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Science and Technology

An implementation of the World Trade Model with the GTAP database

Kristin Fjellheim

Master in Industrial Ecology
Submission date: April 2011
Supervisor: Anders Hammer Strømman, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

Problem Description

Global production and consumption activities are continuously scrutinized to mitigate mounting environmental concerns, in particular global warming. This scrutiny has also been extended to the inter-regional and intercontinental transportation system. Concerns are being raised over energy use and associated emissions related to the transport of goods. There are many examples of individual global value chains that are resource and emission inefficient. There is however and economic rationale for this. Access to cheap labor in developing countries and economies in transition provides strong incentives for locating production there. Although there are adverse environmental implications caused by locating this production in economies with less strict environmental regulations and more distant from markets, it is very important to recognize that production of goods for western markets provides an opportunity for countries to improve economic growth and all that may follow with that. That is, the prospect of improving global equity is the main novel motivation for globalization.

The serious implications associated with global warming and especially the immediate concern for achieving a tipping point in emissions of greenhouse gases does though have implications for our global production and consumption system. Despite the potential economic and social upsides of globalization, it is important to understand the environmental repercussions caused by changes in the international division of labor.

The world trade model with bilateral trade offers a framework for assessing both changes in the international division of labor, equity and associated environmental impacts. The world trade model with bilateral trade is an input-output model based on comparative advantage. The model solves for production by countries for an exogenously defined demand by countries. The current literature on the model only demonstrates applications using highly aggregated datasets. There are ongoing efforts to implement the model using the EXIOPOL database. However, further effort to implement detailed datasets is required to better understand the potential this model holds.

The main objective of this work is to implement the GTAP7 database in the WTMBT. This involves adaption of datasets and modifications required. The second objective is to benchmark the model output with the statistical data from the GTAP7. This involves both output by regions as well as trade patterns.

The work should include following elements:

1) An overview of the WTM model and its rationale.
2) An overview of the GTAP database structure.
3) Adaption of GTAP data for implementation in the WTM.
4) Implementation , development of benchmarking tests and analysis of results.
5) Discussion and conclusion.

Assignment given: 05. November 2010
Supervisor: Anders Hammer Strømman, EPT

Preface

Taking on a task to evaluate the production and trade system of the entire world is a great challenge. Not being overwhelmed by the magnitude of the datasets and seemingly endless amounts of technical issues has been hard. Looking at the finished product I am glad I overcame it, and hope the readers find my work interesting and useful.

First of all I would like to thank my supervisor Anders Hammer Strømman for all the guidance and encouragement along the way. I appreciate that he takes the time to have weekly meetings and that he is so involved in the work of his master students.

Further I wish to thank my father, Roar Fjellheim, for proof reading and feedback and encouraging words.

Lastly my thanks go to Dina Aspen, Guillaume Majeau-Bettez, Marina Magerøy and the rest of the Industrial Ecology students who have been a welcome distraction when the days have gotten too long and lonely.

Kristin Fjellheim

Abstract

In this thesis the world trade model with bilateral trade is applied to a large database. The model is based on the economic theory of comparative advantage, equilibrium production levels and benefit of trade. Statistical data on a large number of countries and sectors are applied to the model. Input-output calculations are used to convert the statistical variables to the necessary technology coefficient matrix, factor coefficient matrix and transportation matrix. These matrices are the basis for the world trade model with bilateral trade.

The no trade version of the model, where there is no international trade, is solved to give grounds for comparison and the use of the benefit-of-trade constraint. The world trade model with bilateral trade opens up for trade based on comparative advantage. In addition the cost of transportation between countries is included so to integrate the cost and environmental consequences of different trade patterns.

The model is applied with a large database from GTAP that provides information on 113 countries, 57 sectors, 5 primary factors, and 3 transportation sectors. The statistical values are in US dollars for the year 2004. The model solves for an alternative production layout and trade pattern based on comparative advantage, which would reduce the primary factor and product use.

Comparing the statistical values to the model values gives a clear picture of the effect of comparative advantage on international trade. The total production levels were reduced due to lower inter-industry demand. The primary factor use was consequently reduced both from a lower production level and because production occurs in the country with comparative advantage. Higher levels of international trade were also observed due to production being more widespread. Even though emissions were not calculated in this thesis, the overall reduction indicates lower levels, as well as the reduced use of natural resources and land.

This thesis is the first step to apply the world trade model with bilateral trade to a large database, hence some desired aspects were not included. Suggestions as to how the model can further be developed by including more constraints are put forth, such as restriction on factor movements, distances and transportation costs.

The results clearly show the benefit of having a world economy based on comparative advantage. It illustrates how it is possible to have sustainable development by keeping the same consumption level as we have today while simultaneously reducing factor use.

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1 Introduction

The great concern of economists and policy makers today is no longer just how to achieve economic growth, but how to achieve economic growth while preserving the natural environment. It has long been clear that the climate is changing, that the temperature of the planet is increasing, and that there is a higher concentration of greenhouse gases (GHGs) in the atmosphere (IPCC, 2007). According to the IPCC 4th assessment report, the GHG emissions due to human activities have increased 70% between 1970 and 2004. This indicates that the change in the world's climate is not only natural fluctuations but a consequence of human activity (UNFCCC, 2007). In the last decades a new way of looking at the planet has emerged; looking at the earth as a system where land, oceans, atmosphere, living and non-living parts are elements that all interact with each other (Steffen et al., 2004). System analysis is one of the main concepts within the field of industrial ecology, where also the interaction between humans and the environment is being analyzed. Through a system analysis approach it is possible to see the relationships between human activities and behavior, and the natural environment. This idea of economic development and simultaneous preservation of nature is referred to as sustainable development. While economic growth and reduced environmental impact are often viewed as contradictory elements sustainable development tries to combine them so that they together can make a sustainable future for future generations.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
(Brundtland, 1987)

There are three main categories of impacts that human activities have on the environment. One is population which is increasing every year, the other is the consumption level per capita, and the last is the technology level (Brattebø, Ehrenfeld, & Røine, 2007). Reduced consumption level is hard to achieve, especially in the developing regions of the world. As over 1 billion of the world's population lives under the poverty line their first aspiration is to gain higher living standards and thus higher consumption level (OECD, 2001a). Therefore having lower consumption coming from final demand is difficult to achieve. The other option would be to reduce the inter-industry flows of material and services. Improving the efficiency and decreasing the use of natural resources in production processes is therefore an important way of de-coupling economic growth and emissions. Improving the efficiency of a production process could be done through technical improvements and innovation. This might have ambiguous effects in that it might lead to a higher extraction of resources and unforeseen effects on the environment (OECD, 2001a). Another possibility would be to move the production of products to the regions of the world with the lowest use of inputs. This means to base the world economy on a concept of comparative advantage where the regions that have a lower opportunity cost and cheaper and less input intensive technologies, produce the good (Mankiw, 2009). The concept of comparative advantage will lead to lower levels of factor use and cost, and in some cases the use of better and cleaner technologies. When production occurs in the regions of the world with comparative advantage it might lead to a higher level of trade in the world economy, which is also an effect of a more globalized and “smaller” world. To accommodate for the widespread production pattern a higher use of transportation would be required. The sectors with the highest increase in greenhouse gas emissions are energy supply, industries and transportation. Transportation stood for about 13% of the total GHG emissions in 2004 (IPCC, 2007).

Input-output analysis is a system analysis approach that can take into account the main elements in both the economic sphere and the environmental sphere. In input-output tables the inter-industry flows of products and services within one region are illustrated, as well as the final demand, total production and use of primary factors such as labor, land, and capital (Miller & Blair, 1985). In the later years more focus has been on the inclusion of natural resource use in input-output tables (Polenske & Hewings, 2004). Input-output analysis can then be used to depict the interactions between not just the economic entities, but also include environmental effects. Generally input-output tables show the current economic situation, and this can be used further to analyze future scenarios.

One theory of international trade is the concept of comparative advantage and how implementing this would affect the world economy and environment. The World Trade Model (WTM) developed by Faye Duchin (2005) uses the input-output framework to see the effect comparative advantage has on production level, factor use, and trade. This model shows a world economy that is based on comparative advantage given certain restrictions and where the goal is to minimize factor cost. The restrictions are: a benefit-of-trade constraint making sure no region enter into trade unless they are better off than before trade, factor constraint making sure no region use more labor, land, capital etc. than what they currently have, and a constraint making sure that the final demand for products are met (Duchin, 2005). Further the model was developed by Anders H. Strømman and Faye Duchin (2006) to account for transportation, since this sector is growing in use and as a GHG emission contributor it is an important factor to account for.

In this report the World Trade Model with Bilateral Trade (WTMBT) (Strømman & Duchin, 2006) is tested on a large dataset. The original WTM was used on data for 10 regions, 8 sectors, and 3 primary factors while the WTMBT was tested for

11 regions, 8 sectors and 3 primary factors. The model has been tested on large dataset in the master project by Kristin Fjellheim (2010) where the EXIOPOL database for 39 regions, 126 sectors, 1 primary factor and 6 transportation sectors was used. In this thesis data from the GTAP (Global Trade Analysis Project) database is used with information on the total value of final demand, total production, inter-industry flows, primary factor use, imports, exports, and the use of transportation for each region. This information provides the statistical data used for the benchmarking tests and the exogenously given variables needed to perform the input-output analysis. Information on 113 regions, 57 sectors, 5 primary factors, and 3 transportation sectors is provided (Hertel & Walmsley, 2008).

This report will start by explaining the methodology and necessary background needed to understand the WTMBT fully. First the economic principles such as goods balance, open/closed economy, trade balance, returns to scale, comparative advantage, and benefit from trade that the WTMBT is based on are explained. Then the concept of industrial ecology is elaborated explaining its use in input-output analysis. Further the input-output (I-O) framework is defined showing how the tables are constructed, basic input-output calculations and explaining how prices are treated. There will also be a short introduction to linear programming and how it is used in this analysis. In chapter 3 a detailed description of the GTAP database is shown, including how it is structured and how prices are treated. Chapter 4 explains the different models, the no-trade model (NT), World Trade Model (WTM) and World Trade Model with Bilateral Trade (WTMBT). The implementation process with Matlab and GAMS showing how the input-output variables were derived from the database is shown in chapter 6. Chapter 7 represents the results in the form of benchmarking tests between the model values and the statistical values. The comparison is on the aggregated levels comparing total production, total factor use and trade patterns. The discussion and further development in chapters 8 and 9 focus on the accuracy and usefulness of a model based on comparative advantage. Further the limitations of this model are described and possible improvements to make the model more realistic are presented.

2 Methodology

The methodology chapter gives an overview of the tools that are used to build the foundation for the world trade model. First some very fundamental economic theory is described which is the basis for input-output analysis and the world trade models. Then the industrial ecology concept is explained. Next the basic input-output analysis method is explained with main focus on the construction of input-output tables, the issues concerning pricing and the basic input-output calculations. There will also be a short explanation of linear programming and its purpose and use in the world trade model.

2.1 Economics

The World Trade Model by Faye Duchin (2005) and the World Trade Model with Bilateral Trade by Anders H. Strømman and Faye Duchin (2006) have certain economic theory as a base. In this chapter the difference between a closed and open economy will be explained, since both a no-trade model and world trade model are used in the analysis. Further the concept of comparative advantage is described; this is a widely used concept in analyzing trade between countries. In addition the benefit-of-trade constraint used in both world trade models is explained, this is to ensure that no region enters into trade unless they are better off than under no trade conditions.

2.1.1 Goods balance in a closed and open economy

In economic analysis it is often differentiated between the short run, medium run and the long run. The short run is defined as the period when prices and wages are given and do not fluctuate (Carlin & Soskice, 2006). The medium run looks at how the output is affected when the prices and wages change over time, while in the long run the focus is on the long term growth of the economy and not only fluctuations (Blanchard, 2006). In this thesis the models are focused on the short run, where it is assumed that the prices of production and wages (also other primary factor inputs) are constant. This is the A-matrix and the F-matrix which is directly derived from the database in use, and is exogenously given, or constant.

In the short run the goods market and the financial market determine the level or regional output. For this thesis however it is only of interest to look at the balance in the goods market since the model values could in theory be either physical goods or monetary values (in this case all values are monetary). There is also the difference between an open or closed economy. When an economy is closed it means that there is no trade with other countries, while when it is open it is free to trade with other regions. For both an open and a closed economy the gross domestic product (GDP) have to be known. GDP can be seen from both the production side of the economy and the income side. From the production side

GDP is the sum of all goods and services produced in the economy at a given time, while from the income side it is the sum of all incomes in the economy.

The GDP can also be seen as the aggregated output of a country, and is composed of four main parts: Consumption (C), which is goods and services that are purchased by consumers, investment (I) which is purchases by firms, government spending (G) and lastly the net exports, which is the difference between exports (X) and imports (IM) (Blanchard, 2006). Summed up the total demand for goods can be shown as

$$Z = C + I + G + X - IM \qquad 2.1$$

For a closed economy this demand is simply:

$$Z = C + I + G \qquad 2.2$$

This is because both exports and imports are equal to zero in a closed economy and can be excluded from the equation. The equilibrium output of the economy is when production is equal to demand. Taking government spending as an exogenous variable, meaning variables that are taken as a given, the variable that is of most interest is consumption. Decisions made on how much and what to consume depend on several factors, but income (Y) is probably the main factor. The disposable income is what is left after taxes (T) have been deduced, so consumption becomes

$$C = c_0 + c_1(Y - T) \qquad 2.3$$

In function 2.3 there are two parameters. The first parameter c_0 is what would be consumed even if the income was equal to zero, this would be consumption of necessary products such as food. The other parameter c_1 is called the propensity to consume and shows how much a consumer would increase his/her total consumption if the income Y increased by one unit.

The demand function 2.2 will then become

$$Z = c_0 + c_1(Y - T) + I(Y) + G \qquad 2.4$$

The Y in parenthesis after investment I indicates that the investment is dependent on the income level as well. Income will have a positive effect on both consumption and investment level. Investment is also dependent on the interest rate, but it is not included here for simplicity and since it will not have an effect on the overall understanding of the underlying economics. As noted, equilibrium output is when the demand (Z) is equal to the aggregated production (Y). Also noted earlier, GDP can be seen as aggregated production denoted as Y, or aggregated income which is also denoted as Y. Therefore replacing the demand in function 2.4 with aggregated production gives

$$Y = c_0 + c_1(Y - T) + I(Y) + G \qquad 2.5$$

This shows that the production level in a closed economy is dependent on the level of available income, which is the total income minus taxes, the investment level and the level of government spending. Changes in either of these variables would lead to a change in the region's aggregated production.

Figure 1 shows the equilibrium production where Z is equal to production Y. The production line has a slope of 1, since production is equal to income. The slope of the demand line is equal to c_1, the propensity to consume, since an increase in income would lead to a marginal increase in consumption.

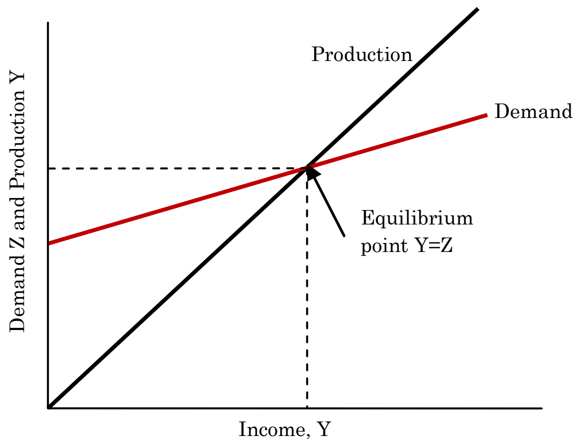

Figure 1 - Point of equilibrium output in a closed economy

On the x axis the income Y is shown while the y axis shows the demand Z and production Y. The equilibrium point is where the production line and the demand line cross. This is where income and production are equal, and also demand is equal to production. Anything to the left of the equilibrium point indicates that there is higher demand for products than there is production, while anything to the right indicates a production level that is higher than the total demand. A change in income would shift the demand curve and alter the production level. Higher income would indicate that both the consumption level and the investment level would increase and make the demand curve shift upwards leading production to follow and increase as well (Blanchard, 2006).

For an open economy the principles are the same as under a closed economy except for that the imports and exports into and out of the region need to be considered. Function 2.1 shows the demand for domestic production, also including imports and exports. Including what is found from the closed economy and what affects the imports and exports the demand function for an open economy becomes

$$Z = C(Y - T) + I(Y) + G + X(Y^*) - IM(Y) \qquad 2.6$$

This demand function shows that it is affected by the consumption level, investments, government spending, exports and imports. The first three terms are the same as under a closed economy, while the two last terms are new for the open economy. Exports, X, is foreign demand that falls on the domestic production and it is dependent on the income level in the other regions, Y^*. Higher income in other regions will lead them to increase their consumption, and hence also increase their imports. The import level in the region is dependent on the income level as well; higher income level will lead to demand for more goods and services, also foreign goods and services. Both imports and exports are also dependent on the exchange rate between the different regions. This is not included here for the same reasons that the interest rate is not included; it will not have an effect on the overall understanding needed for this thesis. Figure 2 shows demand in the economy going from a closed to an open economy (Blanchard, 2006).

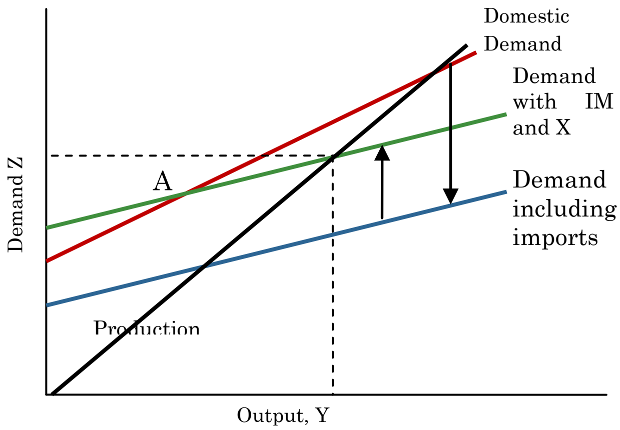

Figure 2 - Transition from closed to open economy

In figure 2 the red line showing domestic demand is the same one as the demand curve in figure 1 where the economy is closed for outside trade. When the economy opens up to other regions there will be imports from other regions, this is shown in the shift from the domestic demand curve to the blue curve depicting demand including imports. There is a downward shift in the demand curve because parts of the domestic demand will be moved from domestic production to foreign production. This leads to both a lower initial demand put on domestic production and a lower fraction of the income used on domestic products, hence a flatter curve. Further the economy also opens up for export of domestically produced goods to other regions; this is shown in the shift up to the green curve showing demand including imports and exports. This upward shift is because same as parts of the domestic demand is placed on other regions, other regions will also demand products from other regions. The equilibrium output is found in the same way as under a closed economy, where the demand for domestic products Z is equal to domestic production Y, so replacing Z with Y in equation 2.6 gives

$$Y = C(Y - T) + I(Y) + G + X(Y^*) - IM(Y) \quad 2.7$$

It is also possible to see if an economy runs a trade deficit or surplus from figure 2. A trade surplus means that the region exports more than it imports, net export (NX) is positive, while a trade deficit means that it imports more than it exports, NX is negative.

$$NX = X(Y^*) - IM(Y) \quad 2.8$$

The point A in figure 2 shows the point where the net exports are equal to zero, the region imports as much as it exports. Moving to the left of point A the demand including imports and exports is higher than the domestic demand. This indicates that the region exports more than it imports and it has a trade surplus. Moving to the right of point A will then lead to a trade deficit (Blanchard, 2006). In this case the equilibrium point in the open economy is at a point to the left of point A, and the country runs a trade deficit. The layout of figure 2 is just one possible scenario, where domestic production is lower under an open economy; the layout could be completely different so that domestic production would end up being higher with an open economy.

2.1.2 Returns to scale

When looking at a sector in the economy, it consists of one or several different companies. Returns to scale considers whether there should be many small companies producing small amounts, or fewer larger companies producing large amounts of output. The concept says what will happen to the output in the sector or individual company if all inputs increase by the same amount. Either there could be increasing returns to scale, also called economies of scale. This is when a certain percentage increase in the inputs leads to a higher percentage increase in the output. Decreasing returns to scale means the opposite; that a percentage increase in all inputs leads to a lower percentage increase in output. The last case is constant returns to scale, where the percentage increase in inputs leads to the exact same increase in output (Frank, 2003).

2.1.3 Comparative advantage

Comparative advantage looks at the differences in technologies on the supply side of different countries and at the difference in factor endowments. Two main theories have been developed to describe comparative advantage; Heckscher-Ohlin theory which focuses on the difference in factor endowments and the

Ricardian model which focuses on the difference in technologies (Maneschi, 1998).

The Ricardian model was developed by David Ricardo and consisted of two regions, two products and only one input (labor). The model showed that even though one country had an absolute advantage in producing both goods, both countries could still benefit from trade (Grossman & Helpman, 2005). A country has absolute advantage in production of a product if it is cheaper and requires less input in the production process (Mankiw, 2009). When a country has absolute advantage in producing both goods, this country should produce everything of both goods while the other country should not produce anything. However, this is not a possible solution since the country not producing anything is worse off than under no trade. Since the Ricardian model shows that it is possible for both countries to gain from trade even though one country has absolute advantage in producing both goods, there must be another way to look at costs. The opportunity cost of a product is what is given up to produce one more unit of that product. Comparing countries on the basis of opportunity cost is the basics behind the concept of comparative advantage. When comparing two countries the country that gives up less of all other goods in order to produce one good has a comparative advantage in producing that good (Mankiw, 2009).

2.1.4 Benefit-of-trade

For a country to engage in trade with other countries it will have to have benefit from trade. The benefit-of-trade constraints make sure that no country can exceed its no-trade factor use (Strømman & Duchin, 2006). By ensuring this a constraint is set so that the value of imported products, at no-trade prices, for a country is equal or higher than its value of exported products at no trade prices (Duchin, 2005).

2.2 Industrial Ecology

The concept of industrial ecology has evolved over time along with the view people and governments have on the economy, consumption, nature and how to make these aspects compatible. The actual concern for how nature was affected by human activities was not really established until the 1960's. While it started out as trying to find ways to reduce pollution and waste trough end-of-pipe technologies it has evolved into a way of implementing sustainable development technologies. This means for example to find ways to reduce the use of energy intensive and pollution intensive technologies and instead use technologies that has a lower emission rate. This is a way of preventing pollution from the start instead of fixing the problem after it has occurred. One way to look at this issue is through the IPAT formula

$$I = P * A * T \quad 2.9$$

The I stand for the impact humans have on the environment through production and consumption of goods, the P stands for population, the A for affluence or consumption level per capita and the T stands for the technology factor. This means that there are three ways of reducing the impact humans have on the environment. However, if it is desired to keep the population level and standards of living at least at the level it is at today, it is only a reduction in the technology factor that will reduce the impact (Brattebø, Ehrenfeld, & Røine, 2007). In addition to improving the technologies that are present today another way of reducing this is through an economy based on comparative advantage (chapter 2.1.3). The issue with improving technology, reducing emissions etc is that there is a worry that it will be at the expense of higher investment cost and lower economic growth. Industrial ecology tries to show that it is possible to have both economic growth and lower effect on the environment simultaneously.

One of the basic principles in industrial ecology is to study the interaction between the technological sphere and the natural sphere with a system analysis point of view. A system consists of different elements which interact with each other and for each element there is a set of inputs, outputs and stocks. A system could for example be a national economy, or the world economy as it is used in this thesis (Heijungs, Udo de Haes, & Røine, 2007). One approach to system analysis can be seen in figure 3.

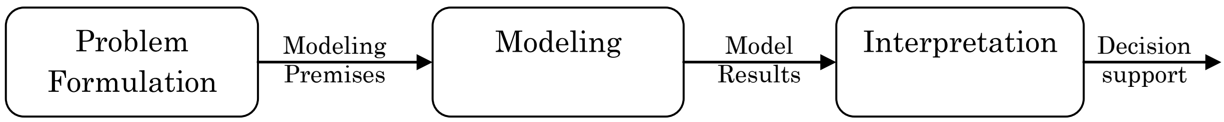

Figure 3 - System analysis approach (Heijungs, Udo de Haes, & Røine, 2007)

First the problem to be solved is described and formulated in terms that are available in the model. Second is the actual modeling process, where a model is defined as a representation of the real world or a part of it. In the modeling process the system has to be defined; where the boundaries are, what time scope it covers and the total scope of the model. This could include how many regions and sectors are involved and whether stocks or flows that being assessed. Further the relationship between the different elements must be set up mathematically. The model could either be a static model, only looking at one year, or it could be dynamic, looking at the evolution over time. The whole model must then be put together so as to see the interconnections between all the elements to make it possible to solve the system of equations linking the elements together. The modeling step produces results that should be interpreted in accordance with what the model was set out to do and to make it available for decision makers to analyze (Heijungs, Udo de Haes, & Røine, 2007). One method used in industrial ecology is input-output analysis, and the system analysis approach is used throughout this thesis.

2.3 Input-Output Analysis

Input-output analysis could be traced back to the French economist François Quesnay. Already in 1758 he made a "Tableau Économique" that showed the expenditures in an economy systematically in table form. Over 100 years later, in 1874 the Frenchman Léon Walras used a set of coefficients that showed the relation between factor requirements to produce one unit of a product to the levels of total production of that product in his theory of general equilibrium in economics. It is Professor Wassily Leontief, however, that first comes to mind when discussing input-output analysis, and the analytical framework in use today stems from his work developed in the 1930s (Miller & Blair, 1985).

Input-output analysis is first and foremost a tool to analyze the inter-industry relations or the interdependencies of different industries within an economy. It is widely used in today's society both for national economic analysis by countries and regional economic planning and analysis by industries, states and research communities. The numbers in the input-output tables are obtained from observed data for the given region or economic area (Miller & Blair, 1985).

Traditionally the input-output framework was used to analyze the flows of materials and services between industries or sectors within a country. However there are several different extensions of the input-output analysis that includes environmental aspects and industrial ecology. One of the first to link input-output analysis with industrial ecology directly was Faye Duchin (Suh & Kagawa, 2009). Environmental input-output analysis is able to deal with interregional flows of products taking into account environmental aspects and value added associated with production, such as employment, land use, and natural resources (Miller & Blair, 1985). In this thesis the focus is on flows of materials and services between countries and the economic and environmental aspects associated with this.

2.3.1 Input-Output tables

Input-output tables are constructed from statistical available data for specific regions, usually countries, by official statistical offices and other approved institutes such as universities, banks, companies, and individual researchers. To ensure consistency in the tables being compiled by so many different institutions that may use different methods to assemble them, they all follow characteristics associated with the system of national accounts (SNA) (Duchin & Steenge, 2007). The SNA is an international standard of recommendations on how economic activities should be compiled. It is based in economic principles with well specified concepts, definitions and accounting rules (*System of National Accounts 2008*, 2009). The tables in the SNA are often divided into supply and use tables that will have to be manipulated for use in input-output analysis. The A-matrix, or the technology coefficient matrix, that shows how much each sector requires from the other sectors to produce one unit, needs to be obtained. There are two main constructs that are used to convert the supply and use tables into A-matrices; the technology assumption method and the industry assumption method, and it is possible to either construct an industry-by-industry A-matrix or a commodity-by-commodity A-matrix (Jansen & Raa, 1990). A full explanation and derivation of these constructs can be read in "An implementation of the world trade model with the EXIOPOL database" (Fjellheim, 2010). The tables from the GTAP database is compiled in a slightly different manner and is more readily available, as will be explained in chapter 3.

An input-output table shows the industries and the products produced in the region. Each industry produces goods as well as consumes goods from other industries. In this way the input-output table can show the use of products by each industry. The rows show the products produced by each industry (outputs) while the columns show the amount of inputs of these products each industry requires to produce its output, these flows are called inter-industry flows. Gathering data for many industries and products in physical values is hard since one industry can produce several goods, and therefore the input-output tables are often showed in monetary values (Miller & Blair, 1985).

In addition to the inter-industry flows there is an end use or final demand (Y) placed upon the industries coming from households purchases (C), government purchases (G), purchases for investments (I) reasons and exports (E) to other regions. The net export (NX) is the exports (E) minus imports (M). If the net export is negative in the final demand it means that the country or region is importing more than it is exporting as explained in chapter 2.1.1.

$$Y_i = C_i + I_i + G_i + NX_i \qquad 2.10$$

Equation 2.10 is basically the same as equation 2.7. However equation 2.7 refers not only to the final demand coming from each sector, but also the inter-industry demand. This equation does not include the inter-industry demand since consumers usually buy the finished products and not intermediate products, and therefore the final demand will be a vertical vector showing the products of all i regions.

The value added is payments from the different production sectors to the payments sectors. These sectors are represented by wages for labor, taxes for government services, interest payments for capital, rental payments for land, profit for entrepreneurship and others. These payments come from the production sectors, so the value added is a horizontal vector. If labor (L) is one component of the value added, while N denotes all the other factors contributing, the total value added is.

$$W_i = L_i + N_i \tag{2.11}$$

If the imports are not included in the final demand it will be added to the value added (Miller & Blair, 1985). In this case the imports are included in the final demand.

The total output from each industry is the sum of the inter-industry sales by each sector plus the sales to the final demand. The total input is the sum of the requirements for each industry to produce its output plus the value added. A simple layout of a general input-output framework is showed in matrix form in table 1.

Table 1 - A simple input-output framework (Miller & Blair, 1985; United Nations, 1999)

	Industries (consumers)		
Industries/ Products (producers)	Inter industry flow	Final demand	Total output
	Value added		
	Total input		

The inter industry flow section of table 1 shows the different industries in the column as consumers that require input of products from industries as producers of these products. Value added shows the primary factors or endowments in the rows showing how much each industry (as a consumer) requires of each endowment. The final demand vector show the total demand placed on the industries as producers. For there to be equilibrium in the economy as shown in figures 1 and 2 total output should be equal to the demand, and also the total input should be equal to total output.

2.3.2 Basic calculations

From the input-output tables the value flow from one sector to another (the inter-industry flows) and final demand is exogenously given and the total output and the A matrix must be derived from these. Table 2 shows the nomenclature that is used in the following calculations.

Table 2 - Nomenclature for basic input-output calculations

n		Number of sectors
Z	Flow matrix	Flow of input from sector i to sector j
X	Total output	Gross output from sector i
A	A matrix	The ratio of input to output from sector i to sector j
Y	Final demand	The demand of products placed on sector i
L	Leontief inverse	Defined as $(I-A)^{-1}$

The total output produced in one sector can be calculated from the flow from that sector to all the other sectors, plus the final demand placed on it. This is the notion of equilibrium output, where aggregated production is equal to aggregated demand.

$$X_i = z_{ij} + Y_i \quad 2.12$$

The technical coefficient is the relationship between the inputs into the production of a good to the output of that product (Miller & Blair, 1985).

$$a_{ij} = \frac{z_{ij}}{X_j} \rightarrow z_{ij} = a_{ij}X_j \quad 2.13$$

Each element a_{ij} shows the fixed relationship between one sectors output and its inputs. This means that a sector does not benefit from increasing its output up to a certain amount, achieving economies of scale, but operates under constant returns to scale, explained in chapter 2.1.2. The total output for each sector will then be equal to

$$X_i = a_{ij}X_j + Y_i \quad 2.14$$

This equation shows that the production for sector *i* is dependent on the final demand placed on that sector and the demand coming from the other sectors. For *n* sectors this can be shown as a linear equation.

$$X_n = a_{n1}X_1 + a_{n2}X_2 + \cdots + a_{ni}X_i + \cdots + a_{nn}X_n + Y_n \quad 2.15$$

The input-output system can be described by n equations with n unknowns and can hence be represented in matrix form (Miller & Blair, 1985).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1i} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2i} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{ni} & \cdots & a_{nn} \end{bmatrix}, \; X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}, \; Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \quad 2.16$$

Setting (I) to be the identity matrix with ones on the diagonal it is possible to solve for the final demand and the total output. The complete sector by sector system would then be

$$(I - A)X = Y \rightarrow X = (I - A)^{-1}Y \qquad 2.17$$

The A matrix consists of the technical coefficients between all the inputs and outputs in the region. One column shows how much that sector requires from all the other sectors in order to produce goods or services worth one monetary unit. The $(I\text{-}A)^{-1}$ is the Leontief inverse (L) and shows the total amount of goods and services that is needed to produce one unit of output (Miller & Blair, 1985).

2.3.3 Pricing

As mentioned earlier the input-output tables are listed in monetary values, but money can be valued in several ways. According to United Nations (1999) there are three ways in which prices can be measured in the systems of national accounts (SNA) which is a framework that sets the international statistical standards for measuring the market economy. The relationship between the price categories are (United Nations, 1999)

Purchaser prices – Trade and transport margins = Producer prices

Producer prices – taxes on products + subsidies on products = Basic prices

Purchaser prices

This is the price paid by the purchaser to get the delivery of a unit of the good or service required by the purchaser (United Nations, 1993). The price is excluded any VAT and other deductible taxes that the purchaser in turn can deduct from the customers they sell to. Included in the price is the trade and transport margin that is separately invoiced by the purchaser (OECD, 2001b).

Producer prices

The amount received by the producer per unit of a good or service from the purchaser is called the producer price. It is not included VAT or other deductible taxes that is invoiced to the purchaser and trade and transport margins (United Nations, 1999).

Basic prices

This is the price received by the producer from the purchaser per unit output of a good or service (United Nations, 1993). The basic price is not including any taxes on products such as sales tax, manufacturers excise tax, and non-deductible VAT (United Nations, 1999). Included in the price are any subsidies that come from the sale or production process of that product (United Nations, 1993). Basic prices are the valuation recommended to use in the system of national accounts.

2.4 Linear Programming

The first uses of linear programming were invented and developed in the 1940s in order to plan production, allocate resources and formulate strategies (Matoušek & Gärtner, 2007). Because of its extensive applicability it is used by several sectors in the economy such as the military, private companies, government, and in urban planning (Bazaraa, Jarvis, & Sherali, 2010). That a problem is linear means that it is restricted by linear constraints or inequalities. A linear program tries to find one solution that either minimizes or maximizes an objective function constrained by system of linear equations and inequalities. The objective function is a linear function that needs to be optimized. The set of constraints within the solution must lie which are also linear equations (Matoušek & Gärtner, 2007). An example of a linear problem:

$$\begin{aligned} &\max z = x + y \\ &satisfying\ x - y \leq 100 \\ &satisfying\ x\ > 50 \end{aligned} \qquad 2.18$$

Here the objective function is to maximize z under the constraint that x – y be no larger than 100 and x be larger than 50. This is a very simple linear programming problem, and usually the variables are many more and the constraints are more complex. Any solution to the problem that satisfies the constraints is a feasible solution and the solution that returns the maximum (or minimum) value of the objective function is called the optimal solution. In general a linear program can have one, several or no optimal solutions. When no solution is found the program is called infeasible, and when there is an infinite number of solutions the program is called unbounded and no solution is found (Matoušek & Gärtner, 2007). Linear programming is an extensively used method because it is transparent, can be used on large and complex systems, and can provide a large amount of information (Bazaraa, Jarvis, & Sherali, 2010). The world trade model with bilateral trade in this thesis is a linear programming problem.

3 GTAP Database

The data the world trade model optimization problem is based on comes from the GTAP (Global Trade Analysis Project) database. This chapter will give a short overview of what GTAP is and the development of the database over time. The structure of the database will be explained with focus on important issues in relation to the world trade model.

3.1 Overview and History

The global trade analysis project was first established in 1992 to give more centralized and easily applicable data for those wanting to perform international economic analysis. The project consists of several different parts. First and foremost it is a global database, but it also constitutes an equilibrium modeling framework and software to implement the model. It is a global network where more than 150 countries participate and over 6700 researchers are associated.

The database consists of detailed input-output tables showing inter-industry flows within regions and also the bilateral trade flows and transportation requirements between regions. Version 1 of the database was developed from another project (the SALTER project) that had been commenced by the Australian Industry Commission in the 1980s to 1990s, and the first database assembled in 1993 had 15 regions and 37 sectors. Since then the database has been under continual development and the latest version is GTAP 7 database. In this database there are input-output tables and bilateral trade flows for 113 regions and 57 sectors for the year 2004 (Hertel & Walmsley, 2008).

Usually the GTAP data base is used with a GTAP model and software where users can aggregate the data to desired levels and use the model to analyze impact of trade, environmental concerns, migration etc. on global policies. The data base is also used, as in this thesis, to get input-output tables and numbers (Center for Global Trade Analysis, 2011).

3.2 Data structure

The GTAP database consists of four different files: sets, parameters, main data and energy volume data (Narayanan G., Dimaranan, & McDougall, 2008). The set files show the different arrays in the database where the list of regions, list of traded commodities, and the list of endowment commodities are important for this thesis. There are 113 regions in the database, and these are aggregated from 226 countries, the full list and aggregation level can be found in the GTAP 7 Data Base (Narayanan G., Dimaranan, & McDougall, 2008). The definitions of the traded commodities stem from the Central Product Classification (CPC) for agriculture and food processing sectors and from the International Standard Industry Classification (ISIC) for all other sectors. The explanation for the use of two different classification systems is that the ISIC does not provide enough detail for the agriculture and food processing sectors. A list of the 57 sectors from the GTAP database can be found in the GTAP7 Data Base (Narayanan G., Dimaranan, & McDougall, 2008). There are 5 endowment commodities divided into mobile endowment commodities, which are skilled labor, unskilled labor, and capital; and sluggish (or immobile) endowment commodities, which are land and natural resources (Narayanan G., Dimaranan, & McDougall, 2008).

The main data file includes all the main arrays in the GTAP database where all flows of goods and services are listed in monetary (US dollar) values. Table 3 below shows the GTAP variables or arrays used in this analysis, its input-output equivalent if there is a direct correlation, and a short description of the arrays.

Table 3 - Relation between GTAP and Input-Output

GTAP variable	Dimensions	Input-output variable (if an equivalent)	Description
VDFM	57 × 57 × 113	Z matrix	Inter industry flows
VDFM_2	57 × 113	Y_f	Final demand on domestic production coming from industries
VDGM	57 × 113	Y_g	Final demand on domestic production coming from government institutions
VDPM	57 × 113	Y_h	Final demand on domestic production coming from households
VIFM	57 × 113	IY_f	Final demand on imported products coming from industries
VIGM	57 × 113	IY_g	Final demand on imported products coming from government institutions
VIPM	57 × 113	IY_h	Final demand on imported products coming from households
TVOM	57 × 113	g	Total domestic production
VFM	5 × 57 × 113		Primary factor purchase or total endowments
VIMS	57 × 113 × 113		Total imports
VTWR	3 × 57 × 113 × 113		Commodity exchange by transportation type

VDFM refers to the domestic purchases by firms and consists of the inter-industry flows and the final demand from industries. This matrix is actually 57 x 58 x 113, but it is only the 57 first columns that represent the tradable commodities. This matrix shows the inter-industry flows going from one sector to all the others for all regions. It is only showing the domestic flows, not including inter-industry demand that is imported. The last column of the VDFM matrix shows the final demand coming from industries, called VDFM_2 in table 3. VDGM and VDPM show the final demand coming from government and households respectively for all regions. The final demand is divided up into these three sectors because they have relatively different demand structures, and if it is desirable to do scenario analysis (at a later stage), it would be possible to change just the household demand and see the changes from this. Further in the input-output analysis the inter-industry demand VDFM is referred to as the Z matrix, the domestic final demand is Y_f, Y_g and Y_h for industries, government and households respectively.

Final demand placed on the domestic economy coming from other regions is also divided into these three sectors, households, industries and government. The industries matrix is constructed in the same way as VIFM, so in this model only the last column is used. VIGM is the final demand coming from foreign governments while the VIPM is the final demand from households in other regions. For the imported final demand IY_f, IY_g and IY_h represent the foreign industries, governments and households respectively.

The total domestic production TVOM shows the production of all sectors in all regions. This production is a sum of all the export going out to other regions plus the inter-industry demand plus the domestic final demand (Rutherford & Arbor, 2005).

Primary factor purchase, VFM, shows the total use of these factors by each sector for all regions. For there to be factor market equilibrium the factor purchases must equal the factor sales, or factor payments (wages, rent etc) must equal factor income (Rutherford & Arbor, 2005).

The total import matrix VIMS shows the import of both inter-industry demand and final demand; it does not differentiate between the two. Lastly the VTWR matrix shows the flow of products between all sectors and showing by which transportation mode it is transported.

To get a better overview of how the different variables in the GTAP database is connected refer to figure 4. This shows the values in an open economy, but shows the economy for one single region, while the other regions are aggregated into "rest of the world". This is to make the model more transparent and clear. The model is based on the figure from the article "A Graphical Exposition of the GTAP model (Brockmeier, 2001) but is simplified to include the parameters that is used in this thesis and with the right prices as used here.

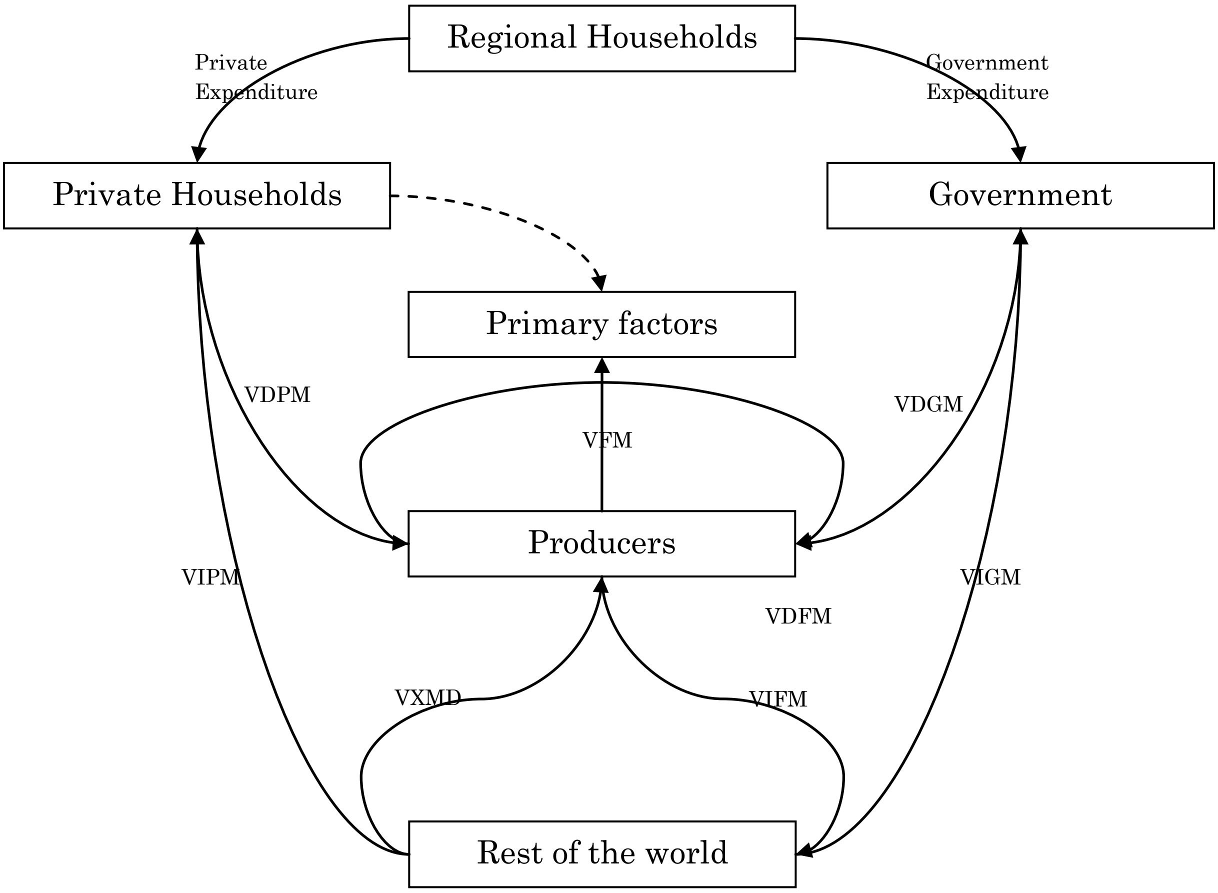

Figure 4 - Representation of the GTAP database in an open economy (Brockmeier, 2001)

This figure shows the variables used for this thesis; however the transportation sector has been left out for better understanding. All variables used are in market prices, which is explained in the chapter below. The economy is here divided into the regional households which consist of private households and the government. Then there are the regional primary factors, the producers and the rest of the world which constitute all the other regions. The private households and the government place a final demand on the producers, VDPM and VDGM. In addition the producers require products from other industries (suppliers) which are the inter-industry demand and also final demand coming from other sectors, VDFM. The producing sectors also have demand of primary factors, shown by the VFM flow. The dotted line going from private household to primary factors indicate the labor force. Finally the figure shows the interaction with the rest of the world. This is through final demand placed on other regions coming from private households, VIPM and government, VIGM, and also coming from the producers, VIFM, this is the imports into the region. Then there is the demand placed on the producers coming from other regions, the exports VXMD.

3.3 Pricing in GTAP

Pricing in general input-output analysis was explained in chapter 2.3.3. In the GTAP database they also use three types of pricing, agent prices, market prices and world prices. World prices are only included when there is an open economy. The agent prices and market prices differ depending on whether the commodity is imported or domestically produced. For imported products the values at market prices and agent prices are

$$Market\ prices = World\ prices + trade\ and\ transport\ margins + import\ duties$$

$$Agent\ prices = Market\ prices + sales\ and\ purchase\ taxes$$

For domestic purchases of domestically produced goods the agent prices also apply. For prices on exports the world price becomes

$$World\ prices = Market\ prices - export\ taxes$$

The prices used in this thesis are that of domestic market prices (Mcdonald & Thierfelder, 2004). This is because the value of the imports would include taxes and international margins if other prices were used (Peters, 2007).

4 World Trade Model

The world trade models are based on the concept of comparative advantage and are designed to address issues associated with sustainable development. Instead of maximizing consumption and growth, which is normal in other such models, the world trade model will minimize factor use (Duchin, 2005). In this section the three models; the no-trade model (NT), the world trade model (WTM), and the world trade model with bilateral trade (WTMBT) are described.

Several models have been developed to answer questions and pose scenarios of the development of the world economy. The models described in this section try to answer questions and pose scenarios on how to lower the impact human activities have on the planet. International trade models typically aim at maximizing growth. The world trade models on the other hand aim at minimizing factor use (Duchin, 2005). These models can be used in analyzing implications of different scenarios such as increased consumption, changes in consumption patterns, better technologies, and change from non-renewable energies to renewable ones. The models are in the form of linear programs that can be represented as matrices. The no-trade model and world trade model have m regions, n goods and k factors of production, while the world trade model with bilateral trade also has s transport sectors. The no-trade model and world trade model (Duchin, 2005) were applied to a database of 10 regions, 8 goods and 3 factors of production. The world trade model with bilateral trade (Strømman & Duchin, 2006) was applied to a database of 11 regions, 8 goods, 6 factors of production, and 4 transportation sectors.

4.1 No Trade Model

The no trade model describes a world economy with m closed economies that do not trade goods or services with each other. This model is mostly for comparison with the other two models to confirm that each country actually has benefit-of-trade.

Table 4 - Nomenclature for NTM and WTM

	m		Number of regions
	n		Number of goods
	k		Number of factors of production
	i, j		Regions i, j = 1·····m
Exogenous variables and parameters	A_i	n x n	Inter-industry matrix in region i
	F_i	k x n	Factor inputs per unit of output in region i
	y_i	n x 1	Final demand in region i
	$f_{nt,i}$	k x 1	Factor use in region i without trade
	f_i	k x 1	Factor endowment in region i where $f_i \geq f_{nt,i}$
	π_i	k x 1	Factor prices in region i
Endogenous variables	x_i	n x 1	Output in region i
	$p_{nt,i}$	n x 1	Commodity prices in region i without trade
	p_0	n x 1	World commodity prices
	r_i	k x 1	Factor scarcity rent in region i
	α_i	scalar	Shadow prices showing benefit-of-trade

The model is represented by a primal input-output quantity model, the dual price model and an income equation. The first part of the primal input-output quantity model makes sure that the input is equal to the output for all regions. When there is no trade each country is only concerned with the final demand in their country so the production only need to meet this demand. In addition there would be no benefit of producing more than what is required to meet the final demand, and hence the production should be just enough to meet the demand. At this point the economy is in equilibrium as seen in figure 1 in chapter 2.1.1.

$$\begin{bmatrix} (I-A_1') & -F_1' & 0 & -(I-A_1')p_{nt,1} & 0 \\ \vdots & & \ddots & & \ddots \\ (I-A_m') & 0 & -F_m' & 0 & -(I-A_m')p_{nt,m} \end{bmatrix} \begin{bmatrix} p_0 \\ r_1 \\ \vdots \\ r_m \\ \alpha_1 \\ \vdots \\ \alpha_m \end{bmatrix} \leq \begin{bmatrix} F_1'\pi_1 \\ F_2'\pi_2 \\ \vdots \\ F_m'\pi_m \end{bmatrix} \qquad 4.1$$

The first statement (I-A)*p ≤ F*π makes sure that the value of production is not larger than the value of the factor inputs, since this would indicate the sectors would have a negative income and would not produce at all. The primal also makes sure that the factor inputs required for production is equal to the total factor use without trade.

$$\begin{bmatrix} -F_1 & & 0 \\ & \ddots & \\ 0 & & -F_m \end{bmatrix} \begin{bmatrix} x_{nt,1} \\ \vdots \\ x_{nt,m} \end{bmatrix} = \begin{bmatrix} -f_{nt,1} \\ \vdots \\ f_{nt,m} \end{bmatrix} \qquad 4.2$$

The dual balance states that

$$\begin{bmatrix} (I-A_1^{'}) & & 0 & -F_1^{'} & & 0 \\ & \ddots & & & \ddots & \\ 0 & & (I-A_m^{'}) & 0 & & -F_m^{'} \end{bmatrix} \begin{bmatrix} p_{nt,1} \\ \vdots \\ p_{nt,m} \\ \pi_1 \\ \vdots \\ \pi_m \end{bmatrix} = \begin{bmatrix} 0 \\ \vdots \\ 0 \end{bmatrix} \quad 4.3$$

It is then possible to find the income equation. Setting the two dual balances equal, transposing and then multiply by *x* and substituting from the primal balance the income equation can be derived (Duchin, 2005).

$$p_{nt,i}^{'} y_i = \pi_i^{'} F_i x_{nt,i} = \pi_i^{'} f_{nt,i} \quad 4.4$$

This shows that the cost of production must be equal to the income from the sale of the products. This indicates that there is no surplus income from the production of goods in the countries. There is equilibrium in the economy, and perfect competition.

4.2 World Trade Model

The world trade model is constructed to solve for minimizing factor use instead of maximizing consumption which is the common goal of international trade models. It is also based on the concept of comparative advantage explained in chapter 2.1.3. The world trade model solves for the best division of labor and world prices based on each country's comparative advantage. The final demand, factor endowment, factor prices and technologies are exogenously given and country specific. In addition there is the benefit-of-trade constraint that makes sure no country can exceed their no-trade factor use under international trade (Duchin, 2005). The world trade model uses the same nomenclature as the no-trade model. In the primal program the goal is to minimize factor cost

$$Minimize Z = \sum_i \pi_i^{'} F_i x_i \quad 4.5$$

Where the factor cost is the product of the factor price, the factor intensity matrix and the total production. This is subject to

$$
\begin{bmatrix}
(I-A_1) & \cdots & (I-A_m) \\
-F_1 & & 0 \\
 & \ddots & \\
0 & & -F_m \\
-p_{nt,1}^{'}(I-A_1) & & 0 \\
 & \ddots & \\
0 & & -p_{nt,m}^{'}(I-A_m)
\end{bmatrix}
\begin{bmatrix} x_1 \\ \vdots \\ x_m \end{bmatrix}
\geq
\begin{bmatrix}
\sum_i y_i \\
-f_1 \\
\vdots \\
-f_m \\
-p_{nt,1}^{'} y_1 \\
\vdots \\
-p_{nt,m}^{'} y_m
\end{bmatrix}
\qquad 4.6
$$

with

$$x_i \geq 0, \forall i \qquad 4.7$$

The first part of the first constraint makes sure that the total production of goods in all countries is large enough to meet the final demand in all countries. The second part ensures that the total factor input in each country does not exceed its factor endowment. Since factors of production have limited potential of being transferred from country to country, in the world trade model this is not an option. The third section of the primal assures for the benefit-of-trade by making sure the value of the imports at no trade prices are higher or equal to the value of the exports. The constraint simply states that no country can have negative output.

In the dual program the goal is to

$$Maximize Z = p_0^{'} \sum_i y_i - \sum_i r_i^{'} f_i - \sum \alpha_i (p_{nt,i}^{'} y_i) \qquad 4.8$$

The first statement is the value of world final demand at world prices. The second statement is the scarcity rent, a rent paid on factors with low supply to raise the prices of these factors, times the factor endowment. The last statement shows the shadow price that assures that the world prices are high enough to account for the benefit-of-trade rent times the value of final demand at no-trade prices. The dual program is subject to

$$\begin{bmatrix} (I-A_1^{'}) & -F_1^{'} & & 0 & -(I-A_1^{'})p_{nt,1} & & 0 \\ \vdots & & \ddots & & & \ddots & \\ (I-A_m^{'}) & 0 & & -F_m^{'} & 0 & & -(I-A_m^{'})p_{nt,m} \end{bmatrix} \begin{bmatrix} p_0 \\ r_1 \\ \vdots \\ r_m \\ \alpha_1 \\ \vdots \\ \alpha_m \end{bmatrix} \le \begin{bmatrix} F_1^{'}\pi_1 \\ F_2^{'}\pi_2 \\ \vdots \\ F_m^{'}\pi_m \end{bmatrix} \quad 4.9$$

With

$$p_0, r_i, \alpha_i \ge 0, \forall i \quad 4.10$$

The first part of the restriction for the dual indicates that the value of the inter-industry flows must be smaller or equal to the value of factor inputs. If the value of the inter-industry flows were larger than the value of factor inputs the sector would have a deficit which would indicate that there should be no production.

The primal and dual has a common optimal value and it is possible to set these equal to each other

$$\sum_i \pi_i^{'} F_i x_i = p_0^{'} \sum_i y_i - \sum_i r_i^{'} f_i - \sum_i \alpha_i (p_{nt,i}^{'} y_i) \quad 4.11$$

Rearranging it becomes

$$p_0^{'} \sum_i y_i = \sum_i \pi_i^{'} F_i x_i + \sum_i r_i^{'} f_i + \sum_i \alpha_i (p_{nt,i}^{'} y_i) \quad 4.12$$

This equality ensures that the value of the world's final demand is equal to the value of factor inputs plus the scarcity rents paid on factors low on supply plus the benefit-of-trade rent (Duchin, 2005).

The world trade model solves for the optimal solution, which is the scenario (including the no-trade scenario) with fewest factor inputs. Here the factor endowments, factor prices, final demand and technologies are exogenously determined and country specific. There is no restriction stating that the factor endowments need to be fully utilized or that there has to be a balance of trade for each country. In addition there are no barriers for trade and hence no transportation costs (Duchin, 2005). In the next model, the world trade model with bilateral trade, transportation factors are taken into consideration.

4.3 World Trade Model with Bilateral Trade

Transportation is one of the main sources of greenhouse gas emissions in the world. The aviation and maritime sector stands for about 6% of the total emissions in the EU-27 (EEA, 2009). Road transport stood for about 18% of all greenhouse emission in the UK in 2002 (UK National Statistics, 2002). From this it would mean that the transportation sector accounts for about 1/4th of the total GHG emissions, while the IPCC states that the sector accounts for about 13% (IPCC, 2007). Either way the emissions are large and it is essential to include transportation in a world trade model. From an economic point of view, if transportation cost was not incorporated into the cost of the product, a country would be indifferent as to where the product was produced. The world trade model with bilateral trade (Strømman & Duchin, 2006) is an extension of the world trade model described above taking into account these transportation costs. The cost comes from the physical input into the transportation sector such as labor, capital and energy, and the cost will differ according to what the weight of the product, the distance it will travel and the mode of transport used (Strømman & Duchin, 2006). The purpose of the world trade model with bilateral trade is to distinguish where the import into a region stems from and to see to what regions their export goes. The nomenclature is slightly different from the NT and WTM nomenclature.

Table 5 - Nomenclature for the WTMBT (Strømman & Duchin, 2006)

	m		Number of regions
	n		Number of goods
	k		Number of factors of production
	s		Number of transport sectors
	i, j		Regions i, j = 1·····m
Exogenous variables and parameters	A_i	(n + s) x (n + s)	Inter-industry matrix in region i
	F_i	k x n	Factor inputs per unit of output in region i
	D	m x m	Distances between regions
	W	(n + s) x (n + s)	Weight of goods
	T_{ij}	(n + s) x (n + s)	Requirements for transport from region i to j
	y_i	n x 1	Final demand in region i
	$f_{nt,i}$	k x 1	Factor use in region i without trade
	f_i	k x 1	Factor endowment in region i where $f_i \geq f_{nt,i}$
	π_i	k x 1	Factor prices in region i
	$p_{nt,i}$	(n + s) x 1	Commodity prices in region i without trade
Endogenous variables	x_i	(n + s) x 1	Output in region i
	p_i	(n + s) x 1	Commodity prices in region i with trade
	r_i	k x 1	Factor scarcity rent in region i
	e_{ij}	(n + s) x 1	Commodities exported from region i to j
	α_i	Scalar	Shadow prices showing benefit-of-trade

Firstly it is important to notice that the transportation sectors are also considered as goods, so for example the A matrix shows the (n+s) goods. In addition to the extra transportation sectors there is a weight matrix (*M)*, a distance matrix (*D)*, a transportation matrix *(T)* and an export vector *(e)*. The M matrix shows the weight of a good and by which mode it is transported. Columns represent the sector producing the good while rows represent the transportation mode. The weight of the good will then be placed in the cell that corresponds to the transportation mode. This means that there will only be numbers in the rows representing transportation. The D matrix shows the distance between all the regions. The T matrix is calculated from the distance and weight matrix

$$T_{ij} = d_{ij}W \qquad 4.13$$

This shows the need for transport from region i to j. Lastly the export vector *(e)* show the amount of goods exported from region i to region j (Strømman & Duchin, 2006). The primal objective function is the same under the WTMBT as under the WTM

$$Minimize\, Z = \sum_i \pi_i^{'} F_i x_i \qquad 4.14$$

The constraints are different however, the first set is

$$\left(I - A_i\right) x_i - \sum_{j \neq i} e_{ij} + \sum_{j \neq i} (I - T_{ji}) e_{ji} \geq y_i \qquad 4.15$$

This is the regional goods balance stating that the total production, minus the exports to other countries plus the imports into the country must be equal or larger than the final demand in that country. Export minus imports *(e_{ij} – e_{ji}),* where the first term means export from country i to all other countries, while the last term means the export from all countries, j, into country i, or simply the import into country i, shows the trade balance for the country. Demand for transportation is placed on the imported products, which means that the cost of transportation is paid by the country importing the goods. The second set of restrictions

$$F_i x_i \leq f_i \qquad 4.16$$

Production of a good requires factor inputs. The total amount of factors required to produce total output in the country cannot exceed its factor endowments. The last set of restriction to the primal is to ensure the benefit-of-trade constraint

$$p_{nt,i}^{'}(I - A_i)x_i \leq p_{nt,i}^{'} y_i \qquad 4.17$$

To ensure that the benefit-of-trade constraint is followed the last set of restrictions states that the value of exports does not exceed the value of imports at no-trade prices (Strømman & Duchin, 2006). The dual formulation is

$$Maximize\, Z = \sum_i y_i^{'} p_i - \sum_i f_i^{'} r_i - \sum_i p_{nt,i}^{'} y_i \alpha_i \qquad 4.18$$

It maximizes the value of the world final demand minus the factor scarcity rent and minus the benefit-of-trade rent. This is subject to two constraints for all i where i ≠ j

$$\left(I - A_i^{'}\right) p_i - F_i^{'} r_i - (I - A_i^{'}) p_{nt,i} \alpha_i \leq F_i^{'} \pi_i \qquad 4.19$$

$$\left(I - T_{ji}^{'}\right) p_i - p_j \leq 0 \qquad 4.20$$

The first constraint determines the prices in the producing and exporting countries which are dependent on the value of production, scarcity rent, and benefit-of-trade rent. The second constraint sets the price in the importing countries, which depends on the price of the good in the exporting country as well as the demand for transportation (Strømman & Duchin, 2006). The world trade model with bilateral trade is the basis for the rest of this thesis and the program being used is based on this model.

5 Implementation

The statistical data for all the 113 countries used in this thesis comes from the GTAP database. Matlab and GAMS is used in combination to solve the linear programming optimization problem. A short introduction to the tools used to solve the WTMBT will be explained following a description of how the data from the GTAP database was used to calculate the necessary input-output variables and the issues encountered.

5.1 Matlab

Matlab is a computing language that is used for algorithm development, data analysis, visualization, and numerical computations. It is developed mainly to support vector and matrix operations which is essential in many engineering programs, and is seen as an easier programming language. For this analysis version R2010b is used (MATLAB, 2010). In the implementation of the world trade model, MATLAB was used to prepare the data so it could be used directly in the minimization problem in addition to solving the no trade model and producing results.

5.2 GAMS

The General Algebraic Modeling System (GAMS) is designed to solve optimization/minimization problems both for linear, non-linear and mixed integer programming problems. For large and complex systems that require several iteration rounds and revisions to give an accurate model GAMS is very good (GAMS, 2009). GAMS is the program that solves the WTMBT minimization problem with all its constraints. It receives data from MATLAB and sends the results back to MATLAB when an optimal solution is found. In GAMS there is an option to choose between several different solvers to find a solution to the problem.

5.2.1 Solvers

After the necessary equations, datasets and variables are included in the GAMS model, the objective function must be stated. To solve the corresponding optimization problem there are several different solution procedures ranging from linear programming to nonlinear programming to mixed integer programming and quadratic programming (Rosenthal, 2008). In solving the WTMBT linear programming, LP, is used and the goal is to minimize the objective function.

In addition to the choice of solution procedures there are several different solvers with different properties in optimizing the objective function. There are 33 different solvers to choose from in GAMS, and for this thesis the CPLEX 11 solver was chosen. This solver is designed to solve difficult and large problems quickly and with little needed involvement by the user. In solving a linear programming problem it uses several alternative algorithms (GAMS, 2008).

When used in this model, GAMS receives data from Matlab containing the needed datasets, parameters, and variables. The no-trade model is calculated in Matlab since this is not a time consuming and large problem. Further the objective function and its constraints are included (see supporting information appendix 5: GAMS LST file). GAMS then uses the CPLEX 11 solver to find an optimal solution to the LP problem of minimizing the objective function. The results obtained from the computation are sent back to Matlab where the results are structured in the desired fashion.

5.3 Application of the model

The data from the GTAP database was readily available to be used in input-output analysis. The structure of the data was explained in chapter 3.2 and data for all 113 countries, 57 sectors, 5 factors of production, and 3 transportation sectors could be used. The WTMBT tries to solve for an alternative solution to world production and trade that reduces the effect human activities has on the climate. All data are values for one year of trade between regions of the World. For the GTAP data to be used in the world trade model the matrices and vectors needed would have to be calculated from the statistical data. Firstly the calculations of the different matrices will be derived with explanation of the assumptions made. Then the issues that arose that prevented the model from finding an optimal solution and the following solution will be explained.

5.3.1 Derivation of input-output variables

From the GTAP database the Z matrix, Y vectors, import values, g vector (total output), factor inputs, value total endowments, commodity exchange by transport type and exports were already given (see table 3 in chapter 3.2). All the derivation explained below can also been found in the matlab file WTMBT_Dataload_Ver400 in the supporting information.

Final demand (Y) vector

The final demand is already given in the GTAP database, but it is divided into final demand coming from industries, governments and households, and also whether the products were domestically produced or imported. The total final demand vector Y results from simply adding the individual final demand vectors together.

$$\begin{aligned} Y_d &= y_f + y_g + y_h \\ Y_{im} &= y_{f,im} + y_{g,im} + y_{h,im} \\ Y &= Y_d + Y_{im} \end{aligned} \qquad 5.1$$

Here Y_d is the final demand placed on domestically produced goods while Y_{im} is the final demand placed on imported goods and the total final demand, Y, is the sum of these two. This then shows the final demand of each product for all countries.

Inter industry coefficient (A) matrix

The A-matrix is a coefficient matrix that shows how much each sector requires as input into the production of one dollar's worth of the product from all the other sectors. In the GTAP database this information is already given in the total inter-industry flow matrix Z, so to get the coefficient matrix dividing by the total output vector (g) is required. For all sectors as producers (t), sectors as consumers (tt) and all regions (r) we have

$$A_{t,tt,r} = Z_{t,tt,r}/g_{tt,r} \qquad 5.2$$

This gives one A-matrix for all 113 countries.

Factor coefficient (F) matrix and total endowments (E) vector

From the GTAP database the VFM variable shows the primary factor purchases for each country. This shows the total flow of primary factors into each industry. To find the factor coefficient matrix, F, the total flows matrix needs to be divided by the total output, g, so as to get a matrix showing the factor requirements for production of one dollar worth of each good. Here *e* is the 5 endowments, *t* is the 57 sectors and *r* is the regions.

$$F_{e,t,r} = vfm_{e,t,r}/g_{t,r} \qquad 5.3$$

If there were any sectors that did not require any factor inputs for production in a country these columns would be set to a large number to prevent this product from being produced in this country. The reasoning behind this is that if the factor inputs were to remain zero, it would indicate that there was no primary factor costs related to the production of that specific product, and this would probably have been due to some error in the collection of data. However, from the GTAP database there were no such cases and the original F matrix could be used.

The total endowment vector, E, shows the total amount of primary factor use. Since all values are monetary values the E-vector can be calculated directly from the GTAP data.

$$E_{e,r} = \sum vfm_{e,t,r} \qquad 5.4$$

However to be sure that there is at least one optimal solution, which would be the no trade solution, the E-vector is calculated from the total output when there is no trade, x_nt.

$$E_{e,r} = F_{e,t,r} x\_nt_{t,r} \quad 5.5$$

When using this E vector the factor constraint should never be too strict for the minimization problem of the WTMBT to solve for an optimal solution.

Transportation (T) matrix

In the world trade model with bilateral trade the transportation matrix is calculated from the weight matrix and the distance matrix. From the GTAP database there was no direct information on neither the weight or the distance on trade flows between countries. There was information on the total commodity exchange and by what transportation mode it was transported between all countries and on the total imports from one country to another. On the first attempt to run the WTMBT this calculation was used to find the T-matrix where m is the transportation sectors.

$$T_{m,t,r,rr} = vtwr_{m,t,r,rr} / vims_{t,r,rr} \quad 5.5$$

The T-matrix is a matrix only showing the transportation requirements for each sector, and it had to be put into a 57x57x113x113 matrix instead of 3x57x113x113 so it could be used in the WTMBT. After some trial and error, and some evaluation of the numbers in the T-matrix, it was clear that it was not applicable to the model. The numbers in the T-matrix, showing the cost of transporting one dollar's worth of a good, should be some percentage of the total value, meaning it should be lower than 1. This was not the case in the T-matrix derived directly from the GTAP database, and it was decided that a reasonable estimate should be used instead.

It is differentiated between bulk products and consumer goods, where the transportation cost of bulk products is set to be 20% of the total value, while the transportation cost of consumer goods is set to be 5% of total value. In addition it is assumed that 80% of the transportation occurs by water transport while the other 20% is by land transport. Air transport is excluded here since it accounts for a very small, only 1 percentage of total transport (Hummels, 2007). Distance is not accounted for in this T-matrix, but it can be assumed that the percentage cost does not change much as the distance increases, since also the carrier will increase in size and there will be economies of scale. For the sectors that could not be traded, such as transportation sector, electricity and other administration sectors, the values were set to a large number.

5.3.2 Final implementation

Since the WTMBT has only been used on large datasets once before, then using the EXIOPOL database (Fjellheim, 2010), there were several issues to be resolved before it produced an optimal solution with all constraints in place. The main issues were concerning the factor constraint, which seemed like it might be too strict. When the model was compiled with the EXIOPOL database the factor constraint was relaxed to the extent that each country could increase their total endowment by up to 50% and that the primary factor used for each good could increase by as much as three times its initial value. With the use of the GTAP database it was possible to find an optimal solution with the factor constraint at its statistical value, but no constraint on the use within each sector. Another issue was concerning the transportation matrix which was explained above. It was found that it was not possible to solve the model with transportation matrix calculated from the GTAP data, and reasonable estimates were used instead.

In the end the world trade model with bilateral trade was run with factor constraint at statistical values, an estimated transportation matrix and without the benefit-of-trade constraint for 113 regions, 57 sectors, 5 primary factors, and 3 transportation sectors.

6 Results and Analysis

In this implementation of the world trade model with bilateral trade there is no benefit-of-trade (BOT) constraint which means that some countries can be worse off after trade than under no-trade conditions. There is no constraint on how much the primary factor use for each individual sector can increase either, which indicates that land, labor, capital, and natural resources can move around freely from one sector to another. Total primary factor use on the other hand cannot exceed the current, statistical level. Some products are traded to a lesser degree statistically than others between regions, such as electricity, water supply, and other service products/sector. In this model it is therefore set that these products cannot be exported at all. All values in this analysis are in U.S dollars (Narayanan G., Dimaranan, & McDougall, 2008).

6.1 Aggregation

From the GTAP database there were 113 regions and 57 sectors, however when an analysis is conducted it gives a better overview when these are aggregated down to fewer regions and sectors. The amount of sectors was aggregated from 57 down to 15 sectors, Appendix 2 shows how the sectors are aggregated. Regions were narrowed down to 11 regions and 6 regions as can be seen in Appendix 3 and 4.

6.2 Change in output

Aggregated worldwide production in 2004 was US$77 753 billion. The NT and WTMBT returns very close values when it comes to worldwide production, US$66 085 billion and US$66 172 billion respectively which is a reduction in production of 15% (for both) from the statistical values. This would indicate that most of the sectors have a lower production compared to the statistical values.

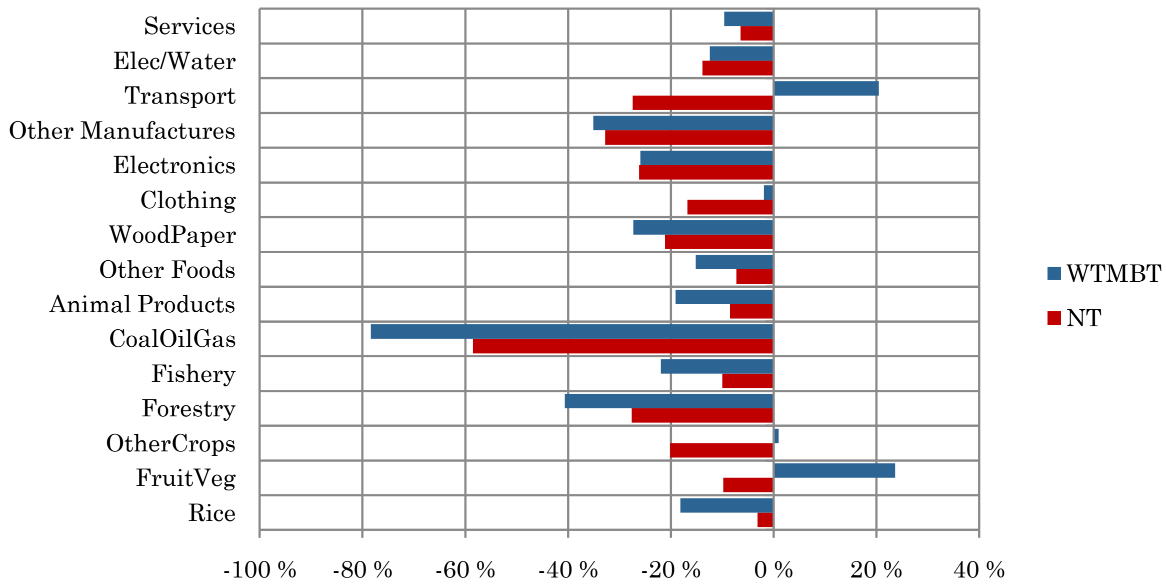

Figure 5 - Change in production by sector (aggregated to 15 sectors)

Figure 5 shows the percentage change in aggregated production by sector from the statistical values in GTAP to the values for the no-trade model and the world trade model with bilateral trade. The y-axis shows the different sectors, here aggregated down to 15 sectors for a better overview and the x-axis shows the percentage change.

As stated most of the sectors have a decrease in production and since the final demand, Y, is exogenously given and cannot change, all the reduction must come from the inter-industry demand. This is in accordance with the concept of comparative advantage, since production will occur in the country with lowest factor and product use up till exploitation point. The figure shows that most of the products have a decrease in production between 5-40% and coal, oil and gas has the greatest reduction of almost 60% in the NT model and almost 80% reduction in the WTMBT.

All sectors have reduced their production from the statistical values to the NT model, but there are three aggregated sectors in the WTMBT where the production increases; Fruits and Vegetables, Other Crops and Transport. Looking at the total 57 sectors there are 7 sectors where production increases in the WTMBT. The aggregated fruit and vegetables sector is aggregated from three sectors; v_f, pfb and ocr[1], where only v_f increases. However, since v_f is 80% of the aggregated fruit and vegetable sector, the total becomes an increase in production. Aggregation of four sectors; wht, gro, osd and c_b[2], gives the

[1] v_f – vegetables, fruit and nuts; pfb – raw vegetable materials used in textiles; ocr – live plants, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, sugar beet, other raw vegetable materials.
[2] wht – wheat and meslin; gro – maize(corn), barley, rye, oats and other cereals; osd – oil seeds and oleaginous fruit; c_b – plants used for sugar manufacturing.

aggregated other crops sector where only wht and osd increase. Since these constitute only half of the aggregated sector the total increase is minimal. It was an assumption that most of the transportation would be done with water transport, wtp, and naturally this sector has greatly increased which has led to the aggregated transport sector to increase as well. In addition to these four sectors there are 3 other sectors that have an increase in production, but that does not affect the aggregated sectors to go from a decrease to an increase in production. These are rmk, wap and otn[3] and are part of the aggregated sectors animal products, clothing and electronics respectively.

On a country basis the reduction in production is not that consistent. Almost 30% of the countries have an increase in production and of the 11 aggregated regions 4 have an increase in production from statistical values to the WTMBT values as can be seen in figure 6.

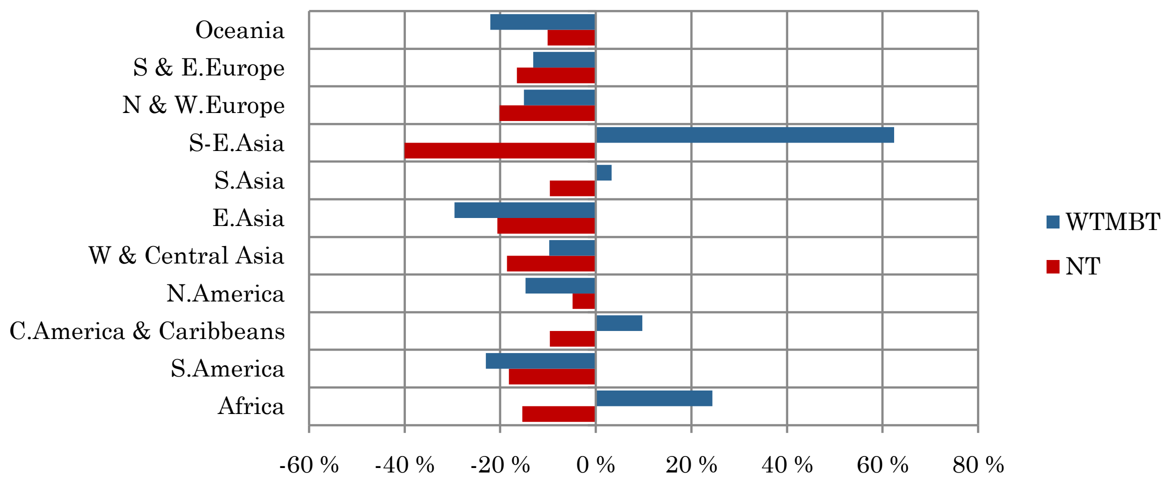

Figure 6 - Change in production by region (aggregated to 11 regions)

This figure shows the percentage change in aggregated production by region from the statistical values to the values of the NT model and the WTMBT. The percentage change is shown on the x-axis while the regions, here aggregated down to 11 regions, are shown on the y-axis.

In the NT model all regions have a reduction in production where South-East Asia has the largest decrease of 40 percent from statistical to model values. The rest of the regions have a reduction between 5-20 %. There are only 8 countries that have an increase in production in the NT model and these changes are not large enough to pivot the total decrease in production in the aggregated regions.

[3] rmk – raw milk; wap – manufacture of wearing apparel; dressing and dyeing of fur; otn – manufacture of other transport equipment.

For the WTMBT the story is a bit different. Still most countries have a reduction in production but almost 30% of the countries have an increase. As can be seen from the graph most of the regions that have a decrease lie in the range between 5-20 %. The regions with increasing production are South-East Asia, South Asia, Central America and the Caribbean and Africa. In South Asia, Africa and Central America and the Caribbean over half of the countries in the aggregated regions have an increase in production which leads to the total overall to increase as well. When it comes to South East Asia only about 40% of the countries have an increase in production, but countries such as Lao People's Democratic Republic and Myanmar have an extremely high increase in production of 4600% and 6000% respectively. This high increase is the reason for the very high increase in the aggregated South East Asia region.

Lastly it is of interest to see if and how the aggregated production patterns have changed in the WTMBT which can be seen in figure 7.

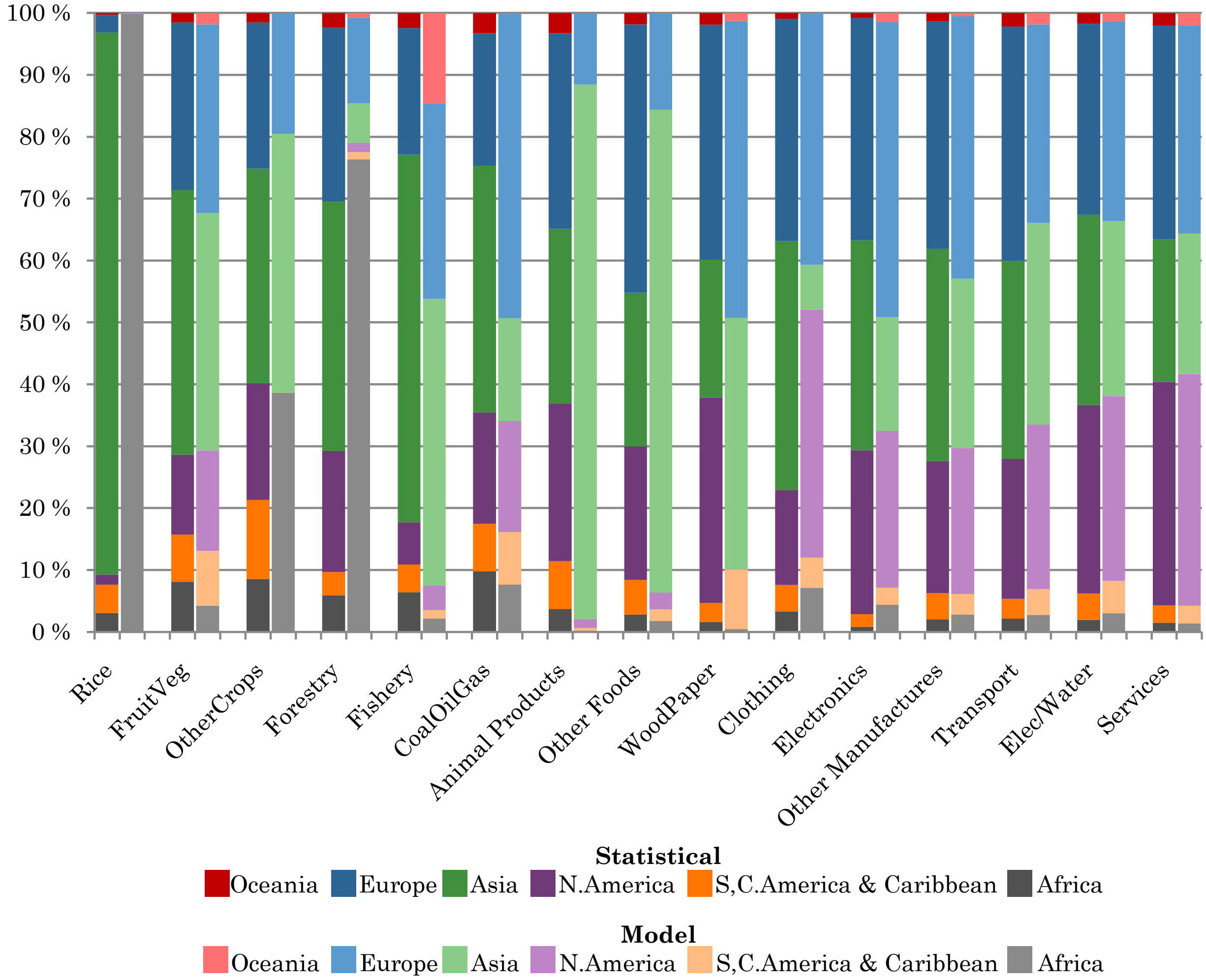

Figure 7 - Change in production pattern in the WTMBT (aggregated to 6 regions and 15 sectors)

Figure 7 shows the 15 aggregated sectors on the x axis and the percentage of how much is produced in which region on the y-axis. In this figure the countries are aggregated down to 6 regions to give better overview. For each sector there are two columns, the first one showing the distribution of production among countries in statistical values and the second column showing the distribution according to the WTMBT. This gives the possibility of assessing how the production patterns change when using the model based on comparative advantage.

Looking at the graph focusing on one region at a time it is possible to see how the production pattern changes. For Oceania the pattern stays pretty stable except for an increase of almost 10% in the fishery sector. Europe has a reduction in total production which comes mainly from sectors such as animal products and other foods that have the largest decrease. This region also has some sectors that increase their production by about 20%, namely fishery and coal, oil and gas sectors. North America has its largest increases in production in the clothing sector, while the rest of the sectors mainly stay the same or reduces production. In the rice, other crops and forestry sectors North America almost stops its production completely.

In the 11 region aggregation South-East Asia, South Asia, Central America and the Caribbean and Africa has an increase in production. Since these regions are further aggregated it is only Africa who still has an increase in total production when the 6 region aggregation is used. However, it is still apparent that the production pattern varies more in the aggregated regions of Asia, South and Central America and the Caribbean and Africa.

Asia which stood for most of the production of rice statistically (almost 90%) produces almost nothing in the WTMBT. Other major decrease in production for Asia is in the forestry, coal-oil-gas, and clothing sectors. It increases production mainly in the animal products, other foods, and wood-paper sectors. South and Central America and the Caribbean stands for little of total world production. Its largest production is in the wood and paper sectors while it stops production in the rice, other crops and forestry sectors. Remembering that Africa is the only region that has an increase in production in the 6 region aggregation, it is in figure 6 possible to see in which sectors this increase has occurred. As can be seen Africa has drastically increased its production in the rice, other crops and forestry sectors. In fact, Africa produces almost 100% of all the rice in the world.

6.3 Change in value added

A reduction in total production will naturally lead to a reduction in aggregated primary factor usage, or endowment use, since this is a product of the factor intensity matrix, which is constant, and production. Total primary factor use in 2004 was US$32 484 billion, which is the total summed over all countries, sectors and factors. In both the NT model and in the WTMBT the total primary factor use decrease. In the NT the value of factor use is US$28 595 billion, which is 12% lower than the statistical values. For the WTMBT the aggregated factor use is valued at US$26 029 billion which is 20% lower than values from the GTAP database. The reduction in primary factor use per region, aggregated down to 11 regions, can be seen in figure 8.

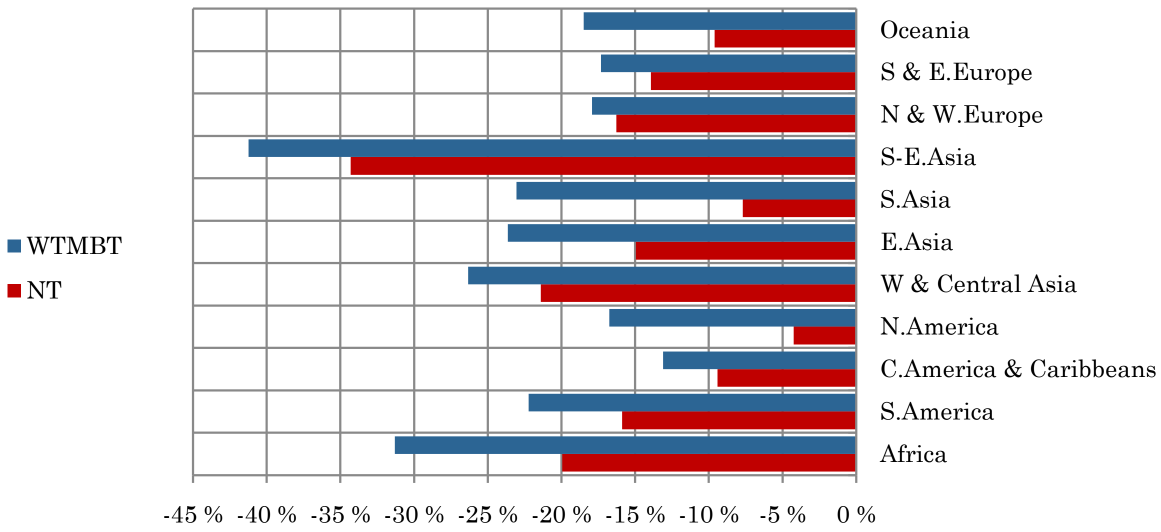

Figure 8 - Change in total primary factor use (aggregated to 11 regions)

Figure 8 shows the percentage change from statistical values to either the NT model or the WTMBT on the x-axis while the y-axis shows the 11 aggregated regions.

In the figure all regions reduce their primary factor use in the NT model, but when looking at the full region list of 113 countries there are 3 regions that have an increase in factor use. These regions are Albania, rest of North America and Ethiopia. However, the increases are very small, only 4, 2 and 1% respectively, so it does not have an impact on the aggregated regions. The rest of the regions have a decrease that ranges from 1 to 66% from the statistical to the no trade values where the average reduction is 19%.

For the WTMBT the decrease in primary factor use is even larger, and because the factor constraint is in use there are no regions that can have an increase. The reduction when looking at all the regions lies between 1 to 68% but the average for the WTMBT is 27% which is much higher than for the NT model. For both models it is South-East Asia that has the greatest reduction in primary factor use with 34% reduction in the NT model and 41% in the WTMBT. When having looked at the total primary factor use and how much it has decreased when using the model, it is of interest to see how the factor use changes in the different regions, which can be seen in figure 9.

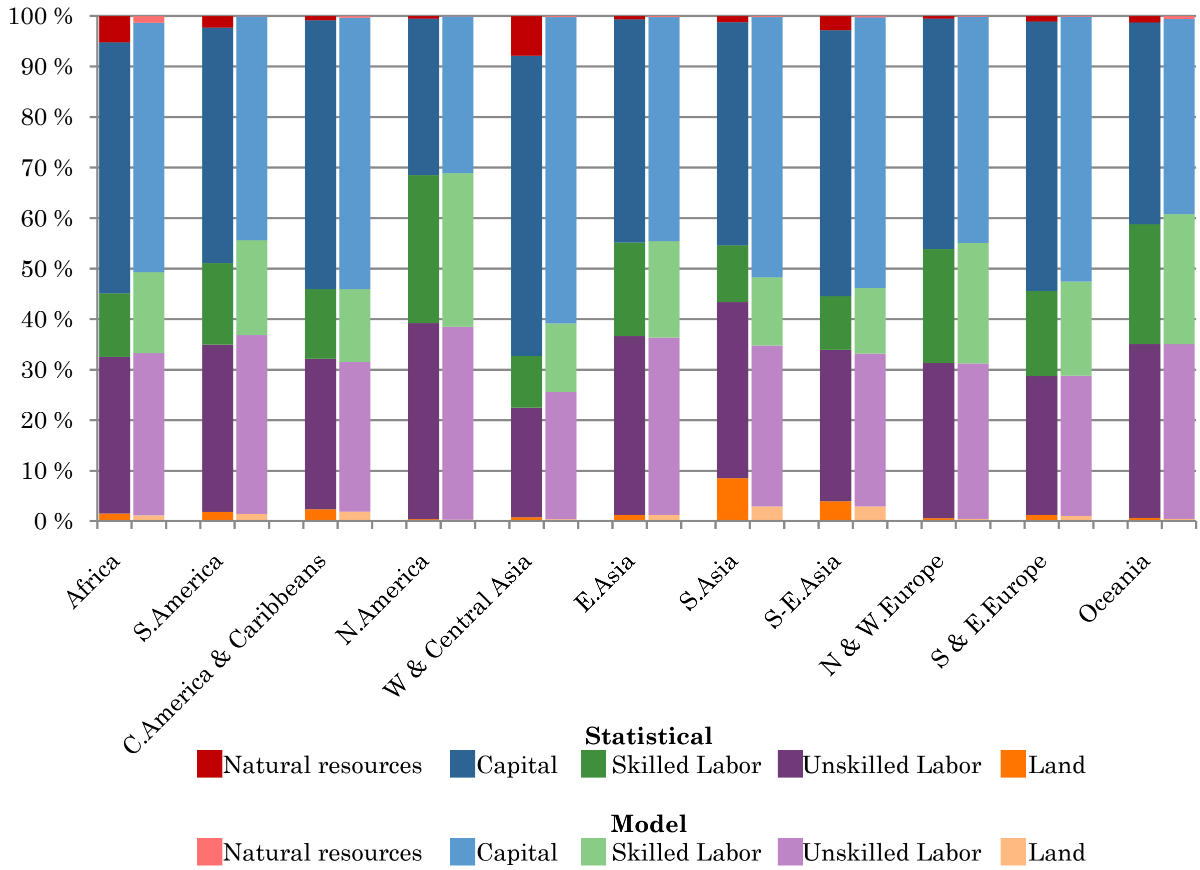

Figure 9 – Distribution of primary factor use (aggregated to 11 regions)

This figure shows the 11 regions on the x-axis and the distribution of the individual primary factors on the y-axis. For each region there are two columns, the first one showing the distribution of primary factor usage from the GTAP database and the second column showing the distribution with the WTMBT values.

Even though the total primary factor usage decreases substantially for each region, the change in the distribution of each individual factor is quite stable. The most prominent changes in the use of primary factors occur in Africa, West and Central Asia, and in South Asia. In Africa there is an increase in skilled labor of 4% and a reduction in natural resources of 4%. West and Central Asia has a 4% increase in unskilled labor and a high decrease of 8% of natural resource use. Lastly South Asia has a decrease of 6% of land use but an increase in capital of 7%. An overview of the increases or decreases in factor use from statistical to model values can be seen in table 6.

Table 6 - Change in the distribution of primary factor use (aggregated to 11 regions)

	Land	UnSkLab	SkLab	Capital	NatRes
Africa	0 %	1 %	4 %	0 %	-4 %
S.America	0 %	2 %	3 %	-2 %	-2 %
C.America & Caribbean	0 %	0 %	1 %	0 %	0 %
N.America	0 %	-1 %	1 %	0 %	0 %
W & Central Asia	0 %	4 %	3 %	1 %	-8 %
E.Asia	0 %	0 %	1 %	0 %	0 %
S.Asia	-6 %	-3 %	2 %	7 %	-1 %
S-E.Asia	-1 %	0 %	2 %	1 %	-3 %
N & W.Europe	0 %	0 %	1 %	-1 %	0 %
S & E.Europe	0 %	0 %	2 %	-1 %	-1 %
Oceania	0 %	0 %	2 %	-1 %	-1 %

Table 6 shows the 11 regions and the 5 primary factors. For each cell it shows by how much the distribution of each primary factor use has changed from statistical values to model values. For example for Africa natural resource usage stood for 5% of the total primary factor use statistically, but in the WTMBT it is only 1% of the total factor use, and therefore there is a decrease in its share of total factor use of 4%. Each cell is colored red if it is a negative change, meaning that the individual primary factor stands for less of the total factor use in the model than in the statistics, and green if it stands for more.

The table shows that land use and use of natural resources is reduced in almost all regions, the only exception is East Asia with a very small increase of 0,02% in land use. Skilled labor is increased in all regions, while unskilled labor and capital is reduced in some regions and increased in others.

6.4 Change in trade patterns

One of the main concepts and what distinguishes the world trade model with bilateral trade from other similar models is that it includes the bilateral trade flows between all regions. It is assumed that exports must equal imports worldwide. The aggregated export/import statistically have a value of US$ 10 067 billion. The WTMBT returns a value of the export/import of US$ 11 393 billion which is an increase of 13%. The total export and import for each individual region when aggregated down to 11 regions can be seen in figure 10.

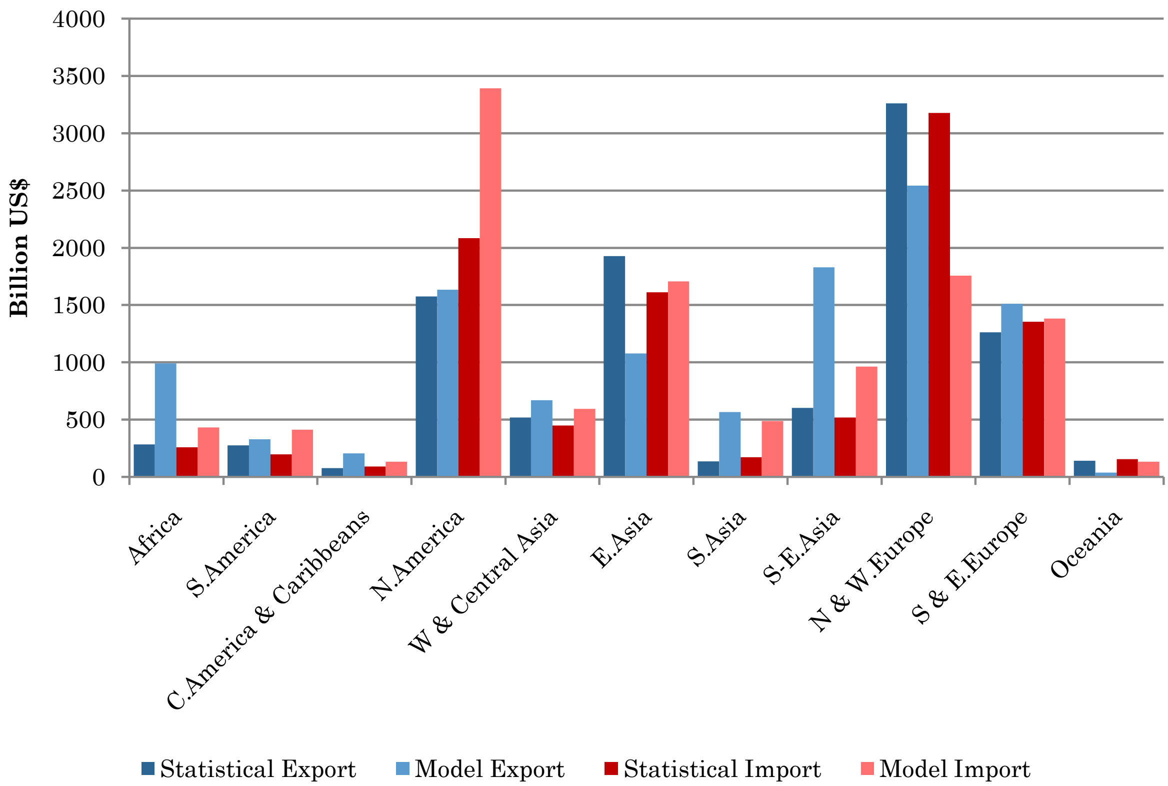

Figure 10 - Change in export and import in total values (aggregated to 11 regions)

Figure 10 shows the 11 regions on the x-axis and the total amount in billion US$ of either export or import on the y-axis. For each region there are four columns, the first showing total export statistically, the second showing exports derived from the WTMBT, the third showing statistical total import and the fourth showing model imports.

Most of the regions have a higher import and export in the WTMBT than in the statistical values. Exceptions are East Asia, who has a reduction in exports, north and west Europe and Oceania who have a decrease in both exports and imports. Africa, South America, Central America and Caribbean, West and Central Asia, South Asia, South-East Asia, and Oceania have export and import under or around US$ 500 billion statistically. North America, East Asia, North and West Europe, and South and East Europe have higher exports and imports, at least over US$ 1000 billion. The region with highest statistical values is North and West Europe with both exports and imports over US$ 3000 billion. Looking at the WTMBT values it is North and West Europe who has the highest value of exports, US$ 2500 billion, while North America has the highest value of imports of almost US$ 3500 billion.

Remembering the trade balance explained in chapter 2.1.1 and figure 2 it is here possible to see if a region runs a trade deficit or a trade surplus. Statistically it is East Asia who has the highest total trade surplus, while in the model they actually run a trade deficit. Africa, South-East Asia, and North and West Europe are the regions that increase their total trade surplus most in the model compared to the statistical values. The most prominent is North America, who statistically has a trade deficit and in the model the import is actually double the amount of the exports.

To get a better understanding of how the trade pattern has changed in accordance with the change in production figure 11 shows the exports relative to total production.

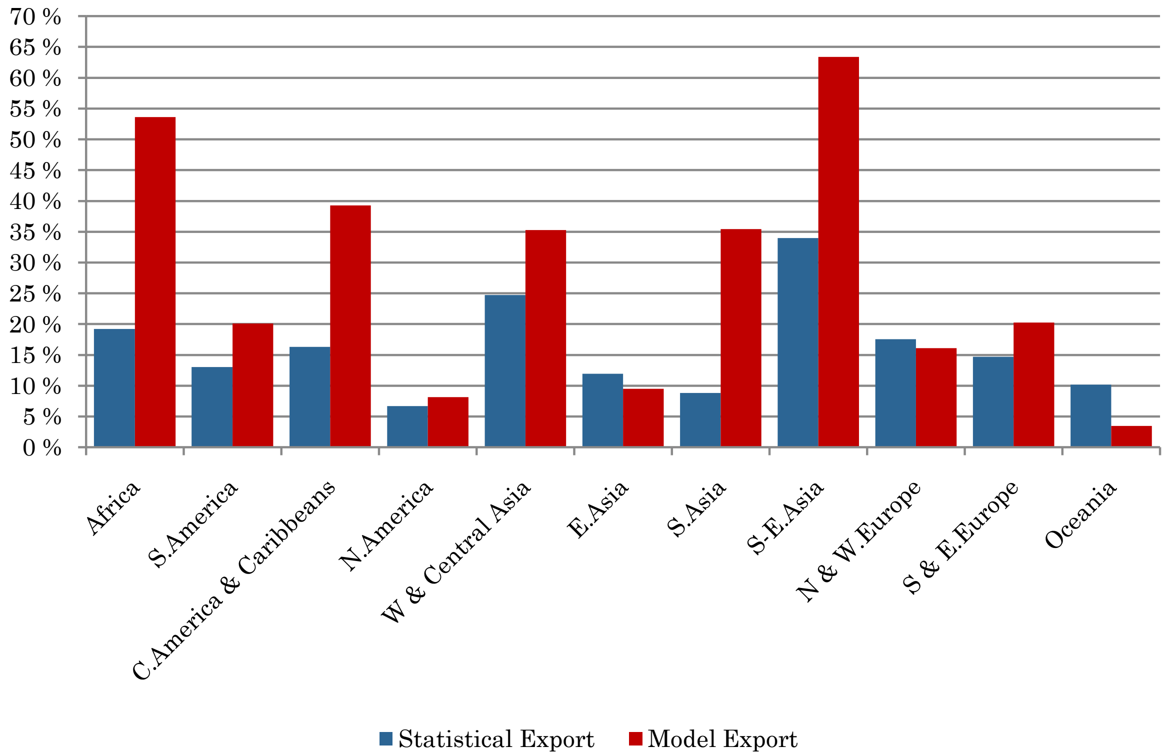

Figure 11 – Export relative to output (aggregated to 11 regions)

This figure shows the export relative to the total production of goods in each region. That means that the statistical export values are divided by the statistical production values, then the same is done for the WTMBT values. The x-axis shows the different regions while the y-axis shows the amount of production that goes to export. For each region there are two columns, the first showing the share of statistical production that goes to export and the second showing the share of production in the WTMBT that goes to export.

Statistically a range between 7-34 % of total region production goes to export. The region having the lowest export share statistically is North America with 7% of total production going to exports and also regions such as South Asia with 9%, Oceania with 10%, and South America with 13% have low export shares. The region with highest export share statistically is South-East Asia with 34% of total production going to exports. In the model calculations the export share in total production has a much larger range, from 3-63%. The region with lowest export share is Oceania with only 3% of total production going to exports, but also North America and East Asia have low export share with 8% and 9% respectively. Highest export shares is in South-East Asia with as high as 63%. A larger share of world total production going to exports shows that in the WTMBT the world economy is more open than it is statistically.

In total values (figure 10) it was East Asia, North and West Europe, and Oceania who had a decrease in exports and these regions are also the ones that have a decrease in export shares relative to total production. This indicates that more of their domestic production is used within the regions instead of being exported. Africa is the region that has the biggest increase in export shares, closely followed by South Asia and South-East Asia. In the WTMBT Africa and South-East Asia exports over 50% of their total domestic production.

In addition to looking at the total exports and imports of the different regions and the export shares of total production, it is of interest to look at how the trade patterns change from statistics to that of the WTMBT. Figure 12 shows the change in trade patterns.

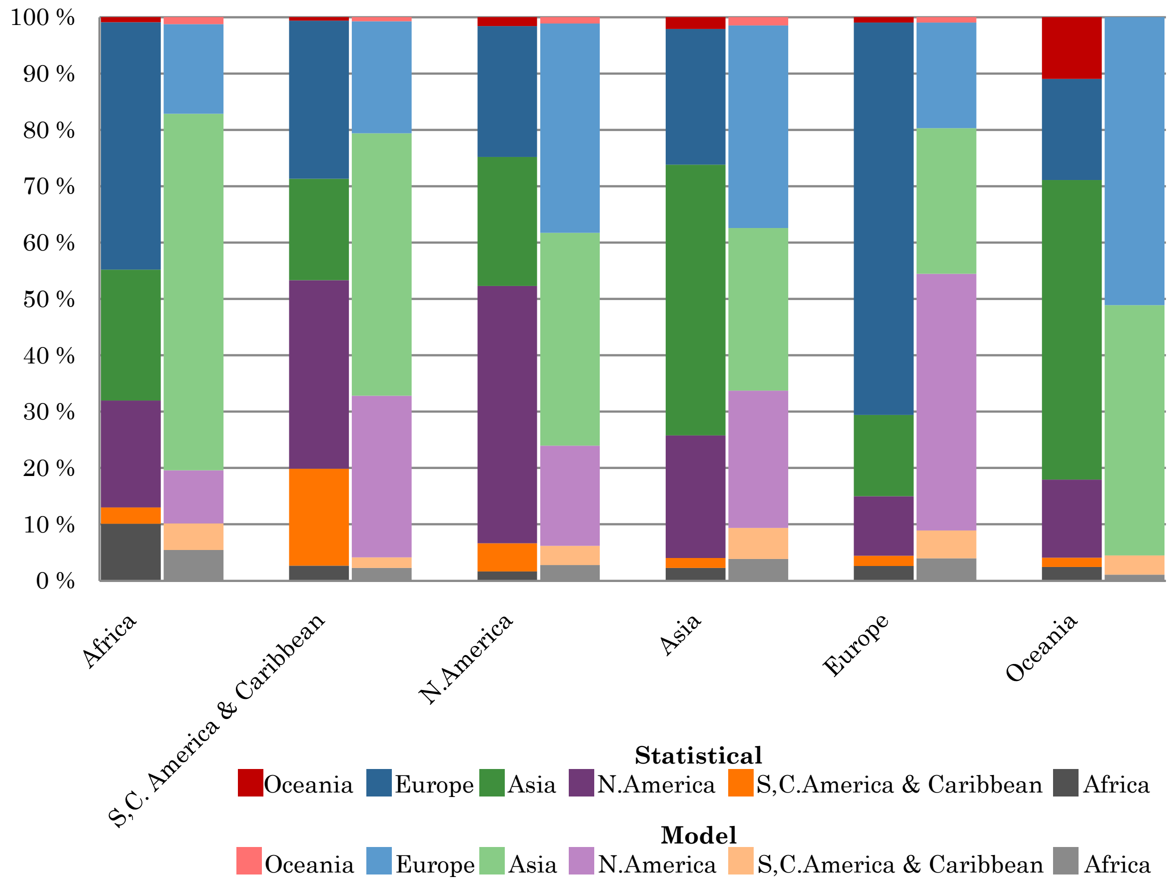

Figure 12 - Change in trade patterns (aggregated to 6 regions)

The x-axis shows the exporting regions aggregated down to 6 regions for a better overview, while the y-axis shows to which regions they export and in which percentage of the total export. Each region on the x-axis have two columns, the first one shows the export shares given statistical values while the second column shows the same for the WTMBT values. From the graph it is possible to see how much is exported from each region to the others, and also see how much is imported, and how the trade flows have changed when using the WTMBT.

For all regions it is consistent that they have a great reduction in trade within the same region from statistics to model trade patterns. Africa reduces by 5%, South and Central America and Caribbean with 15%, North America with 28%, Asia with 19%, Europe with the largest change of 51%, and Oceania with 11% reduction.

Looking at the 6 region aggregation and not the 11 region aggregation there are four regions which have a total increase in export and import; Africa, South and Central America and Caribbean, North America, and Asia, and 2 regions that have a reduction in both export and import; Europe and Oceania.

Other than the reduced export within each region there are several large changes in the trade pattern under the assumption made in the WTMBT. One is how Africa changes from exporting its largest share to Europe statistically to exporting mostly to Asia in the model. Statistically 44% of Africa's export goes to Europe while only 23% goes to Asia. In the model the export to Europe is decreased by 28% and the export to Asia in increased by 40%, so that the export shares stands at 63% to Asia and only 16% to Europe.

To compensate for the lower imports from other countries in Asia and from Oceania, Asia increases its imports from Africa, South and Central America and Caribbean, North America, and Europe substantially. As stated earlier imports from Africa to Asia increases by 40% in the model, while imports from South and Central America and Caribbean increase by 29%, from North America by 15%, and from Europe it increases by 11%.

Even though Europe decreases its imports, the reduction in import from Africa and from within Europe has to be compensated for. Europe therefore changes its import pattern from Africa, Europe and South and Central America and Caribbean to import from North America, Asia and Oceania. It also changes its export pattern significantly form mainly trading within Europe to exporting 45% to North America.

7 Discussion on Model Performance

The model developed by Faye Duchin (2005) and extended WTMBT developed by Anders H. Strømman and Faye Duchin (2006) is used for 113 regions, 57 sectors, 5 primary factors, and 3 transportation sectors in this thesis. The main objective is to evaluate the model regarding its implementation process, the validity of its results, the overall performance, and future development of the model. This discussion first analyzes the implementation process itself and the technical issues involved. Further the discussion focuses on the results where the three main areas which have been assessed; production, endowment, and trade are explained and the overall performance of the model is discussed. The last step in the system analysis approach in industrial ecology is to interpret the results so that policy makers can use it in decision making.

Implementation process

After having derived the necessary matrices and imported the exogenously given variables that were needed to run the model and solve the objective function of minimizing the global factor costs, the main obstacle was running it with the different constraints used in the model. There are 3 constraints; the regional goods balance, the factor constraint, and the benefit-of-trade constraint (see chapter 4.3 for explanation of the constraints). The regional goods balance was not an issue to implement in the model, however the other two presented a greater challenge. The factor constraint can be divided into two elements. One is the traditional factor constraint explained in chapter 4.3 equation 4.16, where the use of primary factors cannot exceed the total available primary factor in each region. This constraint was implemented and working so that no country uses more primary factors than what they used statistically in 2004. The other element, which is not specifically stated as a constraint in the model, is the restriction of how much the primary factor use for each individual product can increase or decrease compared to the statistical levels. This constraint is important since there is a limit to how much the primary factor use within each sector can change from year to year.

$$F_{tot_{k,n,i}} 80\% \leq F_{k,n,i} x_{n,i} \leq F\_tot_{k,n,i} 120\% \qquad 7.1$$

Equation 7.1 shows an example of the extra constraint that could be put in place in the WTMBT. The F_tot is the statistically factor use per sector per region, while F is the factor inputs per output (factor intensity matrix) and x is the model output. The equation states that the total factor use per sector cannot decrease by more than 20% and it cannot increase by more than 20% (the percentages are just examples). It was tested with just a restriction on maximum increase, and one on just maximum decrease as well, but neither returned an optimal solution to the model, and could therefore not be implemented in this version. Lastly it is the benefit-of-trade (BOT) constraint which would make sure no country would enter into trade unless they were better off than under no trade conditions. This constraint should numerically be possible to implement in the model since the NT solution would be an option if no other optimal solution was found. However, even though the model is a linear program there were issues with some of the technicalities in the implementation process. This could stem from the large database, the solvers used or a difficulty of convergence in the model.

Discussion on the results - Production

The results and benchmarking tests between the statistical values and the model values were focused on three areas; production, primary factors, and trade. To give a better overview and results that are easier to analyze the 57 sectors are aggregated down to 15 sectors while the 113 regions are aggregated down to either 11 or 6 regions.

From figure 5 it is apparent that most of the sectors have a reduction in worldwide production both for no-trade and with trade. There are however 3 aggregated sectors in the WTMBT which have an increase, this being fruit and vegetables, other crops and the transportation sectors. The reason why the transportation sector increases substantially is that there is an increase in total world trade, meaning the need for more transportation. For the other sectors it cannot be stated directly why they have an increase in production, but it could be due to the need for more of these products in the inter industry demand. The greatest reduction in production occurs in the coal, oil and gas sector. This is because most of the demand for these products comes from inter industry demand, in fact only 2% comes from the final demand sectors, and will naturally decrease when the inter-industry demand decreases.

Looking at the production on a region basis as in figure 6 there is a general and total reduction also here, but about 30% of the 113 regions have an increase. The regions, on the 11 region aggregated level, that have an increase in the WTMBT are Africa, Central America and Caribbean, South Asia, and South-East Asia. The fact that they have an increase in production, also over the no-trade level, means that they have increased export to other regions. The best example is the region of South-East Asia. In the no-trade model this region has 40% lower production than statistically, while in the WTMBT it has increased more than 60%. This indicates that statistically it is a region that has a high export ratio, and that this export share increases even more in the WTMBT. This can be seen from figure 11. South-East Asia actually has the highest export shares of all the regions both statistically and in the model.

Figure 12 shows the trade patterns both statistically and in the WTMBT so it is possible to see how the regions' export patterns change. Electronics, other manufactures, transport, electricity, and water and services are sectors where the trade pattern is more or less stable. This is due to the fact that many of the sectors they are aggregated from cannot be traded between countries. In the rest of the sectors it is apparent that the comparative advantage comes into play since the trade patterns shift drastically in some cases. The most visible are the increase in production of animal products, other foods and wood and paper in Asia, the increase in production of coal, oil and gas in Europe, clothing in North America and especially rice, other crops and forestry in Africa. As can be seen from figure 7 showing the production composition, within some sectors much of the production is based in only one region, and must then be exported to all the other regions where the products are consumed. This is because these regions have a comparative advantage in the production of these products, and will produce that until they run out of resources or primary factor inputs, and then the next region "in line" with comparative advantage produces, etc. until all demand for that product is covered.

There is however some issues with the model since it was not possible to restrict the movement of primary factor use; within each sector within one region they can move all the primary factor use to one sector where they have comparative advantage and produce only that. That means there is technically no extra cost to train labor to work in a new sector, capital can be used for all types of industry, and land can be used for any type of sectors. A good example of this is within the rice sector (figure 7). Statistically Asia stands for the largest production of rice in the world, but in the model Africa pretty much produces 100% of all the rice. This is because Africa has a higher comparative advantage than Asia and can move all the necessary primary factor use to that sector. In addition to the issue that not all labor can work within all sectors and that capital cannot move freely between sectors, there is nothing that states whether the available land and natural resources can be used for what types of production.

Discussion on the results – Primary Factor Use

The total production changed by the same percentage, 15%, both in the no-trade model and in the WTMBT, however for the primary factor use it changed more in the WTMBT (see figure 8). This is another example of the concept of comparative advantage. Under no-trade conditions we saw that the production decreased, and hence the primary factor use would automatically decrease, the fact that it decreases even more in the WTMBT is because production can shift to the regions that need less use of products and less use of primary factors in their production. The distribution of the use of primary factors in each region does not change much from statistical values to model values, but there are consistencies in whether they increase or decrease. Land use and use of natural resources is reduced in all regions compared to the total factor use while skilled labor is increased in all regions. This shows directly how a world economy based on comparative advantage is consistent with the concept of sustainable development, since there is reduced use of natural resources while still keeping worldwide consumption level the same.

Discussion on the results – Trade

Total export and import worldwide increases by 13%, and it also increases in most individual regions (figure 10). Figure 11 shows the share of total production within each region that goes to export, which also increases in most regions. This indicates that the world economy is more open with much more trade under the WTMBT conditions than statistically. This means that statistically products are not being produced in the region with the highest comparative advantage. The increase in total export could also indicate that there is a shift in the trade patterns. Figure 12 shows the trade patterns for 6 regions both statistically and in the WTMBT. One consistency is that all regions reduce the inter-regional trade in the WTMBT which indicates that one region does not have comparative advantage within all sectors, and will therefore have to import from other regions that have a greater comparative advantage. Another aspect that can be taken from figure 12 is that the distance between regions does not play such a great role in the WTMBT as it does statistically. The best example is Africa's export who mainly exported to Europe statistically while to Asia in the WTMBT. The reason for this is that the T matrix has the same values for all distances due to the assumption of economies of scale. This assumption is simplified and should be further developed in later studies, but it still gives a cost of transportation that is necessary to avoid free flow of goods. What is not included in this version of the WTMBT is the quality of the products and consumer preferences.

Model Performance

Implementation of the WTMBT was done successfully with some restrictions in place while others had to be left out. The model clearly shows the effect of a world economy that is based on the concept of comparative advantage. This is shown trough a reduction in the total production level, while keeping the final demand constant, lower primary factor use, and through higher export shares. The model also shows the correlation between a comparative advantage based economy and the concept of sustainable development. Through lower primary factor use, especially land use and use of natural resources and also lower use of other products in production, it is possible to meet the demand of products worldwide while at the same time having a lower impact on Earth. It can also be noted that the primary factor use that increases in all regions is labor indicating there will be a lower unemployment rate which could be said to have a positive effect on the world economy.

There are however some restrictions that it was not possible to include in this version of the WTMBT, this being restriction on the movement of primary factors between sectors, the quality of the primary factors, especially land and natural resources, no benefit-of-trade constraint, and no difference in transportation distances. Not having any restrictions on how primary factors can move between sectors can lead to situations that are highly unlikely in the real world. For example capital investments that are made and in place in the different sectors cannot suddenly change to a completely different sector, and neither is it possible to add too much new capital, since constructing buildings etc. takes time. It is the same issue when it comes to land use. Labor cannot move freely between sectors either, since this would require a lot of re-training of employees. When it comes to the quality of the primary factors it is most apparent in land use. A clear example is that of Africa producing all the rice for the world demand, while the arable land there might not support this type of agriculture. The benefit-of-trade constraint makes sure that a country does not enter into trade unless it is better off than under no trade conditions and should be in place to make sure this condition is upheld. Transportation costs are an important issue in the WTMBT since this sector stands for large parts of the emission embodied in trade. In this version of the model costs are included, but it is assumed that they are the same for all distances and there are only two different prices for the sectors, one for bulk products and one for consumer goods. This way the cost of transporting products is included in the model, but it would be more accurate if the difference in cost according to distance was also included.

As the model is developed in this thesis it is possible to see how the world economy changes when it is based on comparative advantage on the large macro levels such as total production, total primary factor use, and total export and import flows. When going into more detail it is apparent that there is some need for more precision in the constraints implemented. A model involving all issues concerning economic activity worldwide would be valuable, but very hard to implement. Models such as the WTMBT might not show a completely realistic view of the world economy, but it does highlight an important part of the economy and trade, and identifies how this aspect, comparative advantage, affects these issues.

8 Future Development

The version of the WTMBT developed and implemented in this thesis shows how such a model can be used with a large database. The model shows how comparative advantage works in that the aggregated production and factor use are reduced, but this only explains a part of the difference between statistical and model values. Results obtained shows that there are fairly large discrepancies between the statistical values and the model values. These are explained in the discussion above as a result of the economic basis of comparative advantage and also a lack of certain restrictions in the model. There are also two other main aspects that cause this difference, one is technical issues with the model (restrictions) and the other is political and economic issues in the real world that is not reflected in the model. The objective of this thesis was to test the model and identify and compare it to the statistical values, and it is therefore of interest to see why there is a difference and find what measures could be implemented to move the model values closer to statistical values and a more realistic outcome.

Benefit-of-trade

Total production is as much as 15% smaller in the model values than in the statistical values. The benefit-of-trade constraint, making sure that no region enters into trade unless they are better off than under no-trade conditions is an important basis within the concept of comparative advantage. Therefore the BOT constraint could lead to a lower aggregated production level in the model values. There are however issues with using the no-trade values, since these values do not represent the world economy as it is now. In a no-trade economy regions would have to produce goods that they normally would not or could not produce. Another option for this constraint would therefore be to use the statistical values instead of the no-trade values. This would make sure a region would not enter into trade (or more trade) unless they were better off than their current situation. The new constraint would then have to show that the values of exports and current statistical prices do not exceed the imports and the current prices.

Primary factors

The use of primary factors in the model is significantly lower, as much as 20% for the WTMBT, than what the statistics show (figure 7). This is a natural sequence of events, since aggregated primary factor use is the product of the factor requirements and the total output. Therefore lower production would naturally lead to lower primary factor use. The restriction on total primary factor usage makes sure that no region can use more of each factor than what is already available in the region. This restriction does not put any constraints on how the primary factors can move between the different sectors. The goal of a model like the WTMBT is to model the world based on certain economic foundations, but also to depict the world economy as realistically as possible. Having a free flow of primary factors between sectors does not reflect the world economy as it is. It is not physically possible to move capital, labor, land, and natural resources from one sector to another sector producing something completely different. Workers will have to be re-trained, which takes time and costs money, buildings and factories will have to be torn down and re-built or re-modeled, and land will have to be cleared and readied for the new sector. In addition a very stringent specialization within just a few sectors might arise, the issues concerning specialization and diversification will be discussed further down. Specialization also indicates that a reform of the economy to the new sectors would happen over a long period of time, not instantaneously, since new facilities and training of workers would have to take place before production could start (Brainard & Cooper, 1968). Since the WTMBT is a static model in the version used in this thesis, it does not account for how things change over time, and assumes that changes occur immediately. Lastly the issue of the employment rate is important in an economy. High unemployment rates are very undesirable. There is a certain "full employment" rate which is the optimal unemployment rate. Unemployment should not be above this rate since this would mean higher cost with due to extra welfare costs (Lucas Jr., 1978). Therefore there should be a certain lower level which the use of labor cannot cross. In the WTMBT results from this thesis the labor force in absolute numbers increased in most regions (table 6), but this might not be the case for other exogenous values used in the model. These arguments give good reasoning for why a constraint on employment rate should be put in place in the model. One solution would be to insert another constraint in the model stating by how much a sector could increase and decrease its primary factor use, see equation 7.1. This constraint would most likely lead to a smaller discrepancy between the model values and the statistical values, the reduction in primary factors would not be as large.

On another point, the WTMBT as it is now has very strict constraints on the movement of primary factors across borders; in fact there is no inter-regional movement. In reality there is movement of labor between regions, as people of the labor force seek jobs with the highest chance of improving life quality. This would often be the jobs and regions with higher wages. In addition these movements are often from developing regions to the developed parts of the world (Goss & Lindquist, 1995). Including this in the WTMBT will give a more realistic view of the labor market, whether it affects the aggregated endowments to increase or decrease in the model compared to statistics cannot be stated for sure. One option for implementing this would be to find empirical data on the movement of labor in a matrix showing from which regions and to which regions the flow goes. It would then be possible to include a new constraint stating that these flows cannot increase or decrease by a certain amount.

Quality of primary factors

There is an additional issue concerning the primary factor use, namely the quality of the factors. In the GTAP database there is a distinction between unskilled and skilled labor, but there is no such distinction in land, capital or natural resources. This issue can be seen from figure 6 where Africa practically produces and supplies the rest of the world with rice, while the land might not be optimal for that type of agriculture. Including more primary factors such as mineral deposits and different types of land is one option to solve this issue, and also including the region's specific climate (Polenske & Hewings, 2004). Including more details on the primary factor use requires a more extensive database in this area than what the GTAP database currently has. The EXIOPOL database has the "normal" primary factors such as labor, capital, and land, but they also have more details in that they include; fuels, metals, phosphate rock, and water for example (Duchin, Lutter, Springer, & Giljum, 2010). Including these will give a more accurate notion of where products can be produced given quality of land and resources. It will also provide a much better overview of the resources available and the rate of extraction which is a key to maintain a sustainable economy and development.

Transportation and distances

In the values obtained from executing the WTMBT it was clear that the trade pattern changed drastically. Figure 11 shows the statistical values and the model values so it is possible to see the change. The most prominent change is that of Africa shifting from exporting mostly to Europe statistically to exporting mostly to Asia in the model. This is a result of the fact that distance between regions was not included in the model. Distances between regions and the weight of products is one option in determining how the T matrix should be, see equation 4.13 (Strømman & Duchin, 2006). However, over half of the trade taking place in the international market is between neighboring regions (Hummels, 2007), which might imply that other factors are just as important as distance in deciding the cost of trade. One other aspect is the inclusion of more types of transportation. In addition to the three types included from the GTAP database, transportation by railway and pipeline should be embedded. In addition there are several types of boats and trucks, for example is it often distinguished between tramp and liner shipping (Hummels, 2007). It would then be necessary to find a database which includes more diversity in the transportation sectors. There are also costs associated with on-loading and off-loading goods to the vessels/trucks which should be included.

This implies that there would be economies of scale in the transportation sectors. If the goods are transported over longer distances the cost of loading would be smaller relative to the distance. It is also the case that over longer distances larger vessels or trucks are used with room for a larger quantity of goods, which would also decrease relative cost. As was seen from the model results, there is an increase of 13% more trade when the economy is based on comparative advantage. An increase in the total trade would also lead to economies of scale. At first when there is more trade the transportation sector becomes scarce and prices go up. However over time the vessels/trucks can transport larger quantities and require fewer stops along the way reducing the loading costs (Hummels, 2007). This also shows the need for a more dynamic model that can integrate and show the development of transportation prices as trade increases between regions. Including economies of scale in the model could be done through a type of subsidies placed on large transportation amounts using the same transport type and going to the same region. There should also be put in place a type of constraint that would prevent transportation to exceed the existing fleet of boats, planes, trucks and the other transportation sectors included.

Trade balance

The trade balance was explained in section 2.1.1 and in equation 2.8 it is possible to see what it is. When net exports is zero; exports are equal to imports; the region is in trade balance. If the net export is negative the region has a trade deficit meaning that it imports more than it exports, while it has a trade surplus if exports are higher than imports. In the world economy as a whole there is just as much import as export, but this cannot be the case for each individual economy. If one region has a trade surplus then consequently one or more regions must have a trade deficit. Having a trade deficit is undesirable since this means that less money goes into the domestic market which constitutes a big part of the region's GDP. Reasons for a trade deficit in a region could be based on the difference in exchange rate between its trading partners, that prices on competing products abroad are cheaper or that the demand in the region grows at a higher rate than other regions (Krugman, Baldwin, Bosworth, & Hooper, 2011). In the model values produced in this thesis some of these trade deficits have grown very large. Figure 9 identifies the total export and imports both statistically and in model values. North America is one region that has a trade deficit statistically, however in the model the imports are double the size of the exports. This is not sustainable for the economy on a long term basis. The trade balance should be considered included in the WTMBT to prevent such extreme situations to occur in the model values so it will converge to the more realistic statistical levels. This constraint could state that the total import value cannot exceed the total export value by a certain percentage.

Specialization and diversification

There are also certain economic policy issues that should be considered as an extension to the WTMBT. The notion of diversification can be said to look at two different aspects of the economy. One is the diversification of domestic production, the opposite of specialization, while the other is the diversification of a region's export. These two go hand-in-hand however, since a diversified production economy will also lead to more diversified trade. As can be seen from figure 6 many regions specialize within certain areas, most prominent is Africa in the rice and forestry sectors. A region would want to diversify both its production and export to reduce the risk of fluctuations in world demand and in world prices for products (Brainard & Cooper, 1968). Empirical studies show that diversification in the domestic production occurs at an economies early stage of development, while as the income level increases it moves towards more specialized production (Hesse, 2009). This shows that at early stages there is a risk aversion policy that can be loosened up as the economy grows stronger. The same relationship is shown when it comes to export diversification (Hesse, 2009). This indicates that the model should include a notion that prevents developing regions from specializing too much, while this restriction need not be as strong for developed regions. One way of accomplishing this is through implementing a factor constraint on how much factors can move from sector to sector, explained above. Another option is to implement taxes and subsidies to "guide" the economy in the desired direction, whether it be diversification in production or in exports (Brainard & Cooper, 1968).

Trade and tariffs

As the world economy becomes more integrated and globalized, regions and sectors within regions face much more competition from foreign companies. This means that each region has to have good control over their domestic economy, but also their trading partners. As was seen above, they have to consider transportation of their exports and imports, evaluate the foreign economy, domestic and foreign demand to balance their net exports. Diversification is also a way of protecting their economy against foreign companies. Regions therefore have trade barriers to protect their domestic sectors, which have roots in the notion of diversification described above. These trade barriers can be taxes or tariffs placed on imported or exported products or subsidies to certain sectors of the domestic economy. Peters and Duchin have incorporated trade barriers in the WTM developed by Duchin and Strømman (Peters & Duchin, 2005). They looked at 5 different barriers to trade, the ad-valorem tariff, a specific tariff, an export tax, an import quota and a voluntary export restriction. In the implementation they included an ad-valorem tariff and a specific tariff in the objective function, where the ad-valorem is a percentage of the total value of a good while the specific tariff is a specific value per unit of good. In addition they added an extra constraint, an import quota, stating the maximum amount a region is allowed to import. In addition to these there are more indirect barriers to trade such as subsidies to certain domestic sectors and poorly developed customs regulations that make it difficult to export and import. As the results from the implementation of the model in this thesis shows there is a large increase in both total imports and exports and relative (to output) exports (figure 9 and 10 respectively). Introducing taxes, subsidies and tariffs into the WTMBT would reduce the effect comparative advantage has, since the relative prices of foreign goods compared to domestic goods become larger and regions with initial comparative advantage, but with high trade barriers will no longer be "on top of the list". Use of taxes, tariffs and subsidies will make it possible for the regions to some extend to control how diversified they wish the economy to be by subsidizing the sectors they wish to keep in the economy. They can also affect the trade balance by taxing imported goods so that domestic goods become relatively cheaper.

Environmental pollution controls is another measure that works in the same way as taxes and tariffs; goods produced in regions with pollution control measures will have a higher price than without such measures. This could however lead production of polluting intensive industries to move to regions with low pollution control, since they will have a higher comparative advantage in production than those with higher pollution control. However, in an article by Tobey it is argued that the implementation of pollution measures does not affect the trade patterns, and thus should not be used as an argument to prevent pollution control to be implemented (Tobey, 1990).

Quality of goods

Consumer preferences are the deciding factor when it comes to world final demand for products. These preferences are many and as a way of informing consumers of what the products contain, where they come from etc different measures are taken. This is a way of changing the way trade is distributed between regions and alter the basis in which the WTMBT is based, if included in the model. Instead of taxes and tariffs other measures are being introduced as a way of accomplishing the same; food safety standards, traceability of products, environmental standards, and product certification (Frohberg, Grote, & Winter, 2006). One of these measures is the Geographical indications which "*identify a good as originated in the territory of a WTO member, or a region or locality in that territory, where a given quality, reputation or other characteristic of the good is essentially attributable to its geographical origin*" (WIPO, 2002). GI's can then give the consumers an idea of the quality and production localization of different products from different regions (Marette, Clemens, & Babcock, 2008). Including consumer preferences in the WTMBT is not as straight forward as the other measures mentioned above. However, it might be possible to implement it in much the same way as taxes, or it can act as a way of changing the prices of the products according to their desirability.

Dynamic modeling

In the WTMBT there are many factors that are exogenously given such as the A-matrix, calculated from statistical production and statistical inter-industry flows, the final demand vector, the total endowment vector, and the factor coefficient matrix. When the economy is opened up for world trade, the model does not distinguish between what import into region goes to final demand and what goes to inter-industry demand. Doing this would indicate that there would be a need for two A-matrices, one for imported inter-industry products and one for domestic. It would be possible to include this, however, the model would no longer be linear. As the implementation of the large GTAP database faced certain issues along the way, with a linear model, making the model non-linear could cause even further problems. Until the necessary constraints and suggestions mentioned above are included in the model, it is suggested that the model stays linear. It would however be beneficial for further analysis of the world economy that the model contained as many endogenous variables as possible. One option would then be to make the model dynamic. In addition to having the ability to see trends in the economy such as how the production level, final demand, and trade patterns change, it would also be easier and more accurate in implementing some of the suggested improvements above.

Having a dynamic model will make it possible to calculate the prices and then see how these new prices will affect the world production levels, factor levels, and trade. It would also be of interest to have a changing demand according to the new prices. This would make it possible to see how growth in final demand in other regions will affect the trade balance in one region. In addition there is continuously technological development that makes the inter-industry need for products and the use of factor endowments lower. These changes might be possible to include in a dynamic model.

Emission factors

Lastly to be able to properly see the effect the different regions and world trade has on the environment, the emissions need to be calculated. In the model the focus is on minimizing factor use, not minimizing emissions. There is therefore a worry that the regions that have comparative advantage within a sector might be the cheapest, but also have a higher emission rate than others (Strømman, Hertwich, & Duchin, 2009). This illustrates the problem with pollution control explained earlier. In the GTAP database there is emission data on CO_2, N_2O, CH_4 and fluorinated gases. These can be used to calculate the emission from the current state of the economy, and on the emissions from the model values. For policy makers it would be possible to see in what sectors the emissions are prominent and in what regions these occur. There might also be a need for including a constraint in the model, as done in the study by Strømman, Hertwick and Duchin (2009). By including a constraint on a maximum increase in emissions it will be possible to avoid the movement of production of certain products to the cheap but energy intensive areas. This could also be a constricting factor to the large changes in the WTMBT in comparison with the statistical values.

Implementing the constraints and suggestions above would make the model converge toward the statistical values, making it more useful and probable. It is suggested to start with a linear and static model when implementing large datasets, and then expand them as it is apparent that they work. The use of the model would be the same as was done in this thesis; looking at the change in macro indicators such as production, primary factor use, and trade patterns. Further, as more of the constraints are in place, it would be of more interest to look more deeply into the changes occurring on a sector to sector as well as region to region basis and on the emissions from these. The model could also be used to test out different scenarios of policy implementations and what effect they would have on the global economy and subsequent emissions. Scenarios on changes in the exogenously given variables such as final demand, factor use, and primary factor use could be analyzed. This could be changes such as technological improvements within a sector that would decrease the factor and primary factor need or a surge in final demand coming from certain parts of the world due to economic development.

9 Conclusion

The objective of this thesis was to implement, develop and evaluate the World Trade Model with Bilateral Trade developed by Strømman and Duchin (2005) for a large dataset. The model is based on the economic principal of comparative advantage. The GTAP database was used and provided the exogenously given variables for 113 regions, 57 sectors, 5 primary factors, and 3 transportation sectors. Matlab and GAMS were used in unison to produce the outcome. The implementation process included converting the input-output data from the database into useable matrices and vectors for the model. The exogenous variables were used to run the WTMBT and obtain results.

The main achievements of this thesis can be summarized as follows:

1. The implementation of the WTMBT model with the GTAP database, using Matlab and GAMS, returned an optimal solution to the optimization problem. However this was after certain restriction were omitted, such as the benefit-of-trade constraint and a constraint on the primary factor use for each individual sector. In addition the attempt to get a transportation matrix that worked with the rest of the data was unsuccessful, and therefore reasonable estimates were used instead.
2. The results and benchmarking tests where the model values were compared to the statistical values show the performance of the model and how the macro indicators change when the economy is based on comparative advantage. Main results were split into three sub-categories, production level, primary factors, and trade patterns.
    a. Aggregated production level decreased in the WTMBT compared to the statistical values. This is explained through comparative advantage; since the production occurs in the regions requiring fewer inputs from other industries, and the final demand is exogenously given, the production will go down. Largest increase is seen in the transportation sectors, which is a consequence of the fact that the production of products are more geographically outstretched. It was also discovered that some regions completely change their production composition.
    b. Primary factor usage also decreased in the WTMBT compared to statistical values. Since the aggregated factor use is the product of the factor intensity matrix and the total production there are two variables that could decrease the total usage. The total production decreased and since the model is based on comparative advantage, production occurred in the regions with the lowest primary factor requirements, further decreasing endowments. It was found that the natural resources and land use both decreased, which is of highest importance when it comes to sustainable development. The labor increased for the

most part, which is positive in regards to the unemployment rate and economic issues of each individual region.

   c. Trade increased in the WTMBT both in total values and in the export shares of total production. It was found that some regions run a substantial trade deficit that would not be supported by the regional economy. Further the trade patterns shifted drastically and it was clear that a transportation matrix that did not include distances between regions led to much more trade between regions farther apart.

3. After analyzing the results it is clear that there is room for improvements in the model. The issues discussed concerning further development dealt with primary factors, both including a constraint to prevent free movement between sectors and a higher resolution of the factors, especially land and natural resources, so as to depict the quality better. As was seen some regions ran a very large trade deficit, therefore including a constraint on how much the trade balance can shift from the current situation would improve the model. The issues concerning too much specialization and the policy of diversification were discussed, where a possible solution for policy measures could be the implementation of taxes and tariffs in the model. Lastly making the model dynamic would make it better for scenario analysis. This would also make it possible to have more of the variables endogenous, and it would be possible to see how the economy shifted as world prices changed as a consequence of it being based on comparative advantage. In addition it was suggested that a constraint on the greenhouse gas emissions be included.

The world trade model with bilateral trade shows the effect comparative advantage has on the world economy. It clearly shows a lower consumption level of materials, land use, and natural resources. Even though certain factors are not included, the model is now implemented with a large database covering most parts of the world, and it is much easier to further develop it as the main obstacles are solved.

There is no longer any denying that global warming is a fact, that consumption levels are rising, and that trade between regions is increasing. Especially as developing regions strive for higher living standards there is a need to use models such as the WTMBT to find ways that they can increase their consumption level while still use land and natural resources sustainably and prevent further emissions. The WTMBT, through its factor minimization and further greenhouse gas emission constraint, presents scenarios for a sustainable development of the world economy that secures future generations and also maintains the natural environment.

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Appendix 1 – Project description

Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

EPT-M-2010- 92

NTNU

MASTER THESIS

For
Kristin Fjellheim

Stud.techn.
Autumn 2010

An implementation of the World Trade Model with the GTAP database

En implementering av WTM med GTAP databasen

Background

Global production and consumption activities are contentiously scrutinized to mitigate mounting environmental concerns, in particular global warming. This scrutiny has also been extended to the interregional and intercontinental transportation system. Concerns are being raised over energy use and associated emissions related to the transport of goods. There are many examples of individual global value chains that are resource and emission inefficient. There is however an economic rationale for this. Access to cheap labour in developing countries and economies in transition provides strong incentives for locating production there. Although there are adverse environmental implications caused by locating this production in economies with less strict environmental regulations and more distant from markets, it is very important to recognize that production of goods for western markets provides an opportunity for countries to improve economic growth and all that may follow with that. That is, the prospect of improving global equity is the main novel motivation for globalization.

The serious implications associated with global warming and especially the immediate concern for achieving a tipping point in emissions of greenhouse gases does though have implications for our global production and consumption system. Despite the potential economic and social upsides of globalization, it is important to understand the environmental repercussions caused by changes in the international division of labour.

The world trade model with bilateral trade offers a framework for assessing both changes in the international division of labor, equity and associated environmental impacts. The world trade model with bilateral trade is an input-output model based on comparative advantage. The model solves for production by countries for a exogenously defined demand by countries. The current literature on the model only demonstrates applications using highly aggregated datasets. There are ongoing efforts to implement the model using the EXIOPOL database. However, further efforts to implement detailed datasets are required to better understand the potential this model holds.

Objective

The main objective of this work is to implement the GTAP7 dataset in the WTMBT. This involves adaption of datasets and modifications of required. The second objective is to benchmark the model output with the statistical data from the GTAP7. This involves both output by regions as well as trade patterns.

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The work should include following elements:
1) An overview of the WTM model and its rationale.
2) An overview of the GTAP database structure.
3) Adaption of GTAP data for implementation in the WTM.
4) Implementation, development of benchmarking tests and analysis of results.
5) Discussion and conclusion

-- " --

Within 14 days of receiving the written text on the diploma thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

One – 1 complete original of the thesis shall be submitted to the authority that handed out the set subject. (A short summary including the author's name and the title of the thesis should also be submitted, for use as reference in journals (max. 1 page with double spacing)).
Two – 2 – copies of the thesis shall be submitted to the Department. Upon request, additional copies shall be submitted directly to research advisors/companies. A CD-ROM (Word format or corresponding) containing the thesis, and including the short summary, must also be submitted to the Department of Energy and Process Engineering

Department of Energy and Process Engineering, 1 October 2010

Olav Bolland
Department Head

Anders Hammer Strømman
Academic Supervisor

Co- Advisor:
Professor Anders Skonhoft , Department of Economics

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Appendix 2 – Sector aggregation

This shows the aggregation from 57 sectors down to 15 sectors (Narayanan G., Dimaranan, & McDougall, 2008).

Aggregated sector	Original sector	Description
Rice	pdr	Rice, not husked Husked rice
	pcr	Rice, semi- or wholly milled
FruitVeg	v_f	Vegetables Fruit and nuts
	pfb	Raw vegetable materials used in textiles
	ocr	Live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds Beverage and spice crops Unmanufactured tobacco Cereal straw and husks, unprepared, whether or not chopped, ground, pressed, or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets Plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes Sugar beet seed and seeds of forage plants Other raw vegetable materials
OtherCrops	wht	Wheat and meslin
	gro	Maize (corn) Barley Rye, oats Other cereals
	osd	Oil seeds and oleaginous fruit
	c_b	Plants used for sugar manufacturing
Forestry	frs	Forestry, logging and related service activities
Fishery	fsh	Hunting, trapping and game propagation including related service activities Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing
CoalOilGas	coa	Mining and agglomeration of hard coal Mining and agglomeration of lignite
	oil	Extraction of crude petroleum and natural gas (part) Service activities incidental to oil and gas extraction excluding surveying (part) Mining and agglomeration of peat
	gas	Extraction of crude petroleum and natural gas (part) Service activities incidental to oil and gas extraction excluding surveying (part) Mining and agglomeration of peat
	omn	Extraction of crude petroleum and natural gas (part) Service activities incidental to oil and gas extraction excluding surveying (part) Mining and agglomeration of peat
Animal Products	ctl	Bovine cattle, sheep and goats, horses, asses, mules, and hinnies, live Bovine semen
	oap	Swine, poultry and other animals, live Eggs, in shell, fresh, preserved or cooked Natural honey Snails, live, fresh, chilled, frozen, dried, salted or in brine, except sea

Animal Products (cont)		snails; frogs' legs, fresh, chilled or frozen Edible products of animal origin n.e.c. Hides, skins and furskins, raw Insect waxes and spermaceti, whether or not refined or colored
	rmk	Raw milk
	wol	Raw animal materials used in textile
	cmt	Meat of bovine animals, fresh or chilled Meat of bovine animals, frozen Meat of sheep, fresh or chilled Meat of sheep, frozen Meat of goats, fresh, chilled or frozen Meat of horses, asses, mules or hinnies, fresh, chilled or frozen Edible offal of bovine animals, swine, sheep, goats, horses, asses, mules or hinnies, fresh, chilled or frozen Fats of bovine animals, sheep, goats, pigs and poultry, raw or rendered; wool grease
	omt	Meat of swine, fresh or chilled Meat of swine, frozen Meat and edible offal, fresh, chilled or frozen, n.e.c. Preserves and preparations of meat, meat offal or blood Flours, meals and pellets of meat or meat offal, inedible; greaves Animal oils and fats, crude and refined, except fats of bovine animals, sheep, goats, pigs and poultry
Other Foods	vol	Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil, crude Palm, coconut, palm kernel, babassu and linseed oil, crude Soya-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil and their fractions, refined but not chemically modified; other oils obtained solely from olives and sesame oil, and their fractions, whether or not refined, but not chemically modified Maize (corn) oil and its fractions, not chemically modified Palm, coconut, palm kernel, babassu and linseed oil and their fractions, refined but not chemically modified; castor, tung and jojoba oil and fixed vegetable fats and oils (except maize oil) and their fractions n.e.c., whether or not refined, but not chemically modified Margarine and similar preparations Animal or vegetable fats and oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, but not further prepared Cotton linters Oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; vegetable waxes, except triglycerides; degras; residues resulting from the treatment of fatty substances or animal or vegetable waxes
	mil	Dairy products
	sgr	Sugar
	ofd	Prepared and preserved fish Prepared and preserved vegetables Fruit juices and vegetable juices Prepared and preserved fruit and nuts Wheat or meslin flour Cereal flours other than wheat or meslin Groats, meal and pellets of wheat Cereal groats, meal and pellets n.e.c. Other cereal grain products (including corn flakes) Other vegetable flours and meals Mixes and doughs for the preparation of bakers' wares Starches and starch products; sugars and sugar syrups n.e.c.

Other Foods (cont)		Preparations used in animal feeding Bakery products Cocoa, chocolate and sugar confectionery Macaroni, noodles, couscous and similar farinaceous products Food products n.e.c.
	b_t	Beverages Tobacco products
WoodPaper	lum	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	ppp	Manufacture of paper and paper products Publishing of books, brochures, musical books and other publications Publishing of newspapers, journals and periodicals Publishing of recorded media Other publishing (photos, engravings, postcards, timetables, forms, posters, art reproductions, etc.) Printing and service activities related to printing Reproduction of recorded media
Clothing	tex	Manufacture of textiles Manufacture of man-made fibres
	wap	Manufacture of wearing apparel; dressing and dyeing of fur
	lea	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
Electronics	fmp	Manufacture of fabricated metal products, except machinery and equipment
	mvh	Manufacture of motor vehicles, trailers and semi-trailers
	otn	Manufacture of other transport equipment
	ele	Manufacture of office, accounting and computing machinery Manufacture of radio, television and communication equipment and apparatus
	ome	Manufacture of machinery and equipment n.e.c. Manufacture of electrical machinery and apparatus n.e.c. Manufacture of medical, precision and optical instruments, watches and clocks
Other Manufactures	p_c	Manufacture of coke oven products Manufacture of refined petroleum products Processing of nuclear fuel
	crp	Manufacture of basic chemicals Manufacture of other chemical products Manufacture of rubber and plastic products
	nmm	Manufacture of other non-metallic mineral products
	i_s	Manufacture of basic iron and steel Casting of iron and steel
	nfm	Manufacture of basic precious and non-ferrous metals Casting of non-ferrous metals
	omf	Manufacturing n.e.c. Recycling
Transport	otp	Land transport; transport via pipelines Supporting and auxiliary transport activities; activities of travel agencies
	wtp	Water transport
	atp	Air transport
Elec/Water	ely	Production, collection and distribution of electricity
	gdt	Manufacture of gas; distribution of gaseous fuels through mains Steam and hot water supply
	wtr	Collection, purification and distribution of water
Services	cns	Construction
	trd	Sales, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel

Services (cont)		Wholesale trade and commission trade, except of motor vehicles and motorcycles Non-specialized retail trade in stores Retail sale of food, beverages and tobacco in specialized stores Other retail trade of new goods in specialized stores Retail sale of second-hand goods in stores Retail trade not in stores Repair of personal and household goods Hotels and restaurants
	cmn	Post and telecommunications
	ofi	Financial intermediation, except insurance and pension funding Activities auxiliary to financial intermediation
	isr	Insurance and pension funding, except compulsory social security
	obs	Real estate activities Renting of transport equipment Renting of other machinery and equipment Renting of personal and household goods n.e.c. Computer and related activities Research and development Other business activities
	ros	Recreational, cultural and sporting activities Other service activities Private households with employed persons
	osg	Public administration and defense; compulsory social security Education Health and social work Sewage and refuse disposal, sanitation and similar activities Activities of membership organizations n.e.c. Extra-territorial organizations and bodies
	dwe	n.a.

Appendix 3 – Region aggregation 1

This shows the aggregation from 113 regions down to 11 regions (Narayanan G., Dimaranan, & McDougall, 2008). The aggregation is based on information from the United Nations statistics division (United Nations Statistics Division, 2011).

Aggregated region	Original regions
Africa	Egypt Morocco Tunisia Rest of North Africa Nigeria Senegal Rest of West Africa Rest of Central Africa Rest of South Central Africa Ethiopia Madagascar Malawi Mauritius Mozambique United Republic of Tanzania Uganda Zambia Zimbabwe Rest of Eastern Africa Botswana South Africa Rest of South African Customs Union
South America	Argentina Bolivia Brazil Chile Colombia Ecuador Paraguay Peru Uruguay Venezuela Rest of South America
Central America and Caribbean	Costa Rica Guatemala Nicaragua Panama Rest of Central America Caribbean
North America	Canada United States of America Mexico Rest of North America

West and Central Asia	Kazakhstan Kyrgyzstan Rest of Former Soviet Union Armenia Azerbaijan Georgia Islamic Republic of Iran Turkey Rest of West Asia
East Asia	China Hong Kong Japan Korea Taiwan Rest of East Asia
South Asia	Bangladesh India Pakistan Sri Lanka Rest of South Asia
South-East Asia	Cambodia Indonesia Lao People's Democratic Republic Myanmar Malaysia Philippines Singapore Thailand Vietnam Rest of Southeast Asia
North and West Europe	Austria Belgium Denmark Estonia Finland France Germany Ireland Latvia Lithuania Luxembourg Netherlands Sweden United Kingdom Switzerland Norway Rest of EFTA
South and East Europe	Cyprus Czech Republic Greece Hungary

South and East Europe (cont)	Italy Malta Poland Portugal Slovakia Slovenia Spain Albania Bulgaria Belarus Croatia Romania Russian Federation Ukraine Rest of Eastern Europe Rest of Europe
Oceania	Australia New Zealand Rest of Oceania

Appendix 4 – Region aggregation 2

This shows the aggregation from the 11 region aggregation down to 6 regions

Aggregated region	Aggregated region (11 regions)
Africa	Africa
South/Central America and Caribbean	South America Central America and Caribbean
North America	North America
Asia	West and Central Asia East Asia South Asia South-East Asia
Europe	North and West Europe South and East Europe
Oceania	Oceania

Appendix 5 - Supporting information

The following information is included in the zip file named supporting information.

The MATLAB M-files and the GAMS IDE file contain the program being run.

- WTMBT_Main_ver400.m: Calls other files to run the program.
- WTMBT_Dataload_ver400.m: Loads data from BaseData.gdx in GAMS (not included here because of very large size). Converts data into matrixes that are easier to work with. Calculates the necessary matrices.
- WTMBT_DataPrePro_ver400.m: Makes GAMS ready for the model running
- WTMBT_ModelCall_ver400.m: First solves the No-trade model in MATLAB, then transport data to GAMS to run the world trade model and world trade model with bilateral trade.
- NoTradeModel.m: Solves the no trade model.
- WTM_GM_200_12_Z_GN.gms: The GAMS IDE file finding the optimal solution for the world trade model and world trade model with bilateral trade.

Calculation and Results

- WTMBT_GM_200_12_Z_GN_FinalResults.lst: Shows the LST file containing the results from the final compilation without benefit of trade constraint.
- WTMBT_Results_ver100.m: Manipulates the data received from GAMS into desirable results.
- Endowments.xlsx: Showing the manipulation of the results on primary factor use and the data behind the graphs
- Exports.xlsx: Showing the manipulation of the results on trade flows and the data behind the graphs
- Production.xlsx: Showing the manipulation of the results on production and the data behind the graphs