economy in a consistent manner; (ii) all economic agents are taken into account and their behaviour is well described by microeconomic (neoclassical) theory; (iii) it allows for a variety of policy analysis (including taxation, economic development, allocation of goods, trade, welfare); (iv) agents are able to adapt (change in behaviour) via to endogenous price changes; and (v) because of the economic inter-linkages, secondary policy impacts are shown.

The main disadvantages are: (i) the economic agents often operate on a highly aggregated level; (ii) data requirements, especially data on behavioural assumptions, are difficult to obtain (substitution parameters); and (iii) the main assumptions is about rationality of consumers.

1.2 History of DART

The Dynamic Applied Regional Trade (DART) model was developed by the Kiel Institute for the World Economy (IfW), in the late 1990s. It was designed for the analyses of international climate policies; mainly, to assess the allocative and distributional impacts of the Kyoto Protocol (Klepper *et al.*, 2003). The first DART version (DART93) was based on data from the Global Trade Analysis Project (GTAP), version 3.

DART93 was used for simulating the implementation of the Kyoto Protocol via unilateral action (e.g. emission taxes) (Klepper and Springer, 2003), as well as for investigating the impacts of international capital mobility (Springer, 2002a; Springer, 2002b). In addition, DART93 was coupled to an ocean-atmosphere model to assess the economic impacts of climate change (Kurtze and Springer, 1999; Deke *et al.*, 2001). Later, at the beginning of the new century, DART was updated to run on the GTAP5 data set for 1997, which pro-

vided, for example, disaggregated data for the western and some eastern European countries. At the same time prevailing issues in the debate on the Kyoto Protocol, such as different regimes for international emission trading and the implementation of the European Emission Trading Scheme (ETS), led – via several extensions of DART93 – to DART97 (see Klepper *et al.*, 2003, for an updated brief model description). DART97 was used for assessing issues, such as the role of ‘hot air’ in the Kyoto Protocol (Klepper and Peterson, 2005), the stability of marginal abatement cost curves (Klepper and Peterson, 2006a), and the efficiency of the European ETS (Klepper and Peterson, 2004, 2006b).

Currently, DART is running on GTAP6 data for 2001. The latest model developments at the IfW include the integration of first-generation biofuels (Kretschmer *et al.*, 2008; Kretschmer and Peterson, 2009) and the modelling of technology transfer via trade and FDI. Furthermore, a collaboration between the IfW and PBL started, which led to the joined development of a new DART version – DART-PBL – integrated into the GISMO Model. One of the first projects with this model focuses on the demographic aspects influencing the economy, such as size, quality and health of the labour force. For more details, see Ignaciuk *et al.* (2008).

DART-PBL

2

The DART model is a recursive-dynamic computable, general equilibrium (CGE) model of the world economy. DART is multi-regional, multi-sectoral, based on the GTAP6 data set (Dimaranan, 2006). DART-PBL has 24 regions and 12 sectors (Table 2.1 and 2.2 and Appendix) which can be easily disaggregated by GTAP classification to up to 87 regions and 57 sectors of the GTAP6 data set.

For the static part of DART-PBL, the original GTAP6 data were converted into a GAMS readable format, with the help of the tool GTAPtoGAMS (Rutherford and Paltsev, 2000). The dynamic framework is recursive-dynamic, meaning that the evolution of the economies over time is described by a sequence of single-period static equilibria, connected through capital accumulation and changes in labour supply. The economic structure of DART-PBL is fully specified for each region, and covers production, investment and final consumption by consumers and the government. Primary factors are labour (skilled and unskilled, urban and rural), land, and capital. Labour and capital are inter-sectorally mobile within a region, but cannot move between regions. Land-use curves are used

to determine the land supply. Fossil-fuel resources are specific to fossil-fuel production sectors, that is, coal, natural gas, and crude oil, in each region.

The economic structure is region-specific, and output and factor prices are flexible. The model distinguishes three types of agents: producers, representative consumers and governments. The following sections describe producer and consumer behaviour, foreign trade, factor markets, and the calculation of carbon dioxide emissions that are the basis for climate policy analyses.

2.1 Production

Producers are characterised by cost-minimising behaviour for a given output, at constant returns to scale. For the non-fossil-fuel industry sectors, a multi-level nested constant elasticity of substitution describes the technological possibilities in domestic production (Figure 2.1). On the top level of the production function, there is a linear (Leontief) function (CES_{in} ;

Region definition

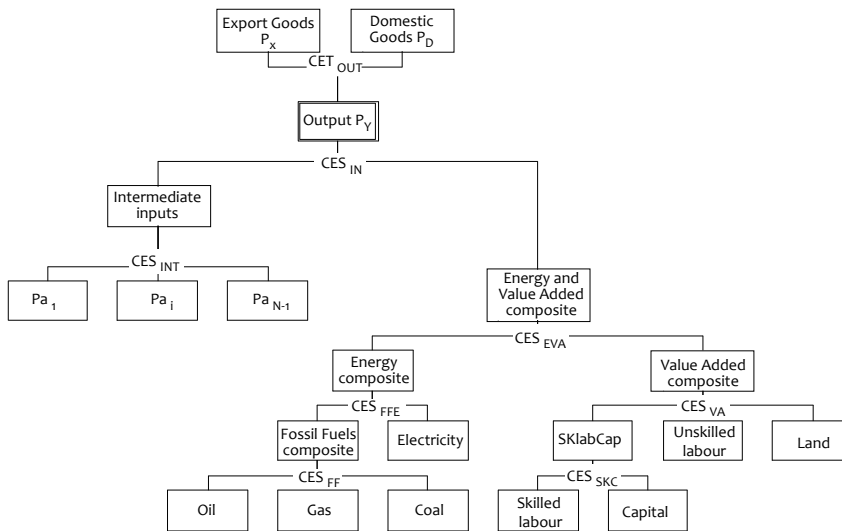
Table 2.1

Abbreviation	Region	Abbreviation	Region
CAN	Canada	ASTAN	Asia –Stan
USA	USA	RUS	Russia
MEX	Mexico	MEA	Middle East
RCAM	Rest Central America	IND	India
BRA	Brazil	KOR	Korea
RSAM	Rest South America	CPA	China
NAF	Northern Africa	SEAS	Southeastern Asia
WEAF	Sub-Saharan Africa	IDN	Indonesia
SAF	South Africa	JPN	Japan
WEU	Western Europe	OCN	Oceania
CEU	Central Europe	RSAS	Rest of South Asia
TUR	Turkey	RSAF	Rest of Southern Africa

Sectoral division

Table 2.2

Abbreviation	Sector	Abbreviation	Sector
AGR	Agricultural sector	GAS	Gas
ANIM	Animal sector	PET	Petroleum sector
FOOD	Food processing	ELE	Electricity
FORE	Forestry	MAN	Manufactures
COAL	Coal	PUB	Public administration
OIL	Crude oil	SERV	Services



$\sigma=0$) of Intermediate Inputs and an Energy and Value Added composite. The Intermediate Goods i in sector j correspond to a so-called Armington aggregate of non-energy input from domestic production and imported varieties (CES_{INT} ; $\sigma=0$). The Energy and Value Added composite is a function of an Energy composite and a Value Added composite (CES_{EVA} ; $\sigma=0.5$). The Value Added composite is a Cobb-Douglas function between the aggregate of skilled labour and capital (CES_{SKC} ; $\sigma=1$), and the rest of primary factors (CES_{VA} ; $\sigma=1$). In the Energy composite (CES_{FFE} ; $\sigma=0.75$), Electricity is combined with a Fossil Fuels composite (CES_{FF} ; $\sigma=1.5$), containing oil, gas and coal. On the output side, products destined for domestic and international markets are treated as imperfect substitutes (CET_{OUT} ; $\sigma=2$).

The differentiation between energy and non-energy intermediate products is useful in the context of climate change policy. Energy use in production and consumption varies between products. Emissions of greenhouse gases (GHGs), here only carbon dioxide (CO_2), depend on the fossil-fuel source only. Emissions from other sources, for example, deforestation are not considered in the model, and neither are the other GHGs: methane (CH_4), nitrous oxide (N_2O), ozone, and halocarbons. The fossil fuels (gas, coal and crude oil) are produced from fuel-specific resources and a composite of all other sectors and factors (Section 2.4.4).

2.2 Consumption

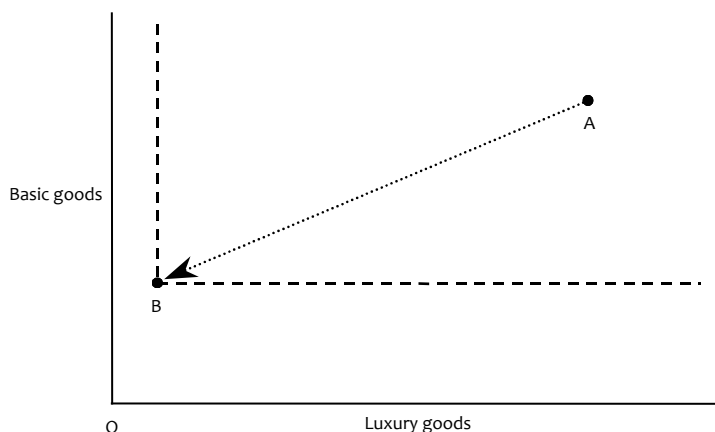
As in the standard CGE, consumers maximise their utility functions subject to their budget constraints. They purchase different goods depending on their relative prices, to obtain the consumption (utility) against the lowest expenditure. A share of income is saved (and invested in production sectors). These shares differ across regions, and are adjusted to the age structure of the populations (Section 2.5.1). Taxes are collected by the government. Producer behaviour is characterised by cost minimisation, for a given output, under the assumption of constant returns to scale. Produced goods are

directly demanded by consumers (regional households and government), the investment sector, other industries, and the export sector.

The CES utility function with unitary income elasticities, as used in the previous version of DART, implies that if income increases, *ceteris paribus*, there will be no changes in the composition of the consumption bundle. In reality, some commodities can be characterised as basic commodities, that is, commodities which have a relatively large share in consumption when income is low, and a declining share when incomes rise. At the same time, with rising incomes, certain luxury commodities will increase their share in total consumption. Basic commodities have an income elasticity of less than one, while luxury commodities have income elasticities above unity.

One way to introduce non-unitary income elasticities into the model is to use the Linear Expenditure System (LES) approach (Stone, 1954). The representative consumer is split into two categories: a ‘subsistence consumer’ and a ‘surplus consumer’. The subsistence consumer category represents the consumer’s basic demand. It is specified as a Leontief function, that is, no substitution possibilities for different consumption commodities, with an exogenously given size. The surplus consumer category reflects how additional income is spent, and has positive substitution elasticities for the different consumption commodities. Though the surplus (sometimes called ‘supernumerary’) part of consumption has unitary income elasticities, total consumption does not. This is so, because for every commodity the division in ‘subsistence’ and ‘surplus’ is different. For basic commodities, the major part of consumption is attributed to the subsistence consumer, while for luxury commodities a relatively large part is attributed to the surplus consumer. Intuitively, one can think of the introduction of the subsistence consumer as changing the origin for the utility function of private households.

The LES split in the consumption of private households is carried out as follows:



$$C_{j,t}^{subs.} = \left(1 - \frac{\eta_j}{cst}\right) \cdot C_{j,t} \quad \text{and} \quad C_{j,t}^{super} = \left(\frac{\eta_j}{cst}\right) \cdot C_{j,t} \quad (1)$$

where η_j is the income elasticity for commodity j and $C_{j,t}$ is the total consumption of commodity j in period t . The elasticities of income come from the US department of Agriculture, and are reported in .

Dellink (2005) suggests choosing the scaling factor for subsistence quantities as follows:

$$C_{j,t}^{subs.} = \left(1 - \frac{\eta_j}{\text{Max}_k \{\eta_k\}}\right) \cdot C_{j,t} \quad (2)$$

This transformation results in a base quantity equal to zero for the commodity with the highest income elasticity, and positive base quantities for all other commodities. If inferior commodities are excluded from the model (which can be done without problems, given the level of aggregation), all surplus quantities are also positive. The intuition behind the transformation function is that the constant cst only determines how much of total consumption is assigned to the surplus part of consumption, but does not influence the elasticities. It should be noted that the subsistence quantities are a modelling construct, and, as such, do not directly represent survival rates of consumption (e.g. for food) or the ‘lower fundamental needs’ in the Pyramid of Maslow. The scaling factor, however, can be used to calibrate ‘empirically meaningful’ subsistence quantities. The implementation in this project follows Dellink (2005) for calibrating to the base year of the model (2001). The application of LES in Dellink (2005) concerns a forward-looking Ramsey-type model. Therefore, a separate updating procedure is implemented here, to fit the LES structure to the Solow-Swan model set-up of DART-PBL. Following Van der Mensbrugghe (2005), the subsistence quantities are updated every year for regional population growth.

Figure 2.2 illustrates how the linear expenditure system changes income elasticities (following Gerlagh *et al.*, 2001). Point A in the figure represents the current consumption bundle, while point B gives the consumption bundle attributed to the subsistence consumer. If income decreases, the subsistence consumption remains constant, so that surplus

consumption shifts linearly from A to B, instead of shifting linearly from A to the origin O. In this way, a decrease in the total consumption by private households will lead to a more than proportionate decrease in total consumption of luxury commodities, and a less than proportionate decrease in total consumption of basic commodities. The transformation constant, cst , determines where point B is on the line through A and B, without affecting the slope of this line.

In effect, the (intertemporal) utility function is of the Stone-Geary type:

$$u(c_i) = \frac{(c_i - c_i^{subs.})^{(1-\theta_i)} - 1}{(1-\theta_i)} \quad (3)$$

where θ refers to the inverse of the intertemporal elasticity of consumption (see for example Philips, 1974; or Barro and Sala-i-Martin, 1995, for more details).

Consumer income is allocated to the surplus part of consumption, from which a fixed part is transferred to the subsistence part (modelled as a lump-sum transfer). This ensures that the subsistence part of consumption does not react to the policy impulse. In the presentation of the results, the subsistence and surplus parts are grouped together, as they represent only one representative consumer.

The subsistence quantities can be scaled, as only their magnitudes relative to each other are essential for creating the appropriate income elasticities. Therefore, an empirically relevant level of subsistence consumptions can easily be implemented. Given the aggregated nature of the commodities in the model, such a scaling should, however be executed with care. Note also that the specification implemented in this project already involves the correction of subsistence quantities for population growth.

One further development in the specification of household consumption behaviour that can be implemented relatively easily, is the incorporation of an ELES consumption function. The ELES function is an extension of the standard LES function. It includes savings, as part of the demand system. An excellent example of an application using the ELES demand system in recursive-dynamic modelling is the ENV-LINKAGES

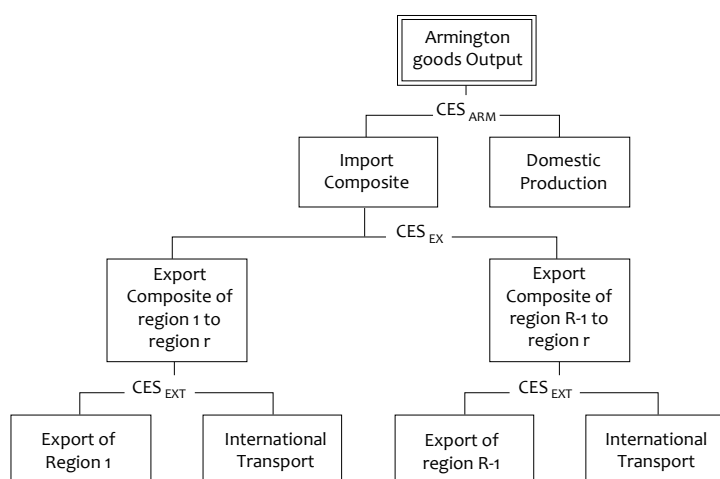
	Low income	Medium income	High income
Agricultural sector	0.73	0.58	0.29
Animal sector	0.73	0.58	0.29
Food processing	0.97	0.97	0.97
Forestry	0.73	0.58	0.29
Coal	1.00	1.00	1.00
Crude oil	1.00	1.00	1.00
Gas	1.00	1.00	1.00
Petroleum sector	1.24	1.18	1.16
Electricity	1.24	1.18	1.16
Manufactures	0.90	0.88	0.86
Public administration	1.40	1.20	1.16
Services	1.59	1.32	1.24

* Income is classified according to the US income: up to 15% low, 15-50% medium, and above 50% high income.

Elasticities of income in high, medium and low income* countries as modified from United States Department of Agriculture (Regimi *et al.*, 2001).

Structure of foreign trade

Figure 2.3



model of OECD (2008). For more information on ELES, see Luch (1973) and Howe (1975). Rimmer and Powell (1996) provide an interesting alternative demand system, AIDADS, with attractive properties, but this alternative is much less popular in applied models.

2.3 Foreign Trade

The world is divided into economic regions, which are linked by bilateral trade flows. All goods are traded between regions, except for the investment good. Domestic and foreign goods are imperfect substitutes (Armington, 1969), and are distinguished by country of origin. Demand distinguishes between imported and domestically produced goods, as well as between countries of origin.

The structure of foreign trade is shown in Figure 2.3. The imports of one region are equivalent to the exports of all other regions to that region, including transports. Transport costs, distinguished by commodity and bilateral flow, apply to international trade, but not to domestic sales. Exports

are connected to transport costs by a Leontief function on the third level. International transports are treated as a worldwide activity which is financed by domestic production proportional to the trade flows of each commodity. There is no special sector for transports related to international trade.

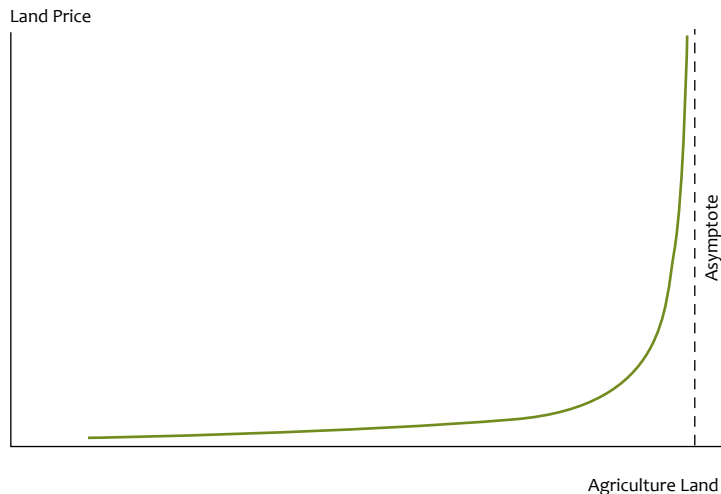
On the export side, the Armington assumption applies to final output of the industry sectors destined for domestic and international markets. Here, produced commodities for the domestic and international markets are imperfect substitutes. Exports are not differentiated by the country of destination.

2.4 Factor Markets

Factor markets are perfectly competitive; all factors are utilised. Factor prices adjust, so that supply equals demand.

2.4.1 Labour

Labour is divided into two categories: high and low skilled, which are provided by the GTAP6 database, and differentiated according to educational achievement. High-skilled



labour encompasses workers with completed secondary education. Choosing for educational achievement rather than for professional status of employees, allows for a better indication of labour endowments in the region, and it catches the differences in labour quality between the regions more accurately (CPB, 1999). Labour is mobile across industries within regions, but not on an international level.

Labour is further disaggregated into urban and rural labour. Following the World Bank approach (Van der Mensbrugge, 2005), we assume that workers employed in the agricultural, animal and forestry sectors, belong to the rural part of the labour force, and the rest is classified as urban. Thanks to such aggregation, we can trace the migration aspects of workers, though only nationally. This might play an important role in, for instance, agricultural markets analyses.

The development of the labour force over time is described in Section 2.5.2

2.4.2 Capital

Capital is inter-sectorally but not internationally mobile. Regional capital stocks are determined at the beginning of each time period, resulting from the capital accumulation equation.

The development of capital accumulation over time is described in Section 2.5.3

2.4.3 Land

In the original DART version, land was provided in fixed supply. In reality, land supply will react to changes in demand. In the model, such demand is revealed through developments in price levels of land. As supply is fixed, any increase in demand can only result in a price increase, as in the equilibrium framework the aggregate demand and supply have to be equal.

In DART-PBL, the fixed factor constraint is released by adding an explicit land-supply function, following the LEITAP methodology (Tabeau *et al.*, 2006; Woltjer and Tabeau, 2008)

Land supply is a function of an average land price (Figure 2.4). This land price is calculated as a weighted average of land prices for different land types. The asymptote shows the maximum amount of land that is available for agriculture. The basic information on the land-use curve comes from the land suitability curve, as used for the land allocation in the IMAGE model (Bouwman *et al.*, 2006). For each cell in IMAGE, 0.5 times 0.5 degrees, land suitability is calculated based on a very rough indicator function. Suitability is the sum of indexed suitability between 0 and 500 for: i) population density, ii) distance to main water infrastructure, and iii) a random factor, with land productivity having a negligible influence. It adds an indicator between 0 and 1 to the calculated suitability, where cells with land productivities of less than 10% of the maximum are not included in the land allocation procedure. This implies that there are differences in land productivities of cells with the same suitability. Land is allocated from highest to lowest land suitability, starting from the current land allocation.

An elastic land supply, that is, a supply that responds to price changes, can be formulated using supply-price elasticity. Following the collaborative work of PBL and LEI in the successful linking of the IMAGE and LEITAP models (Banse *et al.*, 2008), a land-supply curve can be estimated and used to determine land supply, endogenously. The formula suggested by Banse *et al.* (2008) is:

$$LS_r = A - \alpha_0 \cdot (P_r^{LS})^{-\alpha_1} \quad (4)$$

where LS is land supply, A is the total land available for agriculture, PLS is the price of land, and α_0 and α_1 are coefficients specified per region. Woltjer and Tabeau (2008) provide detailed information on the calibration of this curve.

In CGE models, land is not provided in hectares, but as an aggregate commodity in billions of dollars. Following the Harberger convention, all benchmark prices are equal to one, and benchmark quantities reflect benchmark values. Thus, the land-supply curve cannot be implemented directly. The activity level of land use in the model, however, corresponds directly with physical changes in land use; one percent addi-

tional land use, in model terms, implies one percent more land use in hectares. Similarly, prices in hectares vary proportionally with variations in the model price of land. These properties can be exploited to specify a rationing constraint on land use in the model.

We used information that is available from IMAGE on benchmark land supply in hectares per region, $LS(r)$, the asymptote A and elasticity $ELAS$, and an extra entity for calculation of the parameters a_0 and a_1 . Subsequently, we calculated the benchmark rental rate, per hectare, per region, $PLS(r)$. By definition, in the benchmark, the value of land in model terms equals the value of land in hectares, where $evom('land', r)$ is the benchmark endowment of land per region r , and $pevom('land', r)$ is the benchmark rental rate of land use per region r :

$$evom_{land,r} \cdot pevom_{land,r} = LS_r \cdot PLS_r, \quad (5)$$

Following the Harberger convention, all benchmark prices are equal to one ($pevom_{land,r} = 1$), and benchmark quantities reflect benchmark values. The endogenous price level acts as a multiplier for the benchmark rental rate, that is, actual price level in the model simulations equals $pevom_{land,r} \cdot pf_{land,r}$, but as $pevom$ equals one, this variable can be ignored in the rest of this analysis. By definition, in equilibrium, total demand equals total supply, and therefore demand for land does not need to be considered here.

Note that prices in hectares vary proportionally with variations in the model price of land, that is, the endogenous price of land per hectare equals $PLS_r \cdot pf_{land,r}$.

These properties can be exploited to specify a rationing constraint on land use in the model. A multiplication factor for physical land use can be applied directly to ration land supply in the model. The rationing multiplier on land use in the model is denoted as $LANDRAT(r)$, it follows that rationing land supply as $landrat_r \cdot evom_{land,r}$ in line with the land-supply curve given above, is realised through calculating $LANDRAT(r)$, using:

$$landrat_r \cdot LS_r = A - a_0 \cdot (PLS_r \cdot pf_{land,r})^{-a_1} \quad (6)$$

The benchmark values for $LANDRAT(r)$ and $pf('land', r)$ equal unity, and, thus, the rationing constraint in this case corresponds directly to the calibrated land-supply curve.

2.4.4 Fossil fuels

Fossil-fuel production (coal, natural gas, and crude oil) is described by a two-stage nested CES production function (see Figure 2.5). At the lower nest, the intermediate input of labour, capital and fossil fuel is aggregated in fixed proportions, that is, with a Leontief technology ($CES_{CG}; \sigma=0$). At the top level, this aggregates substitutes for the sector-specific fossil-fuel resources at constant elasticities of substitution ($CES_{IN}; \sigma=0.75$). This elasticity is calibrated such that carbon emissions by 2030 will meet the projections of the IEA (2008).

Gas and coal each have fixed carbon content. To calculate the associated carbon dioxide emissions, the physical quantities of gas and coal, used in either domestic production or

domestic consumption (which is given in the GTAP data), are multiplied by their emission coefficient.

For oil emissions, the calculation is more complicated. To determine the CO₂ emissions which originate from the use of crude oil in the different production and consumption processes, one needs to know at which point in the value-added chain this fossil fuel is actually burned, leading to emissions. In the current model, crude oil only enters the production of refined oil products where it is not burned. Only refined oil products are burned when used as input in production or as final consumption goods, leading to CO₂ emissions. The domestic use of crude oil cannot be used for determining CO₂ emissions, since some of these oil products are exported while others are imported; hence, there is no one-to-one correspondence between crude oil consumption and emissions. Since crude oil is the emission relevant input in refined oil production, only the crude oil share can be used for determining CO₂ emissions. The emission coefficient for crude oil is set to 0.02 KgC/MJ (IPCC, 1997). Refined oil consumption is composed of domestically produced and imported oil products. Both may have different carbon contents due to different input shares of crude oil in the production of refined oil products. The crude oil share in the production of oil products in region r is given by:

$$crush(r) = \frac{vafm(cru, oil, r)}{vdm(oil, r) + vxm(oil, r)} \quad (7)$$

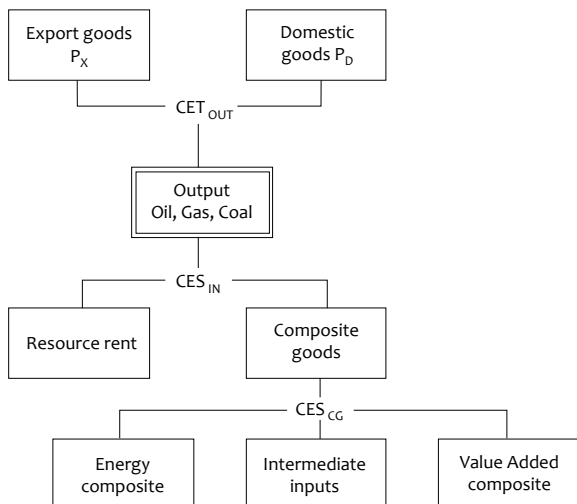
that is, the quantity of crude oil in refined oil production, denoted here $vafm(cru, oil, r)$, as a share of the value of the output of refined oil products (domestic $vdm(oil, r)$ and exports $vxm(oil, r)$).

2.5 From static to dynamic

The DART model is recursive-dynamic, meaning that it calculates results for a sequence of static one-period equilibria in future time periods connected through capital accumulation and changes in labour supply. The dynamics of the DART model are defined by equations which describe how the primary factors capital and labour evolve over time. The major driving, exogenous factors of the labour dynamics are population change, labour productivity growth, and migration. The driving factor of capital accumulation is the savings rate. The DART model is recursive in the sense that it calculates stepwise in time, without any ability to anticipate possible future changes, relative prices or constraints. The saving behaviour of the regional households is characterised by an adjustable savings rate over time. The following sections describe the evolution of labour and capital supply in more detail.

2.5.1 Savings rate

Different to the previous DART versions, DART-PBL does not assume a fixed savings rate. Industrialised economies are confronted with the problem of ageing, while the populations of developing countries grow fast. This affects the saving behaviour of citizens, because people save more in the middle of their life, when being employed, and dissave once they have retired. Moreover, the current economic status, for example, represented by the rate of economic growth, and the resulting expectations of economic agents, influence the



saving behaviour. The methodology used in DART-PBL closely follows the methodology of the WorldScan model (Lejour *et al.*, 2006). The savings rate, $saverate(r,t)$, in region r in year t is given by:

$$\begin{aligned}
 &saverate(r,t) \\
 &= const(r) + \alpha_1 \hat{GDP}(r,t) + \alpha_2 share_{25-45}(r,t) \\
 &\quad + \alpha_3 share_{45-65}(r,t) + \alpha_4 share_{65+}(r,t)
 \end{aligned} \tag{8}$$

, depending on a constant, GDP growth, and the shares of the age groups 25 to 45 years, 45 to 65 years, and above 65 years, in the total population.

The parameter values α_i are econometrically estimated by Lejour *et al.* (2006). The values are reported for OECD and non-OECD countries. Indeed, a larger share of people above 65 years reduces the average savings rate of an economy, according to the estimates. Benchmark savings rates for the year 2001 are given by the GTAP6 data. The population shares of the age groups are computed from Phoenix population data (Section 2.5.2). The GDP growth rate in 2001 can be determined after solving the model for 2001 and 2002. Thus, the remaining constant terms can be calculated as being country-specific effects based on the benchmark data:

$$\begin{aligned}
 &const(r) = saverate(r, 2001) \\
 &- \left[\alpha_1 \hat{GDP}(r, 2001) + \alpha_2 share_{25-45}(r, 2001) \right. \\
 &\quad \left. + \alpha_3 share_{45-65}(r, 2001) + \alpha_4 share_{65+}(r, 2001) \right]
 \end{aligned} \tag{9}$$

Thereafter, the savings rates are adjusted, endogenously, according to equation 8 depending on the endogenous GDP growth rate and the exogenous population shares, in each time period.

2.5.2 Labour supply

Labour supply is measured in efficiency units. It evolves exogenously, over time. Several assumptions are made to determine labour development. These involve population growth,

educational attainment, participation rate, migration aspects, and the health level of workers. The PHOENIX model, as part of the GISMO framework, is used for the labour growth, educational attainment and health projections (Hilderink and Lucas, 2008). DART and PHOENIX create an integrated system, where, among others, economic indicators are used for determining the population dynamics, and these are used to establish labour figures.

PHOENIX is a Population and Health model, which allows exploring, developing, and analysing different demographic scenarios at various geographical aggregation levels (Hilderink, 2000). It captures the transformation of fertility and mortality patterns, a process referred to as the demographic transition. The demographic core is formed by a standard cohort-component model, consisting of 100 one-year cohorts, and the two sexes. The model has an education module which determines enrolment ratios and educational attainment for four levels of education: no education, primary, secondary, and tertiary education. The inflow of the demographic model, the number of births, is provided by the fertility module, while the outflow is provided by the mortality module. The mortality module calculates age and sex specific morbidity and mortality based on a selection of health risks. International migration, the third demographic component, is obtained exogenously.

Different to previous versions, DART-PBL determines the size and growth of the labour force, by using the growth rate of the population cohorts between 15 and 65 years of age. The participation rate is generally defined as the share of adults who actually work. Labour market fluctuations are explained by many economic factors, including: a) woman within the reproductive age cohorts can decide to remain in paid employment or to stay home and take care of children, and b) people within the older age cohorts can decide their age of retirement (OECD, 2003).

The labour participation rates in DART-PBL follow the OECD projections (OECD, 2003). In recent years, the trend in the participation rates was sloping downward, in the OECD

countries, though looking at historical observations from the sixties, the long-term average participation rate is constant, around 60%. For the non-OECD countries, there is often a lack of data available for analysing the trends. Therefore, following the OECD, it is assumed that non-OECD countries are slowly converging to the long-term participation rate of 60%.

In calculating the efficiency of labour also the health of the labour force is included. The health level is based on the Years of life Lived with a Disability (YLD), which indicates the morbidity or disease levels within a population (see e.g., Murray and Lopez, 1994). The YLD takes into account the incidence, prevalence, and duration of diseases, combined with their severity. To determine the healthy workforce, the YLD of the population aged 15 to 65 is subtracted from the total labour force. Applying this methodology, the productivity parameter to the healthy part of the labour force can be calibrated, and the impacts of improvements in the health level of the labour force on production can be assessed.

Labour is divided into two categories: high and low skilled, which are provided by the GTAP6 database, and differentiated according to educational achievement. High-skilled labour encompasses workers with completed secondary education and low-skilled labour the remainder. Labour is mobile across industries within regions, but not on an international level. Rural-urban migration is a common issue in development economics. The DART-PBL approach is based on the World Bank approach by Bussolo *et al.* (2006), and Van der Mensbrugge (2005), adapted from Harris and Todarro (1970).

In most regions, there are large migration flows from villages to cities, which affect the size of the labour force of the land-intensive sectors, and also strongly influence rural wages. Accordingly, migration is a positive function of the expected urban-rural wage differential. For 'a survey of theoretical predictions and empirical findings see Lall *et al.* (2006). The DART-PBL model follows this standard approach:

$$migrate(r) = migstrength(r) \cdot \left(\frac{wage_urban(r)}{wage_rural(r)} \right)^{migela} \quad (10)$$

with r again representing the regions in the model, $migrate(r)$ is the migration rate (referring to the rural workforce), determined by the migration strength, $migstrength(r)$, and the current urban-rural wage differential. Multiplying the migration rate, $migrate(r)$, by the rural workforce yields the migration stream per year, which is subtracted from the rural, and added to the urban work force.

It is assumed that skilled labour is perfectly mobile, while unskilled labour is split into a rural and an urban part. The rural part encompasses the sectors agriculture (AGRI), animals (ANIM), and forestry (FRS). The other sectors are assumed to belong to urban production. Unskilled labour is divided into two parts by separately adding up the benchmark GTAP6 input values for the sectors belonging to rural and urban production. Rural-urban migration in the benchmark situation is calibrated to 2001 values derived from World Bank (2007). Migration is computed as the percentage of change in the share of the rural population in 2002, compared with 2001.

Growth rates of labour (ag) are calculated based on the development of the size of the population cohorts of 15 to 65 years, participation rates, and the development in education and health status. The productivity increase, GTP , represents the total factor productivity improvement and is calibrated such that the yearly growth rates of GDP are in line with the GDP growth rates of the OECD projection (OECD, 2008). The following equations describe how unskilled ($unsklab$) and skilled labour ($sklab$) develop over time:

$$unsklab_urban(r, t + 1) = [unsklab_urban(r, t) + migrate(r) \cdot unsklab_rural(r, t)] \cdot [1 + ag(unsklab, r, t)] \cdot [1 + GTP(r, t)] \quad (11)$$

$$unsklab_rural(r, t + 1) = [unsklab_rural(r, t) - migrate(r) \cdot unsklab_rural(r, t)] \cdot [1 + ag(unsklab, r, t)] \cdot [1 + GTP(r, t)] \quad (12)$$

$$sklab(r, t + 1) = sklab(r, t) \cdot [1 + ag(sklab, r, t)] \cdot [1 + GTP(r, t)] \quad (13)$$

2.5.3 Capital formation

The driving force in capital accumulation is the regionally different savings rate. The DART model is recursive, in the sense that it solves stepwise in time (year by year), without anticipating possible future changes of relative prices or constraints. The equation for the capital stock $Kst(r, t)$ in region r and time t is given by:

$$Kst(r, t) = (1 - \delta) \cdot Kst(r, t - 1) + I(r, t) \quad (14)$$

, where $Kst(r, t - 1)$ is the capital stock in the previous year, $I(r, t)$ is the capital investment which equals savings, and the parameter δ denotes the exogenously depreciation rate, which is equal to 0.04 in all regions and all time periods. The allocation of capital among sectors follows from the intra-period optimisation of firms. For further details see (Klepper *et al.*, 2003).

Appendix

Sector aggregation

Table A.1

DART-PBL sectors	GTAP sectors (Dimaranan, 2006)
1 <i>Agricultural sector</i>	Paddy rice, wheat, cereal grains nec, sugar cane, sugar beet, crops nec, vegetables, fruit, nuts, oil seeds, plant-based fibers, vegetable oils and fats
2 <i>Animal sector</i>	Bovine cattle, sheep and goats, horses, animal products nec, wool, silk-worm cocoons, bovine meat products, raw milk
3 <i>Food processing industry</i>	Fishing, meat: cattle, sheep, goats, horse, meat products nec, vegetable oils and fats, dairy products, processed rice, sugar, food products nec, beverages and tobacco products
4 <i>Forestry</i>	Forestry
5 <i>Coal</i>	Coal
6 <i>Oil</i>	oil
7 <i>Natural gas</i>	Gas, gas manufacture, distribution
8 <i>Petroleum and coal products</i>	Petroleum and coal products
9 <i>Electricity</i>	Electricity
10 <i>Manufactures</i>	Textiles, wearing apparel, leather products, wood products, motor vehicles and parts, electronic equipment, machinery and equipment nec, manufactures nec, transport equipment nec, paper products, publishing, chemical, rubber, plastic products, metals nec, ferrous metals, metal products, minerals nec, mineral products nec
11 <i>Public administration</i>	Public administration, defense, education, health
12 <i>Services</i>	Construction, dwellings, trade, transport nec, water transport, air transport, communication, financial services nec, insurance, business services nec, water, recreational and other services

Region Aggregation

Table A.2

DART-PBL regions	GTAP regions (Dimaranan, 2006)
1 <i>Canada</i>	CAN, XNA
2 <i>USA</i>	USA
3 <i>Mexico</i>	MEX
4 <i>Rest Central America</i>	XCA, XFA, XCB
5 <i>Brazil</i>	BRA
6 <i>Rest South America</i>	COL, PER, VEN, XAP
7 <i>Northern Africa</i>	MAR, TUN, XNF
8 <i>Sub-Saharan Africa (excl. South Africa)</i>	XSS, MDG, UGA
9 <i>South Africa</i>	ZAF
10 <i>Western Europe</i>	AUT, BEL, DNK, FIN, FRA, DEU, GBR, GRC, IRL, ITA, LUX, NLD, PRT, ESP, SWE, CHE, XEF
11 <i>Central Europe</i>	ALB, BGR, HRV, CYP, CZE, HUN, MLT, POL, ROM, SVK, SVN, EST, LVA, LTU,
12 <i>Turkey</i>	TUR
13 <i>Asia –Stan</i>	XSU
14 <i>Russia</i>	RUS
15 <i>Middle East</i>	XME
16 <i>India</i>	LKA, IND
17 <i>Korea</i>	KOR
18 <i>China</i>	CHN, HKG, TWN, XEA
19 <i>Southeast Asia</i>	MYS, PHL, SGP, THA, VNM, XSE
20 <i>Indonesia</i>	IDN
21 <i>Japan</i>	JPN
22 <i>Oceania</i>	AUS NZL XOC
23 <i>Rest of South Asia</i>	BGD XSA
24 <i>Rest of Southern Africa</i>	BWA, XSC, MWI, MOZ, TZA, ZMB, ZWE, XSD

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An economy model for GISMO.

DART-PBL technical documentation

The Global Integrated Sustainability Model (GISMO), developed at the Netherlands Environmental Assessment Agency (PBL), is a platform for analysing the complexity of sustainable development and human well-being with regards to the three sustainability domains: People, Planet, and Profit (PPP). The economic structure of the GISMO1.0 model is the International Futures model. To better address price behaviour in the model, the Computable General Equilibrium (CGE) model DART, developed by the Kiel Institute for the World Economy, was included in the GISMO framework and integrated with the International Futures model. The DART model is tuned to the needs of the GISMO project, and is further referred to as DART-PBL. This report provides an overview of the main changes and additions to the original DART model.