A Dynamic Input-Output Model to Project U.S. Freight Transportation Demand

by

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ABSTRACT

Understanding and modeling U.S. freight transportation demand is essential for infrastructure planning, the development of transportation-related regulatory frameworks, and the assessment of environmental implications. However, existing models that forecast U.S. freight transportation demand are very complicated and require a vast computational effort. In the following, I develop a simpler, yet more effective, model to project economic performance and the resulting freight transportation demand.

I analyze and project economic growth and structural change using an input-output framework. This economic part of my model projects U.S. commodity output values for the next two decades. In the second part of my model, commodity values are transformed into quantities of freight transportation demand. The latter are the basis for deriving environmental implications of growing freight shipment activities.

In the analysis of model outputs, I examine a significant trend towards relatively light, high-value commodities, which reflects ongoing dematerialization in the U.S. economy. Nevertheless, these commodities promote a shift towards faster, more energy-intensive freight transport modes, which gives reason for environmental concern and requires regulatory action to support less carbon-intensive freight transportation.

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ABBREVIATIONS

BAU	Business as Usual
BEA	Bureau of Economic Analysis
BTS	Bureau of Transportation Statistics
Btu	British Thermal Unit
CFS	Commodity Flow Survey
CTS	Commodity Transportation Survey
CO_2	Carbon Dioxide
GDP	Gross Domestic Product
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
I-O	Input-Output
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
N/A	Not Available
NEMS	National Energy Modeling System
NO_x	Nitrogen Oxide(s)
SO_2	Sulfur Dioxide
TMT	Ton-Miles Traveled
UN	United Nations
VA	Value Added
VOC	Volatile Organic Compounds

1 Introduction

1.1 Background

The demand for freight transportation and the economic performance of a country are closely related. As an economy grows, not only are more final goods shipped from manufacturers to customers, but also more intermediate goods run through the production process. Additionally, some economic sectors lose importance over time, whereas other sectors increase their share in the economy's output. These facts make the interrelation of economic growth and freight transportation demand a complicated, non-linear matter. Nevertheless, understanding and modeling freight transportation demand is essential for infrastructure planning, the development of regulatory frameworks, and the assessment of environmental implications.

Existing models that forecast U.S. freight transportation demand are very complicated and require a vast computational effort. The U.S. Department of Energy (DOE), for example, uses a transportation model that can be run only within the National Energy Modeling System (NEMS). In the next chapter, I show advantages and disadvantages of this and other models and draw conclusions for the development of an alternative, more effective, model to relate economic performance and freight transportation demand.

In this model, I subdivide economic performance into growth, measured by GDP, and structural changes, represented by shifts in the composition of intermediate and final demand. While economic growth leads to an increase in the total output of transported goods, structural changes influence the characteristics of the output and thus cause shifts in weight, distance, and modes by which those goods are transported. Input-output tables are the appropriate framework to relate economic growth and structural change. Dynamic effects can be modeled if the change of elements (specifically, I-O multipliers) in I-O tables is projected over time.

I split the economy into sectors that produce physical output (transportation-relevant sectors) and sectors producing non-transportable output (service sectors). The interrelation of these sectors is represented in input-output tables. Using historical data, I project future changes in intermediate and final demand, which I then use to derive projections of commodity output. In the next step, I transform commodity values into physical figures of transportation demand. Those figures reveal connections between economic performance and freight transportation and are the basis for analyzing environmental implications of growing freight shipment activities.

As part of the analysis, I examine the dematerialization of the U.S. economy with respect to freight transportation. I obtain a significant trend towards relatively light, high-value commodities, which causes the average weight of shipments to drop. However, I also discover that the growing importance of high-value products inclines a shift towards faster, more energy-intensive freight transport modes, which gives rise to environmental concern and requires regulatory action to promote less carbon-intensive freight transportation.

1.2 Overview

In the second chapter, I introduce DOE's NEMS Transport Sector Model and a model proposed by Costa [1988], and derive conclusions for the development of a simpler, yet more effective, model. Thereafter, I introduce input-output modeling in Chapter 3 and proceed in Chapter 4 with a description of the economic and transportation parts of my model. In Chapter 5, I illustrate the effects of dynamic changes in economic parameters and in transportation characteristics, and explain how my model deals with them. I analyze the economic and transportation projections of the model in Chapter 6. In Chapter 7, I show how these projections relate to figures from other data sources, and I discuss improvements of the model that would be possible in the event that better data become available in the future. Chapter 8 outlines environmental impacts related to the projected increase in freight transportation demand and simultaneous modal shifts. Finally, I explain in Chapter 9 the data methodology used in this paper, and draw conclusions from my study in Chapter 10.

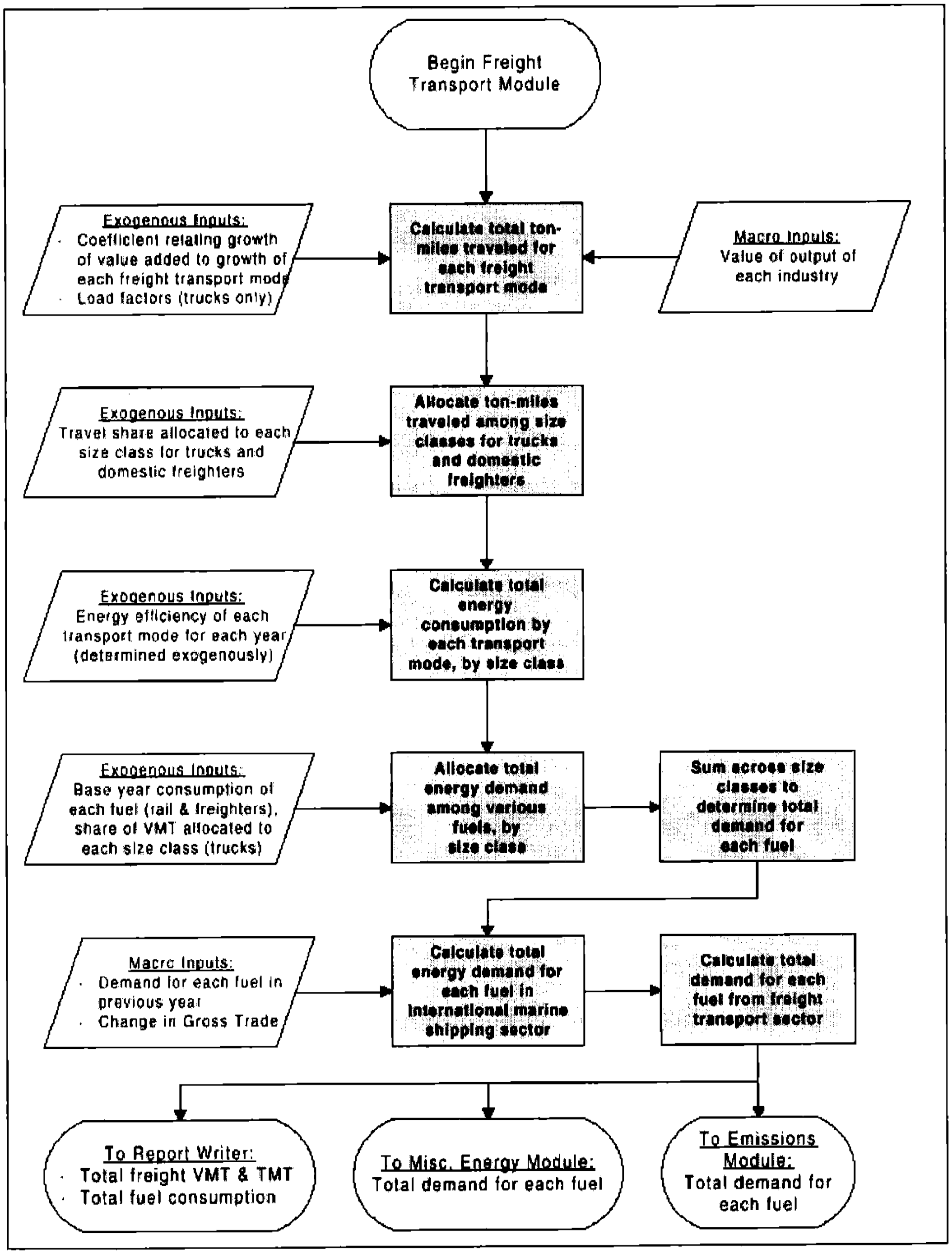
2 Review of Existing Models

2.1 The NEMS Model of the DOE

The U.S. Department of Energy (DOE) has developed a very complex model system to project the entire U.S. Energy Consumption – The National Energy Modeling System (NEMS). Among others, the NEMS includes a Freight Transport Module. The NEMS Freight Transport Module is shown in Figure 2.1. To predict freight transportation demand, the Freight Transport Module receives the value of industrial output from the NEMS macroeconomic model. The macroeconomic model is again a complex model linked with other parts of the NEMS. However, if the objective is to project freight transportation demand, it is not necessary to model the U.S. economy in so much detail. The NEMS has not been developed to predict freight transportation but to model energy consumption of all economic sectors. Consequently, it is possible to develop a simpler and more effective model with the specific aim of modeling U.S. freight transportation demand.

The freight module of the NEMS transforms commodity values directly into ton-miles by relating growth in ton-miles traveled (TMT) to growth in the value of commodity output. This method is a shortcut, the alternative is to first transform quantities into weight and then derive ton-miles figures using exogenous information about average distance of shipments. Although the method used by DOE saves some time in computation and model specification, it sacrifices important information when not calculating commodity weight.[1] For example, an analysis can use the knowledge about commodity weight to study shifts in the characteristics of goods transported that lead to changes in transport modes. Besides that, the time saving is not a true advantage because changes in commodity weight are, among other things, exogenously calculated by the DOE and represented by so-called freight adjustment coefficients. The computation of freight adjustment coefficients involves again many parameters that need to be projected over time.

[1] I develop this argument in detail in Chapter 4.2.1.



Source: DOE 2001, page 113.

Figure 2.1 The Freight Module in the DOE's NEMS Model

Altogether, I believe that the NEMS involves too-complicated a procedure to project commodity output and that the integrated freight module sacrifices valuable information about commodity weight.

2.2 Multiregional Freight Transportation Models

Models that are specifically developed to project freight transportation demand become complicated, as well, if the researchers want to include regional dynamics within the country. I use a model suggested by Costa in 1988 to illustrate this problem. He writes in the same paper [Costa 1988, page 83]:

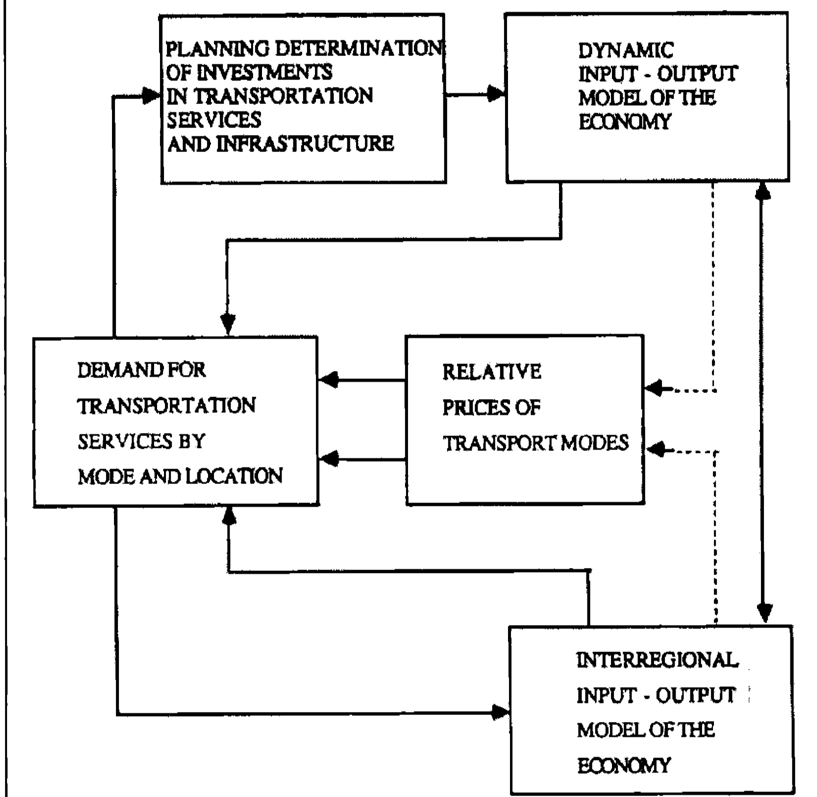
> *Demand for transport, especially demand for freight transport...is a derived one that comes from the rest of the economy. Any variation in the structure, behavior or level of operation of any part of the economic system will affect level, modal split and routing of demand for transport.*

To model the economic system, Costa suggests the use modified input-output tables. His idea is to adjust the transportation sector coefficients in I-O tables so that they measure transportation modal requirements per unit of (national) output of every given industry. As visualized in Figure 2.2, the modified coefficients are dependent on:

- Variations in transportation technologies
- Variations in transportation relative prices that control model mix
- Variations in the interregional mismatching between supply and demand for each commodity.

It is not only difficult to find variables measuring those effects but also hard to fit them into a practical framework that projects the dynamic changes in I-O coefficients.

The main aspect that makes models like the one suggested by Costa complicated, is that they try to include transportation-related variables in the economic projection. I argue that it is simpler, but equally accurate, to divide a freight transportation model into an economic and a transportation part, where the output of the former is used as input into the latter. Moreover, I will show in the following that it is possible to build a model that does not depend on the price of transportation services. Rather, I project the commodity output of the U.S. economy and I then assume that this output needs to be transported from producer to buyer, where the typical pattern by which a certain commodity is transported does not change dramatically in the near term.



Source: Costa 1988, page 92.

Figure 2.2 Integrated System of Models

3 Introduction to Input-Output Modeling

3.1 Input-Output Tables

Input-Output (I-O) tables provide an overview of the flow of goods and services between an economy's producing and purchasing sectors. The information included in input-output tables stem from a range of statistical accounts of the corresponding region or country. Input-output tables show intermediate transactions between producers and purchasers, purchases of final goods, and payments to factors of production. Therefore, input-output tables are a powerful tool to analyze an economy's state and progress, especially when analyzing the impact of changes in final demand on different industries.

3.1.1 Make Tables and Use Tables

For economic analysis, make tables and use tables are most commonly used. From those tables, direct requirements and total requirements tables can be derived. Make tables show which commodities are produced by which industrial sector. Each industry is called the "primary" producer for its corresponding commodity. For example, the agriculture sector is the primary producer of agricultural goods. However, most industries produce not only their primary goods but also secondary goods. This is the case, for example, if the agriculture sector also provides water services.

While make tables show the producers of goods, use tables show which sectors purchase those goods. Since the purchases of a sector indicate which goods it uses in the production of its output, use tables provide industry technology information. For example, the amount of steel, rubber, and aluminum purchased by the car manufacturing sector allows conclusions about the technology used it uses. A commodity-by-industry use table can be subdivided into three sections – intermediate demand, value added, and final demand. The intermediate demand illustrates what value of each commodity is consumed by economic sectors in the course of their production process. Value added indicates the value of factors of production services (e.g. labor and capital) provided to intermediate users. Final demand shows the value of goods consumed by final users (e.g. households or government).

3.1.2 Input-Output Multipliers

The information of use tables is the basis for calculating direct requirement coefficients and total requirement coefficients, which are represented in the same table format as I-O tables. Direct requirement coefficients show the amount that a sector, A, purchases directly from another sector, B, in order to produce one unit of its output. For example, the transportation sector purchases fuel directly from the petroleum sector to provide its output (the transportation service). Total requirements coefficients describe the direct and indirect input requirement of sector A for products (or services) of sector B if the final demand for sector A's output changes by one unit. The following example gives an intuition as to what indirect requirements are: The transportation sector directly consumes petroleum to provide transportation services. The petroleum sector, in turn, needs transportation to ship crude oil and fuel. Hence, an increase in final demand for transportation does not only lead directly, but also indirectly, to a rise in transportation volume. A total requirement coefficient of transportation for manufacturing goods of 0.16 means that the output of manufacturing increases by 16 cents if the final demand for transportation rises by 1 dollar. It is important to note that direct requirements refer to total sectoral output whereas total requirements pertain to the final demand for a sector's output.

The relationship between total requirements and final demand can be used to calculate commodity output. I use this method in the economic projection of commodity output. Under the assumption of constant average propensity to consume,[2] total requirement coefficients can be used to forecast the output of each commodity based on changes in final demand. However, the assumption of constant average propensity is only maintainable in the short-run, since consumption patterns of industries and households change as the economy grows. To examine this structural change, I work with dynamic multipliers in the projection of total output.

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[2] Constant average propensity to consume means that the consumption patterns in an economy remain unchanged if industries grow or decline.

3.1.3 Costs vs. Prices

Figures in U.S. I-O tables are in producers' prices. Wholesale margins, retail margins, and transportation costs are represented separately. Consumers' prices can be calculated by adding transportation costs and trade margins to the producers' prices. Wholesale margins, retail margins, and transportation costs can be seen either (1) as a total for each industry in I-O use tables or (2) as separate figures for each commodity delivered to each industry in I-O margin tables also provided by the BEA.

3.1.4 The Gross Domestic Product (GDP) in Input-Output Tables

By definition, Gross Domestic Product (GDP) is the value of all final goods and services produced in a country within a given period [Dornbusch 1995, p. 20]. Adding to GDP the factor payments from abroad to domestically owned factors of production yields the Gross National Product (GNP). From input-output tables, GDP can be obtained in two different ways: First, by summing up the value added for all economic sectors.[3] Value added consists of all payments of an industry to its factors of production, that is, the amounts paid for labor (wages and salaries), capital (profits, retained earnings, dividends, and interest), land (rent), and indirect taxes [Polenske 1993, p. 205]. Second, GDP is represented in input-output tables by the value of all final goods produced (and consumed) in the respective country. In this procedure, the value of exports is added to GDP while the value of imports is subtracted, which is intuitive because exports are produced within the country under examination whereas imports are produced abroad.

The calculation of GDP as the total of the value added row must yield the same number as the total of the final demand column(s). From an accounting perspective, this equality is explained as follows: Within an economy, the total income of factors of production (total value added) must equal the total consumption expenditures (total final demand). The at-

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[3] In U.S. I-O tables, value added for final demand sectors (e.g. households and government) is zero. This raises a question: What about wages paid by government to its employees and what about wages that households pay their cleaning ladies? The U.S. I-O framework solves this problem by establishing a "General Government Industry Sector" and a "Household Industry Sector" (sector 82 and 84, respectively, in the 1997 U.S. I-O use table). Those sectors belong to the intermediate part of the I-O table.

tentive reader may ask how savings are treated in this framework – an individual takes savings to a bank, which invests the money in the economy. Savings given to a bank show up in the private consumption and in the private and government investment column(s), whereas capital investments undertaken by banks are present in the value added row.

3.1.5 Commodity-by-Industry Input-Output Tables

For transportation analyses, it is useful to work with I-O tables in a commodity-by-industry format (use table). Columns in the use table consist of industries and final uses. The different industries are collections of producing units that share similar production technologies. The column total for an industry represents its total (gross) output. Final uses are categories of expenditures by households, businesses, government, and foreign residents that are included in the GDP. Rows in the use table consist of commodities and value added. Commodities are goods and services (produced by industries or imported) that are consumed either by industries (intermediate demand) in the production process or by final users (final demand). Value added is the difference between an industry's gross output and its total use of commodities (total intermediate inputs) [Yuskavage, 2000].

Table 3.1 shows a commodity-by-industry I-O table in a format that gives detailed attention to the transportation sector. The economic sectors examined are Agriculture & Fishing, Industry & Mining, Transportation (detailed), and Services. Although I will aggregate U.S. I-O tables in a different way later on to develop my freight transportation model, the format used in Table 3.1 is helpful to understand how transportation expenditures are represented in the tables. All numbers are in producers' prices, that is, in the prices that producers of goods charge when commodities leave their factories. The difference between producers' prices and purchaser prices consists of transportation margins, wholesale margins, retail margins, and insurance margins.

Commodity \ Industry	Intermediate Demand								Final Demand					
			Transportation Expenditure											
	Agriculture & Fishing	Industry & Mining	Rail	Motor Freight	Water	Air	Pipelines	Service & Trade	Personal Consumption Expenditure	Government Investment/ Expenditure	Investment / Change in Inventory	Exports	Imports	Total Commodity Output
Agriculture & Fishing	75,136	154,668	2	5	7	1	-	23,668	34,735	2,602	3,697	23,495	-22,910	**295,106**
Industry & Mining	55,347	1,794,136	12,467	16,039	3,239	19,677	2,763	694,204	1,034,152	413,825	1,106,162	535,722	-833,665	**4,854,068**
Railroads and Related Services	1,856	19,833	3,148	435	17	167	40	14,605	25,156	6,488	1,463	5,349	-194	**78,362**
Motor Freight & Warehousing	4,534	75,468	529	41,122	88	312	251	28,954	33,873	7,186	6,780	14,754	-1,985	**211,866**
Water Transportation	377	2,289	19	956	7,333	55	60	3,464	6,081	2,208	15	10,243	4,038	**37,136**
Air Transportation	829	17,725	294	2,083	67	7,763	270	29,597	52,422	7,659	2,663	30,591	-14,786	**137,175**
Pipelines, Freight Forwarders	157	5,422	535	6,849	1,701	11,420	1,028	2,850	4,326	281	-10	3,090	-	**37,648**
Service & Trade	49,462	881,640	10,661	45,413	11,382	28,247	15,030	2,136,717	4,338,540	1,047,652	269,810	278,407	-121,472	**8,991,488**
Value Added	110,194	1,991,302	42,728	112,338	10,696	63,004	24,416	5,963,764	-	-	-	-	-	**8,318,442**
Total Industry Output	**297,890**	**4,942,484**	**70,383**	**225,239**	**34,530**	**130,646**	**43,857**	**8,897,822**	**5,529,283**	**1,487,901**	**1,390,580**	**901,651**	**-990,973**	

Source: Author. Modified U.S. 1997 I-O table. Data Source: U.S. Department of Commerce, Bureau of Economic Analysis, 1997 Annual I-O Table Two-Digit

Notes: Figures in Millions of current 1997 U.S. Dollars at producers' prices.

"( )" Figures in parentheses are negative numbers.

"–" A dash indicates that the corresponding number is smaller than $50,000, according to the underlying BEA accounting framework.

Total Output Calculation

Column Sum (Industry Output): 14,642,850
Row Sum (Commodity Output): 14,642,850

GDP Calculation

Column Sum (Total Final Demand): 8,318,442
Row Sum (Total Value Added): 8,318,442

Table 3.1 The Use of Commodities by Industries in the United States, 1997

For the derivation of transportation models,[4] the commodity output (row-sum) of the transportation sector is generally more useful than the transportation industry output (column-sum). For example, the number in row 6, column 2 in Table 3.1 means that the Industry & Mining sector paid $ 17,725 million for air transportation (goods and passengers) in the United States in 1997. The row-sum, on the other hand, states that the total payments of all U.S. industries and final users for air transportation were $ 137,175 million in 1997. This figure differs from the total air industry output ($130,646 million), which is represented by the column sum of the air transportation industry. The deviation results from the fact that air transportation is also provided by economic sectors other than Air Transportation.[5] Hence, in air transportation the total commodity output is larger than the total industry output. If this is the case, the total expenditures for air transportation are underestimated if one works with the total industry output, which does not consider air transportation provided as a secondary good by other sectors.

There is also the case of total industry output being larger than total commodity output:[6] in the Motor Freight Transportation sector, for example, total industry output is $225,239 million, whereas total commodity output is $211,866 million. This deviation has its reason in the production of Water and Sanitary Services by the Freight Transportation industry.[7] In this case it is also better to work with the total commodity output figure in transportation demand models because the total industry output overestimates transportation demand.

It follows from the above-made arguments that transportation demand models based on I-O transportation expenditures must find transportation commodity output figures and then split those numbers into a passenger and a freight transportation component. However,

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[4] For example, models that use transportation expenditures to calculate ton-miles and tons of goods transported by using transportation prices.

[5] In this case, air transportation is also provided by the Pipeline & Freight Forwarders industry and by the State and Local Government industry (as can be seen in the 1997 I-O-Make Table). Each industry is designated the "primary" producer for its corresponding commodity. If an industry produces goods other than its corresponding commodity it is called "secondary" producer of those goods.

[6] In an I-O Table, total commodity output for all economic sectors must be equal to the total industry output for all sectors. Therefore, as soon as there is a positive difference between total commodity output and total industry output in one sector, there must be a negative difference in another sector.

[7] Again, this fact is derived from the 1997 I-O-Make Table.

there several disadvantages related to this approach, as I will describe in the following.

3.1.6 The Treatment of Imports in U.S. Input-Output Tables

When building a transportation model based on input-output tables, it is important to know how imports are dealt with in the I-O framework. Imports enter the U.S. intermediate and final consumption sectors just like domestically produced commodities and cannot be distinguished from the latter. I use an example to illustrate the treatment of imports in U.S. tables. Imagine a manufacturing sector that produces 4 bikes in a certain year. In the production process, this sector imports 6 bicycle wheels and purchases the remaining 2 wheels from a domestic producer. All wheels show up in the same cell of the I-O table, allowing no differentiation between imports and domestic production. When calculating total output, however, a researcher wants to know how many wheels have been produced domestically. Consequently, imports (6 wheels) must be deducted from the row-total (8 wheels).

The bicycle example provides an important conclusion for the development of a freight transportation model. When calculating freight transport demand, the interesting figure is the number of wheels that circulate within the economy (i.e., 8), rather than the total output of wheels (i.e., 2), because all 8 wheels must be transported to the bicycle producer. I will use this finding and explain it in more detail in Chapter 4.2.2.

3.1.7 Input-Output Tables and Transportation

The information provided in Input-Output tables is helpful to understand the interrelation of economic performance and transportation demand. Transportation expenditures of nearly 500 economic sectors can be examined in U.S. I-O tables provided by the Bureau of Economic Analysis (BEA). From this detailed allocation, sectoral transportation expenditures as well as inputs into the transportation sector (e.g., fuel) can be derived.

In U.S. I-O tables, own-account (i.e., self-operated) transportation of firms is not represented. Thus, value added and total output of the transportation sector are typically underestimated in I-O tables. Moreover, it is not clear from common I-O tables whether the transportation expenditure of a sector is due to goods transported into this sector (the purchasing sector pays for transportation), or the export of goods out of this sector (the selling sector pays for transportation). Another crucial issue is that transportation expenditures in I-O tables are not separated into freight and passenger transportation. For example, most of service sectors' transportation expenditure is due to employee travel rather than goods transportation. Thus, it is very difficult to derive a freight transportation model based upon transportation expenditures in I-O tables.

To analyze freight transportation issues, BEA provides transportation margin tables that show the transportation expenditures related to all goods traded within and between sectors. However, those tables are only available back to 1987 and are not a reliable source to derive trends over time. Furthermore, when developing a freight transportation model based upon transportation expenditures, the dollar values of expenditures must be transformed into ton-miles using the price per ton-mile. This brings a further variable into the model that can change significantly over time. Such a model would need to consider transportation price elasticity and parameters determining the price per ton-mile (e.g. fuel, transportation equipment, and labor prices). An effort like this would go beyond the scope of this study, making it necessary to think about alternative approaches.

The approach that appears to be most practicable is to project the total output of a characteristic set of commodities and to derive the weight of those commodities using their value per ton. Since several commodities are summarized in each commodity class, the value-per-ton-volatility within those commodity classes is lower then the price volatility of transportation services. In this approach, input-output tables are used to project commodity output in dollar values, which is then transformed into output in tons, using commodity value per ton. For each commodity class, transportation patterns can be derived from historical data, for example, by which mode and over which average distance agricultural goods are (and have been) transported.

The approach of forecasting commodity output and then deriving transportation characteristics from the monetary projections is the cornerstone of my model, which I explain in the next chapter.

4 The Model

The model to project U.S. freight transportation demand consists of two essential components, an economic model to forecast commodity output and a transportation model that derives transportation demand from commodity output. The economic model is based upon a dynamic analysis of U.S. input-output tables for numerous years between 1972 and 1998.[8] The transportation model is derived from commodity flow survey (CFS) data for 1972, 1977, 1993, and 1997 as well as from other data sources. In the following, the economic and the transportation model are introduced and their interaction is described.

4.1 Economic Projection with a Dynamic I-O Model

4.1.1 Definitions

Before delving into the description of the economic model, it is useful to define the economic sector classification and all relevant variables. Input-Output tables available from the Bureau of Economic Analysis (BEA) are in current dollars, but current dollar figures are not comparable over time because prices of goods change due to inflation or deflation. For example, a dollar spent for building material in 1972 could buy much more stone or clay than a dollar spent in 1998. Consequently, when analyzing transportation demand, it is desirable to work with inflation-adjusted (constant) values. For this purpose, I adjust all commodity and service values in I-O tables with implicit price deflators derived from BEA data.[9] Thus, all values and multipliers explained and defined in the following refer to constant (1996) dollars, unless stated otherwise.

As explained earlier, an input-output table consists essentially of intermediate and final sectors. In the economic model used in this paper there are four final demand sectors: Personal Consumption, Government Investment and Consumption, Exports, and Imports. In the intermediate part, commodities are subdivided into nine sectors – six types of commodities that can be transported and three service sectors, producing non-transportable out-

[8] The exact years are 1972, 1977, 1982, 1987, 1992, 1996, 1997, and 1998.
[9] See the Chapter 9.2 for an explanation of the method.

put. The classification of the six transportation sectors is based upon a two-stage process: First, commodities are classified as food products, raw materials, or energy related goods. Second, the remaining goods are classified as low- medium- or high-value intermediate and final goods according to their value per ton of commodity weight.[10] The three non-transportable output (service) sectors are differentiated by the average annual growth of their output between 1972 and 1998. Sectors with less than 1.5% average annual growth fall into the small-growth category; sectors with an average annual growth over 4% are considered high-growth services and all sectors between 1.5% and 4% growth fall into the medium-growth category. Table 4.1 shows the sectoral classification of commodities and final demand.

Commodities:

1	Agricultural and Food Products	Transportable Commodities
2	Mining, Minerals, Sands, Stone, Waste	
3	Coal, Petroleum, Fuels	
4	Low-Value Intermediate and Final Products	
5	Medium-Value Intermediate and Final Products	
6	High-Value Intermediate and Final Products	
7	Non-Trp Small Growth (g < 1.5%)	Non-Transportable Commodities (Services)
8	Non-Trp Medium Growth (1.5% ≤ g < 4%)	
9	Non-Trp High Growth (g ≥ 4%)	

Final Demand Sectors:

1	2	3	4
Personal Consumption	Government and States: Investment & Consumption	Exports	Imports

Source: Author; Non-Trp = Non-Transportable Output Sectors; g = average annual growth rate of sectoral output between 1972 and 1998.

Table 4.1 Commodity and Final Demand Sector Classification

From this sectoral classification follows that the Input-Output table used in the economic forecast model has the shape shown in Table 4.2, where m_{ij} is the value of commodity i consumed in the production process of the intermediate sector j and f_{ik} is the value of commodity i consumed by the final demand sector k. The column sums in the intermediate sectors $m_{\bullet j}$ describe the total payments of sector j to inputs in year y

[10] See Chapter 9.1 for a detailed description of the sector classification.

$$(4.1) \qquad m^y_{\bullet j} = \sum_{i=1}^{I} m^y_{ij} \;, \forall j \in J \,, \forall y$$

where in the present model, $I = 10$ and $J = 9$.[11] The column sums $m_{\bullet j}$ can also be referred to as total industry output of sector *j*. The row sums $m_{i\bullet}$ give the total output of commodity *i*, delivered to intermediate and final demand

$$(4.2) \qquad m^y_{i\bullet} = \sum_{j=1}^{J} m^y_{ij} + \sum_{k=1}^{K} f^y_{ik} \;, \forall i \in I \,, \forall y$$

with $I = 10$, $J = 9$ and $K = 4$ in this model. The row sums $m_{i\bullet}$ are also called total commodity output of commodity *i*. The total output of transportable commodities ($i = 1,\ldots, 6$) will be of particular interest when the economic model is linked with the transportation model.

Note that $m_{\bullet j}$ does not necessarily equal $m_{i\bullet}$ because of the differences between commodity output and industry output in I-O-Use tables.[12]

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[11] We have I≠J in this case because value added is treated like a commodity input into the intermediate sectors. Later in this chapter, value added will be left out to obtain a quadratic matrix.

[12] Those differences are described in detail in the chapter Introduction to Input-Output Analysis

Commodity \ Industry	Intermediate Sectors									Final Demand				Total
	1	2	3	4	5	6	7	8	9	1	2	3	4	
1	m_{11}	m_{12}							m_{19}	f_{11}			f_{14}	$m_{1\bullet}$
2	m_{21}									f_{21}				
3														
4														
5					m_{ij}						f_{ik}			$m_{i\bullet}$
6														
Small Growth (7)														
Medium Growth (8)														
High Growth (9)														
Value Added (10)	$m_{10\,1}$								$m_{10\,9}$	$f_{10\,1}$			$f_{10\,4}$	$m_{10\bullet}$
Total	$m_{\bullet 1}$	$m_{\bullet 2}$			$m_{\bullet j}$				$m_{\bullet 9}$	$f_{\bullet 1}$			$f_{\bullet 4}$	

Source:Author

Table 4.2 Shape of the Input-Output Table

The column sums of the final sectors $f_{\bullet k}$ correspond to the total final demand of final sector k:

$$(4.3) \qquad f_{\bullet k}^{y} = \sum_{i=1}^{I} f_{ik}^{y}\ , \forall k \in K\ , \forall y\ .$$

The sum of all final expenditures in a given year equals the gross domestic product:

$$(4.4) \qquad GDP^{\,y} = \sum_{i=1}^{I} \sum_{k=1}^{K} f_{ik}^{y} = \sum_{k=1}^{K} f_{\bullet k}^{y}\ , \forall y\ ;$$

where $GDP^{\,y}$ is given in constant 1996 dollars.[13] The row sums of the final sectors $f_{i\bullet}$ represent the total final demand for commodity i:

$$(4.5) \qquad f_{i\bullet}^{y} = \sum_{k=1}^{K} f_{ik}^{y}\ , \forall i \in I\ , \forall y\ .$$

Note that $f_{10\,k} = 0\ , \forall k \in K$ because wages and other value added paid by final sectors

[13] The real GDP rather than the nominal GDP is obtained because the I-O tables were adjusted with implicit price deflators.

(e.g. wages that households pay their babysitters) are not included in the accounting framework underlying the I-O tables.

Having introduced the sectoral classification, I will now define several multipliers that can be derived from the above I-O table. Beginning with the intermediate part of the I-O table, let a_{ij} be the direct requirement of intermediate sector *j* for commodity *i*:

$$(4.6) \qquad a_{ij}^{y} \equiv \frac{m_{ij}^{y}}{m_{\bullet j}^{y}}, \forall i \in I, \forall j \in J, \forall y,$$

which means that to produce one unit of its output, sector *j* requires a_{ij} units of commodity *i*. Using equation (4.1), it is clear that

$$(4.7) \qquad \sum_{i=1}^{I} a_{ij}^{y} = a_{\bullet j}^{y} = 1, \forall j \in J, \forall y.$$

Turning to the final demand side of the I-O table, I define s_{ik} as the share of commodity *i* in the demand of final sector *k*:

$$(4.8) \qquad s_{ik}^{y} \equiv \frac{f_{ik}^{y}}{f_{\bullet k}^{y}}, \forall i \in I, \forall k \in K, \forall y.$$

Note that $s_{10\,k} = 0, \forall k \in K$ since $f_{10\,k} = 0, \forall k \in K$ for the reasons explained above. Substituting equation (4.3) into (4.8) yields

$$(4.9) \qquad \sum_{i=1}^{I} s_{ik}^{y} = s_{\bullet k}^{y} = 1, \forall k \in K, \forall y.$$

An important figure in the projection of final demand is the share s_k of a final sector *k* in the total final demand (GDP):

$$(4.10) \quad s_k^y \equiv \frac{f_{\bullet k}^y}{GDP^y} = \frac{f_{\bullet k}^y}{\sum_{k=1}^{K} f_{\bullet k}^y}, \forall y.$$

For example, s_1^y gives the share of personal consumption in GDP in year *y*. The definition of multipliers is visualized in Table 4.3.

Commodity \ Industry	Intermediate Sectors									Final Demand			
	1	2	3	4	5	6	7	8	9	1	2	3	4
1	a_{11}	a_{12}	…	…	…	…	…	…	a_{19}	s_{11}	…	…	s_{14}
2	a_{21}									s_{21}			
3													
4													
5					a_{ij}						s_{ik}		
6													
Small Growth (7)													
Medium Growth (8)													
High Growth (9)													
Value Added (10)	$a_{10\,1}$	…	…	…	…	…	…	…	$a_{10\,9}$	$s_{10\,1}$	…	…	$s_{10\,4}$
Total	**1.0**	**1.0**	…	…	**1.0**	…	…	…	**1.0**	**1.0**	…	…	**1.0**

Source:Author

Table 4.3 Input-Output Multiplier Table

In order to present equations of the model in a simple way, it is useful to define several elements of the I-O table in matrix notation. Let A be a quadratic ($J \times J$) matrix of direct requirements a_{ij}. The value added row $a_{10\,j}$ is left out when creating A so that in the present model with $I = 10$ and $J = 9$, A has the following shape in year *y*:

$$A^y = \begin{pmatrix} a_{11}^y & \cdots & a_{19}^y \\ \vdots & \ddots & \vdots \\ a_{91}^y & \cdots & a_{99}^y \end{pmatrix}.$$

Let X be the final demand vector of dimension $(I - 1) \times 1$ with each element $f_{i\bullet}$ representing the final demand for commodity *i*, as defined in equation (4.5). Consequently, in year *y*, X has the shape

$$X^y = \begin{pmatrix} f_{1\bullet}^y \\ \vdots \\ f_{9\bullet}^y \end{pmatrix}.$$

Finally, define Y as the commodity output vector of dimension $(I - 1) \times 1$ with each element $m_{i\bullet}$ being the total output of commodity i, as defined in equation (4.2). Thus, in year y, Y has the form

$$Y^y = \begin{pmatrix} m_{1\bullet}^y \\ \vdots \\ m_{9\bullet}^y \end{pmatrix}.$$

Having defined the relevant variables of the economic model, I will explain in the following how figures for those variables are obtained and projected from time-series data.

4.1.2 The Derivation of Model Variables from Time Series Data

The economic model is essentially based upon the projection of two sets of data: First, the GDP of the United States between 2000 and 2020 and second, the forecast of input-output multipliers depending on the GDP. I explain the basic framework of variable derivation and projection in this chapter, whereas the chapter Data Methodology presents the underlying methods.

I use time series data for real GDP per capita (1950-1998) from the International Monetary Fund (IMF) to project GDP per capita.[14] Later in this paper I will apply three different growth scenarios to reflect possible fluctuations in the projection of GDP per capita. The growth projection derived from IMF data will be referred to as business-as-usual (BAU) scenario. A population forecast for the United States is available from United Nations (UN) data. Multiplying those population figures for 2000-2020 with the GDP per capita projec-

[14] A comparison of GDP figures from the IMF with figures obtained from inflation-adjusted I-O tables shows that both data sets are very similar.

tions yields the GDP (real) projection.

In the projection of I-O multipliers I again distinguish between intermediate sector multipliers (direct requirements) and multipliers of final sectors (GDP composition). In the projection of the latter, I use real (1996) per-capita-GDP as explanatory variable.[15] The projection of final demand by commodity and sector requires two multipliers: First, the share s_k of a final sector *k* in GDP and second, the share s_{ik} of commodity *i* in the total demand of final sector *k*. In the present I-O table with $K = 4$ and $I = 10$, I run 4 regressions to obtain s_k as a function of GDP and 36 regressions (4×9, since $s_{10\,k} = 0, \forall k \in K$) to obtain s_{ik} as a function of GDP.

I regress direct requirements (A-Matrix), on time as an explanatory variable. In the intermediate part of the I-O table, I run 90 regressions ($I = 10$ and $J = 9$) to obtain the direct requirement a_{ij} of intermediate sector *j* for commodity *i* as a function of time.[15]

Figure 4.1 visualizes the derivation of model variables from time-series data. The regression procedure is explained in the chapter Data Methodology. Detailed information about regression output can be found in Appendix B.

[15] The reasons for this specification are explained in Chapter 9.3.

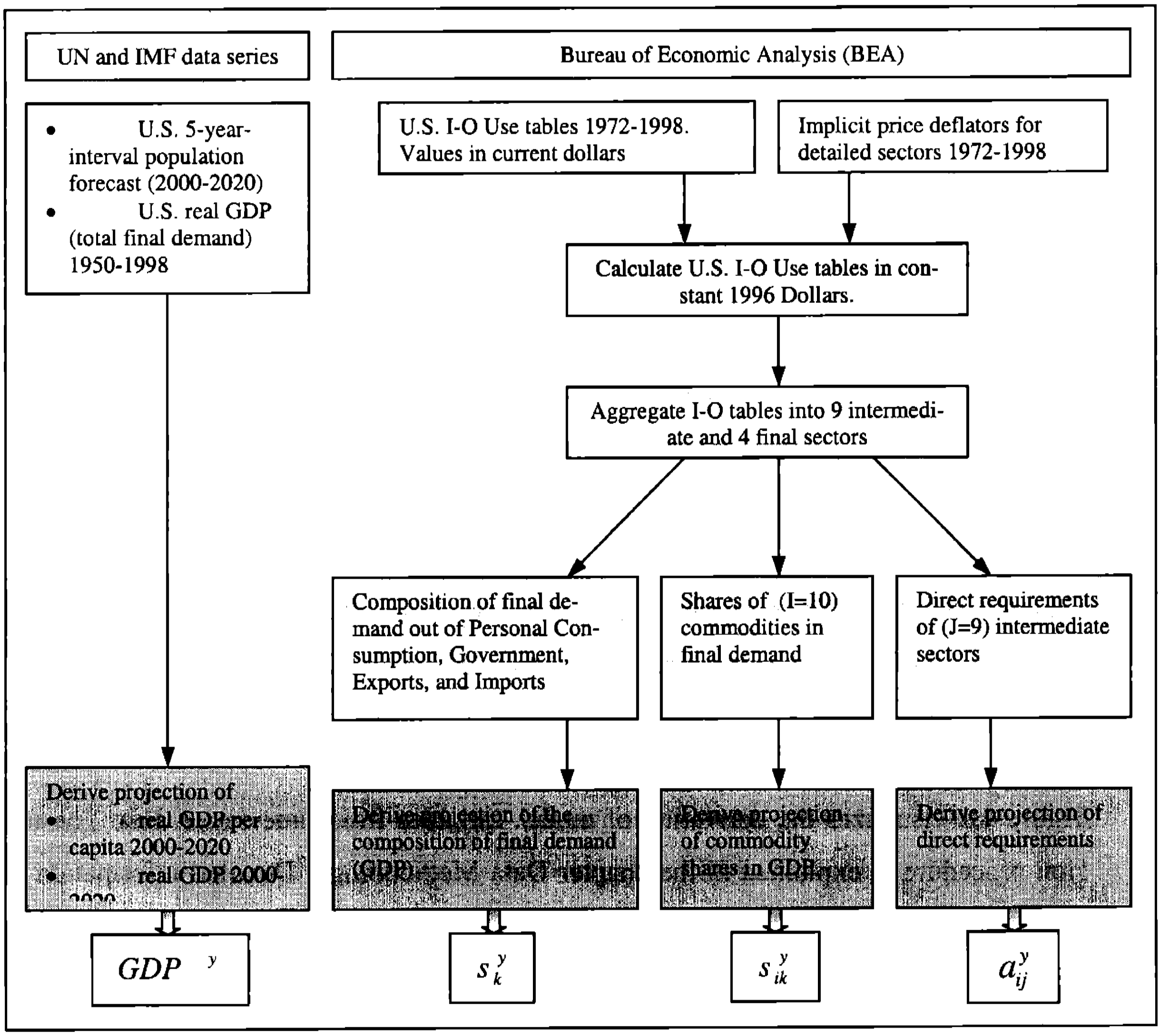

Figure 4.1 The Derivation of Model Variables

4.1.3 Essential Equations and Procedures

My final purpose in developing the economic model is to project total commodity output $m_{i\bullet}$ for all transportable goods ($i = 1, \ldots, 6$), which I then use as an input to the transportation model. One possible way of projecting commodity output is to analyze the relationship between GDP and the total output of each (compounded) industrial sector (e.g., how does the total output of agriculture change as GDP grows). This is, however, not a very sophisticated method and is not useful in analyzing how shifts in the final demand for commodities influence the output of commodities. Such detailed analysis is needed, for example, when examining the influence of government consumption and investment on transportation demand.

A thorough analysis, examining the ramifications within an economy, is the projection of commodity output based upon intermediate sector multipliers and final demand by commodity. In the following I describe the logic and algebra behind that approach starting with the matrix notation of the I-O table introduced in Chapter 4.1.1. Using matrix notation, the relationship between the final demand vector X and the total commodity output vector Y is

$$(4.11) \quad A^{y} Y^{y} + X^{y} = Y^{y},$$

where the 9×1 vector AY gives the output of the commodities $i = 1, \ldots, 9$ delivered to intermediate demand and the 9×1 vector X is the final demand for those commodities. The index y is used because I work with a dynamic analysis, meaning that not only final demand and total output but also the direct requirements change over time. Many short-term analyses use a static A matrix from the last available I-O table. However, since the structure of the economy changes and since I am looking far into the future, a static approach would not serve as well as the dynamic one. Equation (4.11) can be re-arranged to obtain the total output vector in year y:

$$(4.12) \quad Y^{y} = (I - A^{y})^{-1} X^{y}, \forall y,$$

where I is a 9×9 identity matrix. Note that $(I - A^{y})^{-1}$ is the total requirements matrix that indicates how changes in final demand affect total commodity output.[16] Equation (4.12) is the central element in the total output projection. Inputs to the economic model are final demand by commodity and direct requirements of intermediate sectors. The derivation of the latter – the A matrix – has already been shown: a_{ij}^{y} is projected as described in Chapter 4.1.2 and is then used to form the A^{y} matrix (for each relevant projection year y) according to the definition in Chapter 4.1.1.

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[16] I explained total requirement coefficients in Chapter 3.1.2.

The final demand vector X is derived from the projections of GDP^{y}, composition of GDP (s_k^y), and commodity shares in GDP (s_{ik}^y) according to the following equations. Rearranging equation (4.10) yields

$$(4.13) \quad f_{\bullet k}^{y} = s_k^y \times GDP^{y}, \forall y.$$

The total final demand of final sector k, $f_{\bullet k}$, is then used to calculate the elements $f_{i\bullet}$ of the final demand vector X, applying equations (4.5) and (4.8):

$$(4.14) \quad f_{i\bullet}^{y} = \sum_{k=1}^{K} f_{ik}^{y} = \sum_{k=1}^{K} s_{ik}^{y} \times f_{\bullet k}^{y}, \forall i \in I, \forall y$$

The projection procedure is summarized in Figure 4.2.

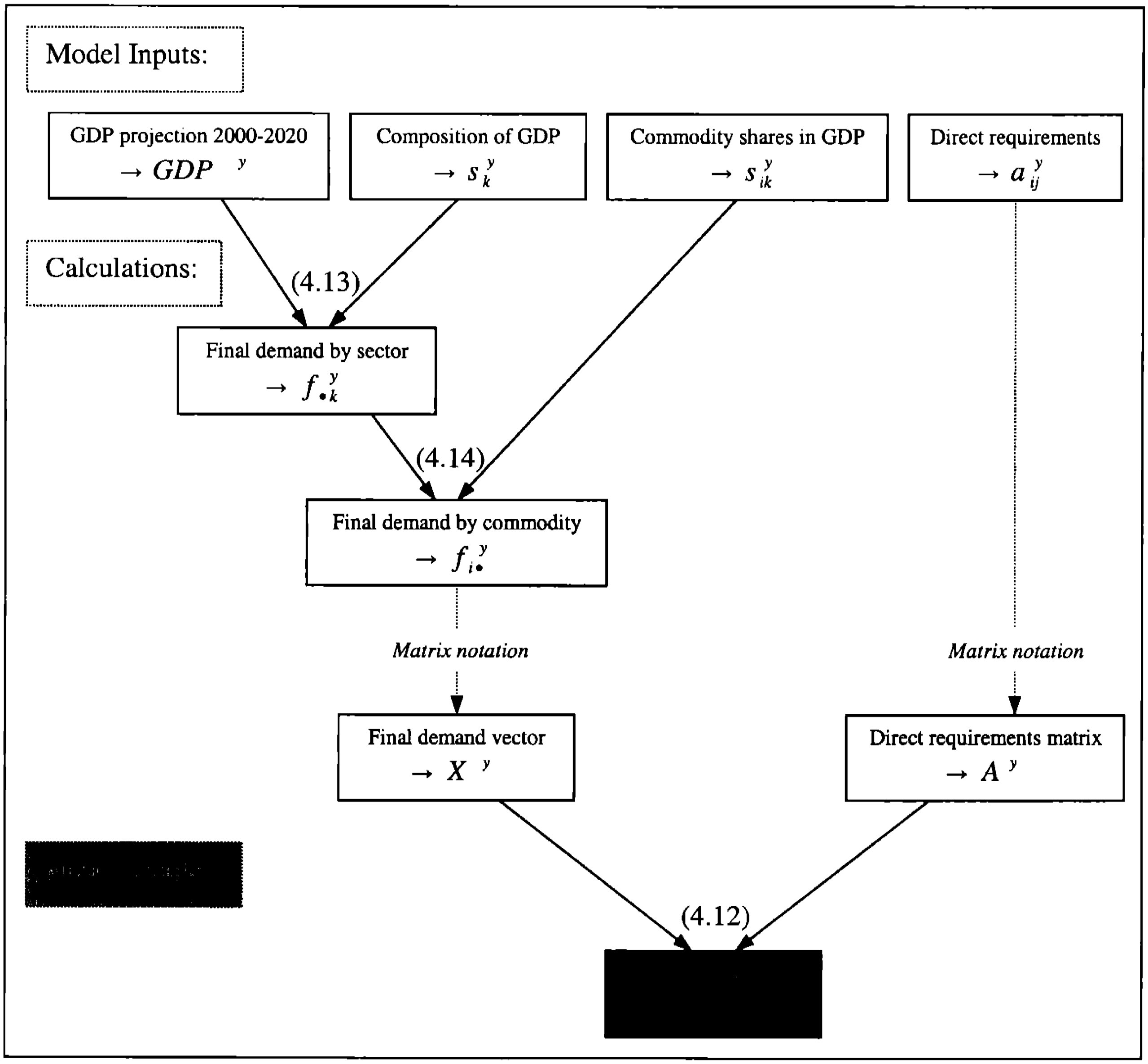

Figure 4.2 The Economic Model

4.2 The Transportation Model

In the previous chapter, I explained the derivation of projections for the U.S. economy based on input-output tables. The monetary values of transportable commodities must now be transformed into quantities of transportation demand. This transformation process is explained in the following. To provide a clear distinction, monetary values are expressed in capital letters whereas lower case letters represent physical parameters.

4.2.1 Model Specification

There are various ways of relating the economic model with the transportation model. A straightforward approach is to transform commodity dollar values into commodity weight, using the value of each good, expressed in dollar per ton. Following this model, the main driver of changes in the transportation characteristics of a certain good is the change in value per ton of this good. For example, computers with similar speed and features tend to become ever smaller so that a dollar output of the computer industry is related to decreasing weights that need to be transported; in other words, the value per ton of computers is increasing. The basic equation underlying a value-per-ton based model is[17]

$$(4.15) \quad ton_i^y = \frac{1}{V_i^y} \times TC_i^y \text{ , } \forall i, y \text{ ,}$$

where ton_i^y is the weight of commodity i transported in year y, measured in tons; V_i^y is a multiplier related to the value of good i in dollars per ton,[18] and TC_i^y is the transportable output of good i in dollars. It is important to note that V_i^y is not necessarily the real value of a commodity i in dollar per ton. Rather, V_i^y is a measure that describes how many tons of a good are transported for each dollar production output of this good. This distinction

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[17] This equation simply outlines the basic principle; it will become more detailed in Chapter 4.2.3. Also, at this point, I do not yet distinguish between different transportation modes. I will analyze commodity weight by mode in Chapter 4.2.4.

will become obvious in Chapter 4.2.3.

Besides tons, another important measure of transportation demand is ton-miles. When analyzing the impact of transportation on environment or infrastructure, ton-miles is the appropriate measure because it reflects the weight as well as the distance of shipments. The ton-miles over which good *i* is transported in year *y* can be obtained from

$$(4.16)\quad ton\text{-}miles_i^y = d_i^y \times ton_i^y \ , \forall i, y,$$

where d_i^y is the average distance of shipments of commodity *i* in year *y*. Equations (4.15) and (4.16) show that the ton-miles of transportation for each commodity depend on the commodity value (in $ per ton) and on the characteristic distance of shipment for that commodity. One could also construct a model in which those two factors are combined into one variable, i.e., a model that transforms the transportable output of a commodity directly into ton-miles. Such an approach would follow the formula (obtained by combining (4.15) and (4.16))

$$(4.17)\quad ton\text{-}miles_i^y = Variable_i^y \times TC_i^y \ , \forall i, y, \quad with : Variable \equiv \frac{d_i^y}{V_i^y}.$$

The characteristics and time trends of $Variable_i^y$ could then be determined using regressions of historical data and other sources of information about future trends. The advantage of this approach is its simplicity, however, this simplicity also leads to a loss of explanatory power. $Variable_i^y$ consists of a physical parameter (d_i^y) and a monetary parameter (V_i^y); both have different underlying factors of influence, i.e., the change of a good's value may have nothing to do with a change in its average transportation distance. Therefore, putting both parameters into one variable sacrifices explanatory power. This approach corresponds to the DOE's NEMS Transportation Model [DOE 2001], in which the growth in ton-miles

[18] The meaning of V_i^y is discussed in more detail below. Note also that dollar values must be inflation adjusted, i.e., they need to be constant dollar values. As explained earlier, I use constant 1996 dollar values in

traveled (TMT) is related to the growth in the value of output in corresponding industrial sectors. However, historical patterns show that these growth rates are not equivalent [DAC 1995] because of structural change in the economy and altering distances of shipments. To correct for the deviation, DOE introduces time-dependent freight adjustment coefficients (FAC's) that account for effects of changes in output mix, changes in freight carrier operations, the evolution of new physical distribution strategies, and shifts in consumer demand. FAC's thus account for a variety of effects and are used in a similar way as $Variable_i^y$ introduced in equation (4.17).

In modeling transportation demand, one can reach more explanatory power by splitting $Variable_i^y$ into V_i^y and d_i^y. In such an approach, V_i^y accounts for changes in economic parameters like output mix and consumer demand, whereas d_i^y describes shifts in transportation characteristics, such as changes in freight carrier operations and the evolution of new physical distribution strategies. Splitting $Variable_i^y$ (or FAC) into a monetary (economic) and a physical (transportation) component provides the basis for a better understanding of dynamic effects that lead to changes in transportation patterns.

As a consequence of this discussion, I put equation (4.17) aside and concentrate on equations (4.15) and (4.16) to transform monetary values of commodity output into physical transportation figures.

4.2.2 Characterization of Transportable Commodity Output

In the following, I refer to transportable commodity output ($TC_{p,i}^y$)[19] as the amount – in dollar values – of a commodity i that has potentially been shipped (or will potentially be

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the whole study.

[19] Later on, I will distinguish between transportable commodities produced (index p) and transportable commodities transported (index t). The characterization of Transportable Commodity Output in this chapter refers to the former. For clarity, the index is introduced here already. It is explained in detail in the next chapter. Note also that the expression "transportable commodity" is redundant. However, in the I-O notation services are termed "commodity" as well, which makes this redundant expression necessary to provide clarity.

shipped) within the United States in year y.[20] Potential shipment means that industry accounts (i.e. I-O tables) show a monetary transaction between industrial sectors allowing a user to conclude that the commodity referred to by the transaction has been shipped from seller to buyer. For example, if I-O tables show that the retail service sector transferred $1 million to the agriculture sector, then this transaction very likely resulted (or will result) in the shipment of agricultural goods to vegetable markets.

In the standard input-output framework, the transportable output of a commodity is not necessarily equal to the total output of this commodity. The reason for this (potential) difference is the way imports are treated in input-output tables. Imports are represented as negative numbers in the final demand. Thus, an increasing share of imports of a certain commodity leads to a decreasing total output of this commodity within the United States. From an economic point of view this makes sense because less of the commodity is produced within the country's boundaries. In a transportation model, however, this treatment of imports would yield counter-intuitive results if total output were taken as a measure for TC_i^y. In this case, U.S. transportation demand would decrease as imports increase. But the contrary is true: The import of a good leads to more transportation demand than its domestic production because the good enters the country at its border and must then be shipped a longer average distance to its destination. Consequently, total commodity output is a poor measure of transportable output.

A better measure of transportable output is one that comprises goods produced within the United States (for intermediate & final consumption and exports) and goods imported into the United States. This measure is equal to the sum of domestically produced intermediate and final goods and imported goods. Using the definitions visualized in Table 4.2, the transportable output of commodity i, produced in year y, is

[20] The attentive reader may ask what effects stored commodities have, i.e., commodities that are bought in year 1 but transported in a later year. I assume in the following that this effect is negligible over a period of several years because they cancel out each other and because manufacturing processes are optimized so that the effects are small.

$$(4.18)\quad TC_{p,i}^{y} = \sum_{j=1}^{9} m_{ij}^{y} + \sum_{k=1}^{3} f_{ik}^{y} \quad , \ \forall i \in [1,\ldots,6], \forall y ,$$

where $\sum_{k=1}^{3} f_{ik}^{y}$ denotes the domestic (personal and government) and foreign (exports) final consumption of a domestically produced commodity i, including imports purchased by final sectors.[21] $\sum_{j=1}^{9} m_{ij}^{y}$ is the output of commodity i (including imported goods) consumed in the production process of domestic goods (intermediate demand). There is a straightforward intuition behind using this definition of $TC_{p,i}^{y}$. Shipments of goods can be separated into four categories:

(1) Commodities i are shipped between intermediate sectors j in the production process (m_{ij}^{y})

(2) Commodities i are transported to the final consumption sectors households and government (f_{i1}^{y} and f_{i2}^{y})

(3) Commodities i are shipped to foreign destinations (f_{i3}^{y})

(4) Commodities i are imported from abroad (included in m_{ij}^{y} and f_{ik}^{y} in the U.S. input-output framework)

Equation (4.18) sums the value of commodities related to (1) – (4), giving equal weight to each category. In a more comprehensive study, a researcher could give different weights to the categories, for example, give higher weights to imports and exports because they are related to transportation, for sure, whereas a commodity shipped from one intermediate sector into another may simply be handed over to another factory on the other side of the road. However, such an analysis requires a huge amount of data and would go beyond the

[21] I explained the treatment of imports in U.S. I-O tables in Chapter 3.1.6.

scope of this study.

Note that equation (4.18) is only defined for commodity sectors 1-6 because only those sectors produce physical output (recall that sectors 7-9 are service sectors and sector 10 denotes value added). Equation (4.18) can be simplified using equation (4.2):

$$(4.19) \quad TC^{y}_{p,i} = m^{y}_{i\bullet} + \left|f^{y}_{i4}\right| , \quad \forall i \in [1,...,6] , \forall y .$$

where $\left|f^{y}_{i4}\right|$ is the absolute value of imports of commodity i in year y.[22] Note that $\left|f^{y}_{i4}\right|$ is added because imports have been subtracted in the calculation of $m^{y}_{i\bullet}$. In other words, $m^{y}_{i\bullet}$ is the total amount of commodity i, circulating in the United States in year y, minus the imports of commodity i (i.e., $m^{y}_{i\bullet}$ denotes the total domestic output of good i in year y). What is needed in this analysis is the transportable commodity output, which includes the domestic output as well as the 'imported output' of good i. Consequently, $\left|f^{y}_{i4}\right|$ must be added to $m^{y}_{i\bullet}$ in order to yield transportable commodity output.

4.2.3 Characterization of Commodity Value

Having derived a measure for transportation relevant output, I will now show how the monetary value $TC^{y}_{p,i}$ can be transformed into the physical figure ton^{y}_{i}. First, it is important to explain the way in which the Commodity Flow Survey (CFS) gathers its data. For each trip, the survey asks transporters (among other things) to provide information about commodity weight, value and distance of shipment. Due to this methodology, it is possible that the same good is included more than once in the CFS, especially if different modes of transportation are involved.[23] For example, a good may be shipped by truck from its producer in Boston to an airport and than be flown to LA where it is again picked up by a

[22] The absolute value must be used because imports are negative numbers in the U.S. I-O framework.
[23] The CFS tries to avoid double-counting by registering multiple mode shipments (see Chapter 9.4.1). However, I show in this chapter (e.g., in Table 4.4) that data suggest that the CFS does not completely account for multiple mode shipments.

truck and brought to its final destination. In this case, the CFS "double-counts" so that the value of the good as well as its weight enter the survey three times.[24] It is thus necessary to distinguish between the weight (in tons) and value (in $) of goods that are produced by economic sectors, $ton_{p,i}^{y}$ and $TC_{p,i}^{y}$, and the weight and value of goods that are transported within the United States, $ton_{t,i}^{y}$ and $TC_{t,i}^{y}$. In the Boston-LA example, we have $ton_{t,i}^{y} = 3 \times ton_{p,i}^{y}$ and $TC_{t,i}^{y} = 3 \times TC_{p,i}^{y}$.

The figures for $ton_{t,i}^{y}$ and $TC_{t,i}^{y}$ are obtained from CFS data, and $TC_{p,i}^{y}$ is derived from input-output tables and projections as explained in the previous chapter. Figures for $ton_{p,i}^{y}$ are available from industry accounts but they are not needed in the further analysis. I will show in the next paragraphs how historical data for the measures $ton_{t,i}^{y}$ and $TC_{p,i}^{y}$ can be used to derive physical transportation figures from monetary commodity output projections. First, I obtain commodity value per ton from the variables defined above:

$$(4.20)\quad CV_i^{y} = \frac{TC_{p,i}^{y}}{ton_{p,i}^{y}} = \frac{TC_{t,i}^{y}}{ton_{t,i}^{y}},\ \forall i \in [1,\ldots,6]\,, \forall y\,,$$

where CV_i^y is the value of commodity i in year y in dollar per ton. Note that the commodity value can be calculated from production-related data as well as from transportation-related data. However, what I am looking for is a relationship between production and transportation – a relationship between $TC_{p,i}^{y}$ and $ton_{t,i}^{y}$. In the next step towards relating these variables I define the transportation intensity of commodity i,

$$(4.21)\quad t_i^{y} \equiv \frac{ton_{t,i}^{y}}{ton_{p,i}^{y}}\,,\ t_i^{y} \in [0,\infty)\ \ \forall i \in [1,\ldots,6]\,, \forall y\,.$$

The transportation intensity t_i^y is a measure for how complex the typical transportation

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24 Since the CFS double-counts some multiple shipments but avoids it for others, the Boston-LA example must not necessarily lead to double-counting.

process of a commodity is, i.e., how many transportation modes or stops at warehouses it involves during the transportation from its origin to its destination. The transportation intensity can thus be understood as the average number of trips in the shipment process of a commodity i in year y.[25] Consequently, $t_i^y = 1$ if the commodity is transported directly to its destination. In the Boston-LA example, we have $t_i^y = 3$. Re-arranging equation (4.20) and substituting it into equation (4.21) yields

$$(4.22) \quad t_i^y = \frac{TC_{t,i}^{y}}{TC_{p,i}^{y}}, \; t_i^y \in [0,\infty) \;\; \forall i \in [1,...,6], \forall y ,$$

which enables the computation of t_i^y from commodity value data (derived from CFS for $TC_{t,i}^{y}$ and from I-O tables for $TC_{p,i}^{y}$). Note that t_i^y is zero for all service sectors since those sectors do not produce transportable output, i.e., $TC_{t,i}^{y} = 0$ for $\forall\, i \in [7,...,10]$. On the other extreme, t_i^y becomes (theoretically) very large if a shipment involves many changes of transportation mode or stops in warehouses. However, data show that t_i^y does not exceed 2.6 for any of the six commodity sectors analyzed in this paper.

The definition of t_i^y provides the last element to find the relationship between monetary and physical transportation parameters. Re-arranging equation (4.20) gives:

$$ton_{t,i}^{y} = \frac{ton_{p,i}^{y}}{TC_{p,i}^{y}} \times TC_{t,i}^{y} = \frac{1}{CV_i^y} \times TC_{t,i}^{y},$$

which yields, with equation (4.22),

$$(4.23) \quad ton_{t,i}^{y} = \frac{1}{CV_i^y} \times t_i^y \times TC_{p,i}^{y}, \; \forall i \in [1,...,6], \forall y .$$

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[25] Note that this interpretation refers to the theory. In reality, the transportation intensity may also account for differences in two data sets. See the discussion of Table 4.4 for more details on this issue.

This equation is the central element in the derivation of freight transportation demand from the economic projections. The commodity value per ton CV_i^y is obtained from CFS data, the produced transportable commodity output $TC_{p,i}^y$ is derived from input-output figures, and the transportation intensity t_i^y is calculated according to equation (4.22). I outlined the basic structure of the transportation model in equation (4.15) and announced that I would put more detail into this formula. The result of this process is equation (4.23). When comparing those two equations it follows that multiplier V_i^y is inherently defined in equation (4.23) as

$$(4.24) \quad V_i^y = \frac{CV_i^y}{t_i^y} = \frac{TC_{p,i}^y}{ton_{t,i}^y}, \forall i \in [1,\dots,6], \forall y .$$

The difference between the multiplier V_i^y and the real commodity value CV_i^y becomes obvious when comparing equations (4.20) and (4.24). While CV_i^y is calculated from CFS data only, V_i^y is calculated using CFS data for commodity weight ($ton_{t,i}^y$) and I-O figures for commodity output ($TC_{p,i}^y$). Average values of V_i^y and CV_i^y derived from 1993 and 1997 CFS and I-O tables[26] are shown in Table 4.4 together with the corresponding figures for t_i .[27]

[26] For 1993, an I-O table is not available. The 1993 figures are based upon a linear interpolation between the 1992 and 1996 I-O tables. I chose this approach as opposed to an interpolation of CFS data because CFS figures prior to 1993 are only available in 1977, which does not provide a proper justification for an interpolation.

[27] At this point, it needs to be emphasized again that values for the transportation intensity may be influenced by inaccuracies in the I-O and CFS data sets. Also, a more comprehensive definition of the transportation intensity is shown in Chapter 9.4.2 (which is not shown here because it requires the discussion in Chapter 9.4.1 about methodology in my model and in the CFS.

Value of Transported Goods (in constant 1996 $ per ton)		Average 1993-97		
		CVi *	Vi **	ti ***
1	Agricultural and Food Products	734.8	580.9	1.26
2	Mining, Minerals, Sands, Stone, Waste	29.9	11.8	2.54
3	Coal, Petroleum, Fuels	142.9	110.8	1.29
4	Low-Value Intermediate and Final Products	529.1	421.5	1.26
5	Medium-Value Intermediate and Final Products	3,998.7	2,829.0	1.41
6	High-Value Intermediate and Final Products	11,302.7	11,312.8	1.00

Source: Author. Compounded data from the 1993 and 97 Commodity Flow Survey and I-O Tables.
* Commodity Values from CFS, ton figures from CFS.
** Commodity Values from I-O tables, ton figures from CFS.
*** Transportation Intensity, without unit.

Table 4.4 Commodity Values and Transportation Intensities

As Table 4.4 shows, building materials summarized in sector 2 have the highest transportation intensity, whereas high-value commodities (sector 6) have the lowest transportation intensity. The fact that t_6 is exactly 1 can have two reasons:[28] (1) The CFS successfully avoids double-counting shipments of sector 6 products, i.e., all shipments of high-value products that involve two or more modes are correctly assigned to the corresponding multiple mode (e.g. truck and rail or truck and air); (2) the CFS underestimates $TC^{y}_{t,i}$, i.e., it does not fully cover sector 6 shipments; (3) Input-Output tables overestimate $TC^{y}_{p,i}$: the transportable commodity output ($TC^{y}_{p,i}$) calculated from I-O figures for sector 6 may involve some services (e.g. computer repair) that have not been assigned to a separate service sector. Both cases, (2) and (3), yield an underestimate of t^{y}_{i}. The behavior of CV^{y}_{i} and t^{y}_{i} over time is described in the chapter Model Dynamics. Note that I give a more comprehensive definition of the transportation intensity in Chapter 9.4.2.

There is one more point that needs to be mentioned: Could the "real" transportation intensities (i.e., calculated from a perfect dataset) be smaller that the ones shown in Table 4.4? They could not, unless the CFS would double-count the exactly same shipment (the same good by the same mode, e.g., in the Boston-LA example, count the single flight twice). To

[28] The computation of transportation intensities according to the extended method explained in Chapter 9.4.1 yields higher values than those shown in Table 9.4. For example, the transportation intensity of sector 6 is 1.18, according to the revised method.

assume that this was the case would imply that the CFS made some enormous mistakes, which is unlikely. Thus, the transportation intensities depicted in Table 4.4 can be interpreted as underestimates rather than as overestimates of the "real" numbers.

4.2.4 Shares of Transportation Modes

The $ton_{t,i}^{y}$ figures calculated with equation (4.23) represent the total weight of commodity *i* transported in year *y*, irrespective of the transportation mode. In this chapter, I will split those cumulated commodity transportation figures into five transportation modes. Those modes of transportation are: truck, railway, water carriers, air, and pipelines. Table 4.5 shows those transportation modes and introduces the notation that I use for tons transported.

Commodity *i*	Transport Mode *m*	*m*=1 Truck	*m*=2 Rail	*m*=3 Water	*m*=4 Air	*m*=5 Pipeline	SUM
1	Agricultural and Food Products	$ton_{t,11}$	…	…	…	$ton_{t,15}$	$ton_{t,1\bullet}$
2	Mining, Minerals, Sands, Stone, Waste	⋮				⋮	⋮
3	Coal, Petroleum, Fuels	⋮				⋮	⋮
4	Low-Value Intermediate and Final Products	⋮		$ton_{t,im}$		⋮	$ton_{t,i\bullet}$
5	Medium-Value Intermediate and Final Products	⋮				⋮	⋮
6	High-Value Intermediate and Final Products	$ton_{t,61}$	…	…	…	$ton_{t,65}$	$ton_{t,6\bullet}$
	SUM	$ton_{t,\bullet 1}$	…	$ton_{t,\bullet m}$	…	$ton_{t,\bullet 5}$	

Source: Author.

Table 4.5 Commodity Sectors and Transportation Modes

Note that in Table 4.5, the notation of total commodity tons transported ($ton_{t,i\bullet}^{y}$) differs from the above made definition of total tons transported of commodity *i* ($ton_{t,i}^{y}$) in that the former includes a dot to indicate the row-sum (similar to the notation in the I-O tables). To keep notation simple, I will leave out this dot in the following and stick with the notation:

$$\text{(4.25)} \quad ton_{t,i}^{y} \equiv ton_{t,i\bullet}^{y} = \sum_{m=1}^{5} ton_{t,im}^{y}, \ \forall i \in [1,...,6], \forall y,$$

where $ton_{t,im}^{y}$ is the weight of commodity *i* transported by mode *m* in year *y*; and

$$\text{(4.26)} \quad ton_{t,m}^{y} \equiv ton_{t,\bullet m}^{y} = \sum_{i=1}^{6} ton_{t,im}^{y}, \ \forall m, y,$$

with $ton^{y}_{t,m}$ being the total weight in tons transported by mode *m*.[29]

When defining transportation shares, it is necessary to differentiate between the share of a transport mode in the transportation of a commodity (e.g. the share of railway in the transportation of coal) and the commodity share in a transportation mode (e.g. the share of tons of coal in the total commodity weight transported by rail). In order to split up the total commodity tons $ton^{y}_{t,i}$, calculated with equation (4.23), into different transportation modes, I work with the following definition of transportation share. Let b^{y}_{im} be the share of transport mode *m* in the transportation of commodity *i* in year *y*.

$$(4.27) \quad b^{y}_{im} \equiv \frac{ton^{y}_{t,im}}{ton^{y}_{t,i}}, \quad \sum_{m=1}^{M} b^{y}_{im} = 1, \quad \forall i \in [1,...,6], \forall y, \forall m .$$

This definition is visualized in Table 4.6. Note that each element $ton^{y}_{t,im}$ is divided by the row-sum $ton^{y}_{t,i}$ so that the row-sum of b^{y}_{im} equals one (as opposed to the column sum, as was the case in Table 4.3.

Commodity *i*	Transport Mode *m*	*m*=1 Truck	*m*=2 Rail	*m*=3 Water	*m*=4 Air	*m*=5 Pipeline	SUM
1	Agricultural and Food Products	b_{11}				b_{15}	1.0
2	Mining, Minerals, Sands, Stone, Waste						
3	Coal, Petroleum, Fuels						
4	Low-Value Intermediate and Final Products			b_{im}			
5	Medium-Value Intermediate and Final Products						
6	High-Value Intermediate and Final Products	b_{61}				b_{65}	1.0

Source: Author.

Table 4.6 Modal Shares in Commodity Transportation

I derive b^{y}_{im} as a weighted average of the 1993 and 1997 CFS. This procedure is justified

[29] This notation may lead to unclarity when not used carefully, for example, $ton^{y}_{t,3}$ could mean total tons of commodity 3 transported in year *y* or total tons transported by mode 3 in year *y*. To avoid such confusion, I will be clear in the following as to whether a ton figure refers to a commodity or to a transport mode. Whenever I refer to a transportation mode, I use the name of the mode rather than a number in the index. When referring to commodities, on the other hand, I use the commodity's sector number.

because there is no clear trend in the modal split of commodity transportation between the two years so that differences in b_{im}^{1993} and b_{im}^{1997} are probably due to measurement errors, which can be accounted for by using both data sets. However, transportation shares are influenced by increasing average commodity values. For example, the average value of agricultural goods increases if more flowers and less wheat and corn are shipped. I show in the chapter Model Dynamics that an increasing average commodity value leads to shifts away from rail and water, favoring truck and air transportation. Those dynamic effects are considered in the fast-growth scenario but not in the baseline scenario.

4.2.5 Average Distance of Shipments

I use the average distance of shipments to derive ton-mile figures from transportation weight (ton) numbers. Transportation characteristics differ across transport modes and commodities. For example, agricultural goods shipped by truck have an average distance of 215 miles, while this value is 814 miles for agricultural goods transported by railway, and high-value products shipped by truck have an average distance of 466 miles as compared to 52 miles for building materials transported by the same mode. An average distance variable must thus take transport modes as well as commodities into account. I define d_{im}^{y} as the average shipment distance of commodity *i* by transport mode *m*:

$$\text{(4.28)} \quad d_{im}^{y} \equiv \frac{ton\text{-}miles_{im}^{y}}{ton_{t,im}^{y}}, \ \forall i \in [1,...,6], \forall y, \forall m.$$

The resulting equation to compute ton-miles is

$$\text{(4.29)} \quad ton\text{-}miles_{im}^{y} = d_{im}^{y} \times ton_{t,im}^{y}, \ \forall i \in [1,...,6], \forall y, \forall m,$$

which is essentially the same as equation (4.16), but now transportation modes are considered. Moreover, the transportation weight now refers specifically to tons transported $ton_{t,im}^{y}$ (as opposed to tons produced $ton_{p,im}^{y}$). This clarifying remark was not included in equation (4.16). Note that $ton\text{-}miles_{im}^{y}$ does not have an index *p* for production or *t* for transportation. Such an index is unnecessary because it is clear that ton-miles can only refer to transported commodities.

I derive average distance figures from CFS data for 1993 and 1997 for each commodity $i = 1,..,6$ (recall that commodities $i = 7, 8, 9$ are services and $i = 10$ denotes value added). The derivation procedure is explained in more detail in Chapter 9.4.5; and the behavior of d_{im}^{y} over time is described in the chapter Model Dynamics.

4.2.6 Essential Equations and Procedures

As visualized in Figure 4.2, the economic model projects the total commodity output vector Y and the shares in GDP s_k and s_{ik}. Those three figures are needed to compute transportable commodity output according to equation (4.19). With respect to this equation, the total output of commodity *i* in year *y*, $m_{i\bullet}^{y}$, is simply the i^{th} element in the total output vector Y, and the absolute value of imports of commodity *i*, $\left|f_{i4}^{y}\right|$, can be derived from GDP in the following way:

$$(4.30) \quad \left|f_{i4}^{y}\right| = \left|s_{i4}^{y} \times s_{4}^{y} \times GDP^{y}\right|, \forall i, y,$$

where s_{4}^{y} is the share of imports in GDP in year *y* and s_{i4}^{y} is the share of commodity *i* in imports (both shares have been projected in the economic model). Note that s_{4}^{y} is negative because imports are negative figures in the I-O framework. Inserting equation (4.30) into equation (4.19) gives the formula to derive transportable output from the economic model:

$$(4.31) \quad TC_{p,i}^{y} = m_{i\bullet}^{y} + \left|s_{i4}^{y} \times s_{4}^{y} \times GDP^{y}\right|, \ \forall i \in [1,...,6], \forall y,$$

where $TC_{p,i}^{y}$ denotes the transportable output of commodity *i* produced in (or imported to) the U.S. in year *y*. The results of equation (4.31) are then plugged into equation (4.23) to calculate the weight of commodity shipments. To provide a better overview, equation (4.23) is shown here again.

$$(4.23)\quad ton_{t,i}^{y} = \frac{1}{CV_{i}^{y}} \times t_{i}^{y} \times TC_{p,i}^{y}\ ,\ \forall i \in [1,...,6]\ ,\forall y\ ,$$

where CV_i^y is the commodity value per ton and t_i^y is the transportation intensity of commodity i. This equation gives the weight of each commodity i, shipped by all transport modes m.[30] The next step is to split the weight among the transport modes shipping commodity i. The corresponding formula is derived from equation (4.27):

$$(4.32)\quad ton_{t,im}^{y} = b_{im}^{y} \times ton_{t,i}^{y}\ ,\ \forall i \in [1,...,6]\ ,\forall y,\ \forall m\ ,$$

where $ton_{t,im}^{y}$ is the weight of commodity i transported by mode m, and b_{im}^{y} is the share of transport mode m in the transportation of commodity i in year y. Having obtained transported weight by commodity and mode, I derive the ton-miles that each commodity i is transported by mode m. This process is guided by equation (4.29), which I mention again for the sake of a complete overview:

$$(4.29)\quad ton\text{-}miles_{im}^{y} = d_{im}^{y} \times ton_{t,im}^{y}\ ,\ \forall i \in [1,...,6]\ ,\forall y,\ \forall m\ ,$$

where d_{im}^{y} is the average shipment distance (in miles) of commodity i by transport mode m. Having obtained data of commodity shipments by mode, only one step is missing from the final output of the model. From a transportation policy point of view, it is desirable to know how many tons and ton-miles of transportation have been provided by each of the five transportation modes. The calculation of those cumulative figures is guided by the equations

$$(4.26)\quad ton_{t,m}^{y} = \sum_{i=1}^{6} ton_{t,im}^{y}\ ,\ \forall m, y\ ,$$

and

[30] Remember that the index p denotes commodity produced whereas the index t symbolizes commodity transported.

$$(4.33) \quad \text{ton-miles}_m^y = \sum_{i=1}^{6} \text{ton-miles}_{im}^y, \ \forall m, y,$$

where the modes considered in the model are $m \in [Truck, Rail, Water, Air, Pipeline]$.[31]

The link between economic model and transportation model as well as the consecutive steps to derive freight transportation demand by transport mode are summarized in Figure 4.3. The numbers ton-miles and tons by transport mode are important and widely used indicators for an economy's freight transportation demand. They can be used to calculate impacts of transportation on the environment (e.g., pollution), as I show in Chapter 8. In the next chapter, I show the model projections in five-year steps until 2020.

[31] Remember that – in contrast to the ton variable – the ton-miles variable does not have an index t for 'commodity transported' because it is clear that ton-miles can only refer to transported commodities.

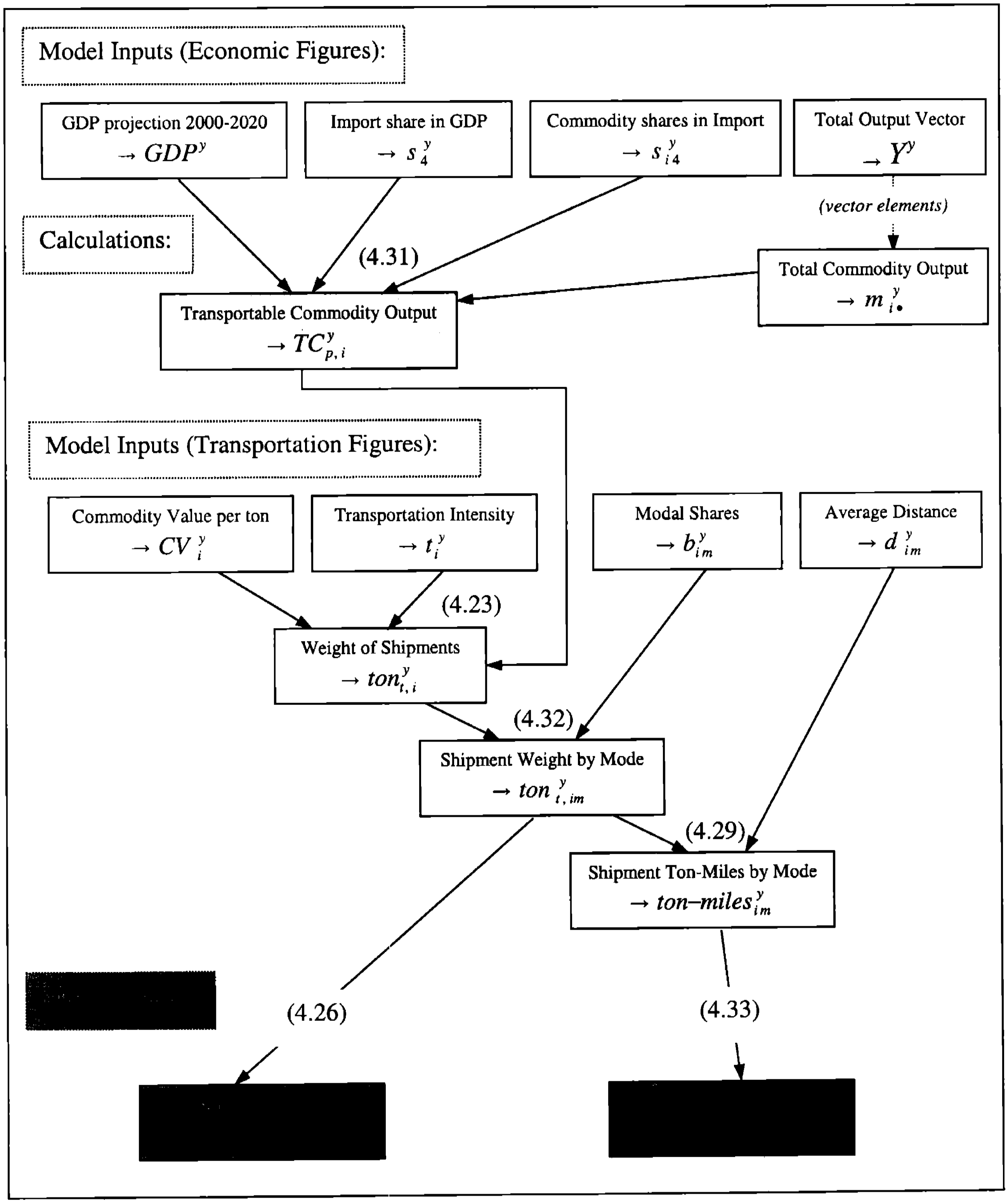

Figure 4.3 The Joint Economic and Transportation Model

5 Model Dynamics

5.1 Dynamics in the Economic Model

5.1.1 Changes in Final Demand

The projection of total final demand (GDP) and the commodity shares in GDP are the cornerstone in the economic part of my model. The growth of GDP pulls the whole economy and the GDP shares determine which industries profit from the growth. The meaning of GDP growth for freight transportation demand is obvious: The increase of total commodity output leads to a general increase in the shipment of goods and the share of each commodity in GDP determines the pattern of freight transport demand. For example, an increase in the output of building materials (sector 2) favors truck transportation, whereas an increase in the output of the energy sector (sector 3) favors pipeline transportation.

Modeling the dynamic shifts in final demand is essential in a model that projects freight transportation demand. I perform those projections according to the methodology outlined in the chapter Data Methodology.

5.1.2 Changes in Intermediate Demand

Shifts in intermediate demand are represented by changes of direct requirements, i.e., by changes in the A matrix. Such shifts arise, for example, if manufacturers substitute synthetic materials for metals in their production processes or if manufacturing processes become less labor intensive. In a model that projects transportation demand, it is important to reflect those shifts because they may be closely related to changes in transport patterns. I project those dynamic changes in my model as explained in the chapter Data Methodology.

The interrelation of final demand shifts and changes in the A matrix provide the basis for the dynamic projection of total output (equation (4.12)) and transportable output (equation (4.31)) in my model.

5.2 Dynamics in the Transportation Model

5.2.1 Changes in Average Distance of Commodity Shipments

The dynamic effect related to an increase in average distance of shipment is a growth in ton-miles of commodity transportation and thus an increase in transportation impacts. Changes in average distance of shipment may result from shifts in industry linkages (e.g., an industry begins to import its intermediate products instead of buying it from domestic producers), shifts in transportation modes[32] (e.g., a producer decides to transport her commodity by truck instead of rail to be more flexible), or shifts in infrastructure (e.g. shorter ways become available due to new highway construction).

The data source I use for an analysis of trends in average distance of shipment is the Commodity Flow Survey (CFS). As indicated earlier in this paper, CFS data are available only in a very limited form for years prior to 1993. It is thus not possible to analyze trends in the average distance of commodity shipments. In fact, comparable CFS data are available only for the years 1977, 1993, and 1997,[33] and even for those years, sector definition and coverage are not equivalent. Due to those constraints in available data, I do not analyze average distance by mode and commodity (d_{im}^{y}), as any significant changes in average distance could simply emerge from different sectoral definitions or methodology. Nevertheless, the potential errors in data can be mitigated by using aggregated figures. I use aggregated figures for transportation modes (d_{m}^{y}) and for commodities (d_{i}^{y}), where d_{m}^{y} stands for the average distance of all commodity shipments by mode m and d_{i}^{y} represents the average distance of shipments of commodity i by all modes. If there is no significant trend in the aggregated numbers, I will assume that no considerable trend can be derived for detailed figures d_{im}^{y}, either.

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32 In this chapter, shifts in transportation modes refer to the case where the transport mode of an unaltered good changes. In the next chapter, I analyze the effects of changes in average commodity value on the transport mode chosen.

33 A Commodity Transportation Survey exists for 1972, 1967, and 1963 as well. However, data for those years are not comparable to later years due to different or incomplete coverage of economic sectors.

The first step is the analysis of average distance of shipments by commodity. Table 5.1 shows the average distance of shipments d_i^y for the years 1977, 1993, and 1997.

Average Distance of Shipment Commodity (in miles)		**1977**	**1993**	**1997**
1	Agricultural and Food Products	301.0	366.0	358.8
2	Mining, Minerals, Sands, Stone, Waste	N/A	95.3	91.5
3	Coal, Petroleum, Fuels	220.6	256.9	258.9
4	Low-Value Intermediate and Final Products	188.0	279.9	268.8
5	Medium-Value Intermediate and Final Products	398.8	426.4	454.0
6	High-Value Intermediate and Final Products	507.4	588.1	541.5

Source: Author. Aggregated Data from CFS and CTS. U.S. Dept. of Commerce.

Table 5.1 Average Distance of Shipment by Commodity

Although average distance of shipment increased for all commodities between the 1970's and the 1990's, there is no clear indication in the data as to whether this trend continued in the 1990's. To the contrary, Table 5.1 shows that average distance actually declined for four of the six commodities between 1993 and 1997. However, it is not clear whether this decline is a correct observation or whether it is due to measurement errors in the CFS. Consequently, I cannot derive any significant trend in average distance for future time periods from the analysis of d_i^y.

The second step is the examination of average distance of shipments by transport mode, d_m^y, which is shown in Table 5.2.

Average Distance of Commodity Shipment (by Mode) (in miles)	**1977**	**1993**	**1997**
Truck	147.3	129.7	133.3
Rail	493.0	609.6	658.5
Water	459.8	553.2	464.1
Air	983.9	1,313.4	1,370.8
Pipeline	150.2	N/A	N/A

Source: Author. Aggregated Data from CFS and CTS. U.S. Dept. of Commerce.

Table 5.2 Average Distance of Shipment by Mode

Again, except for truck, there is a trend of increasing average distance between the 1970's and the 1990's but it is not clear if this trend continued in the 1990's. For railway and air transportation, the trend of growing average distance is continuous over the time observed, whereas it is reversed for water transportation. An interesting finding is that the average distance of truck shipments decreased between 1977 and 1993. Assuming that this decrease is not solely due to measurement errors, a possible explanation is the shift towards smaller lorries with loads transported over shorter ranges.

Having found no clear pattern in the development of average distance of shipments, I leave this variable constant in my model, upholding the qualitative statement that an increase in average distance would enlarge the impact of freight transportation on infrastructure and environment.

5.2.2 Changes in Commodity Value – Analyzed by Commodity Class

Commodity values are the decisive step in the transformation of monetary figures for transportable output into physical figures of transportation demand. This transformation is guided by equation (4.23). Commodity values enter this equation by commodity (i.e., as CV_i^y) as opposed to by transport mode (i.e., CV_m^y). For example, it is not crucial for the model to know the average value CV_{Rail}^y of goods transported by railway. But it is essential to identify the value CV_1^y of all agricultural goods. Knowing this value (in $ per ton) enables the transformation of transportable agriculture output (in $) into commodity weight transported (in tons).[34]

Although the commodity value by transport mode CV_m^y is not needed in the model, it can provide an insight into the dynamic effects of shifts in commodity value. I analyze those effects in the next chapter. In the present chapter, I examine changes in commodity value by commodity CV_i^y.

I begin the analysis of commodity value by commodity with a comparison of 1977, 1993, and 1997 data from the CFS, shown in Table 5.3. I have described in the previous chapter that the analysis is restricted to those three sources because of poor comparability of the data for other (earlier) years and the complete lack of data for the 1980's.

Commodity Value in Constant 1996$ per ton		**1977**	**1993**	**1997**
1	Agricultural and Food Products	707	805	668
2	Mining, Minerals, Sands, Stone, Waste	N/A	31	29
3	Coal, Petroleum, Fuels	187	151	135
4	Low-Value Intermediate and Final Products	480	577	489
5	Medium-Value Intermediate and Final Products	4,667	4,123	3,898
6	High-Value Manufacturing Products	4,588	9,802	12,525

Source: Author. Compounded Data from CFS. U.S. Dept. of Commerce.

Table 5.3 Comparison of Commodity Value for several years

Table 5.3 shows that the average values of agricultural goods (sector 1), building materials (sector 2), and low-value products (sector 4) fluctuate in the sense that they increase between 1977 and 1993 but then decrease again until 1997. I cannot determine whether those fluctuations are true observations or whether they result from different data methodology or measurement errors in the CFS. For sectors 3 and 5, commodity value changes steadily over time. The observed decrease in sector 3 is most likely due to changes in oil price (which is not adequately accounted for by the price deflators.)[35] By contrast, the decline in commodity value in sector 5 cannot be explained by economic observations. Appendix A.II shows that sector 4 includes, among others, basic chemicals, fertilizers, wood and printed products, and articles of base metal. To the best of my knowledge, there is no indication for an ongoing decrease in value per ton of any of these goods. In fact, if there were a deflation in the price of those products, price deflators should account for it, so that the only remaining possibilities for a change in commodity value would be (1) a significant alteration in the shape of sector 4 goods (e.g., basic chemicals of comparable quality become much heavier so that their value per ton falls, which is not intuitive), and (2) a shift towards lower-value goods within sector 4, which cannot be modeled because the CFS sector classification changed.

Following the above discussion, I do not presume a pattern in the change of commodity

[34] Note that this transformation also requires the knowledge of the transport intensity, as described in equation (4.23).

[35] See Chapter 9.2 for details.

value for sector 1-5 goods and leave their value constant in the model. The way in which I calculate the commodity value of those commodity classes (as a weighted average of 1993 and 1997 figures) is explained and justified in Chapter 9.4.3.

The sector of high-value products has thus far been left out of the discussion – for a good reason: Unlike the other sectors, commodity class 6 shows a pattern of commodity value development over time in which data and economic intuition match. The commodity value of this sector is thus not a constant in the model but it changes over time according to a pattern that I derive in the following. Table 5.3 shows that the average value of goods falling into sector 6 increased steadily between 1977 and 1997. To better understand those dynamics, I provide a detailed overview of the goods in sector 6 in Table 5.4, derived from the 1997 CFS.[36]

Sector 6 Goods in Detail, 1997		Value (1996 $million)	Weight (1000 Tons)	Value per ton (1996$)	% in Weight
6a	Pharmaceutical products	224,634	9,897	22,697	6.3%
6b	Electronic and other electrical (office) equipment	870,396	39,612	21,973	25.4%
6c	Motorized and other vehicles (including parts)	571,455	98,074	5,827	62.9%
6d	Transportation equipment, n.e.c.	129,292	5,477	23,606	3.5%
6f	Precision instruments and apparatus	158,077	2,939	53,786	1.9%
Total		**1,953,854**	**155,999**	**12,525**	**100%**

Source: Author. Data from 1997 CFS .

Table 5.4 Detailed Listing of Commodities Comprised by Model Sector 6

Table 5.4 reveals that the exceptional goods within sector 6 are motorized and other vehicles in the sense that their value per ton is the lowest, while their share in weight is by far the highest. Thus, vehicles (and vehicle parts) pull down the average commodity value of sector 6. The value per ton of all other goods in sector 6 is about the same,[37] so that sector 6 can be split up into two major components, as shown in Table 5.5.

[36] I use the 1997 CFS as the basis for the sector 6 analysis because it provides the most detail. Besides that, sector definitions in the 1993 CFS are different for high-value products, which makes a congruent analysis difficult (though not impossible since sector 6c and 6d are similarly defined in 1977, 1993, and 1997, which I make use of later on).

[37] Although I recognize that precision instruments and apparatus have a significantly higher value per ton, I do not give this fact particular attention because of the extremely low share of those goods in sector 6. Moreover, a separate analysis of precision instruments and apparatus is impossible due to the poor available data.

Sector 6 Goods, aggregated, 1997		Value (1996 $million)	Weight (1000 Tons)	Value per ton (1996$)	% in Weight
6c	Motorized and other vehicles (including parts)	571,455	98,074	5,827	62.9%
	All other sector 6	1,382,400	57,925	23,865	37.1%
Total		**1,953,854**	**155,999**	**12,525**	**100%**

Source: Author. Data from 1997 CFS .

Table 5.5 Aggregate Listing of Commodities Comprised by Model Sector 6

Table 5.4 and Table 5.5 help in understanding why the average commodity value of sector 6 increased between 1977 and 1997: If the share of "All other sector 6" goods increases, the average commodity value of sector 6 goes up. My proposition is that such an increase occurred in the last 20 years in the output of electronic equipment (e.g., computers). This hypothesis is not only intuitively feasible but is also supplemented by CFS data. Luckily, the sector "Electronic and electric equipment" is one of the few CFS sectors that kept the same specification in 1977, 1993, and 1997 so that the corresponding data are comparable over time.

6b - Electronic and other electrical (office) equipment	1977	1993	1997
Share in Total Sector 6 Weight	20.8%	23.7%	25.4%
Value per ton (in 1996 dollars)	7,310	13,268	21,973

Source: Author. Data from 1977, 1993, and 1997 CFS .

Table 5.6 Characteristics of the Electronic Equipment Sector over Time

Table 5.6 supports my hypothesis of an increase in the share of electronic and electrical equipment in sector 6. It even suggests that the average value within sector 6b increased, i.e., that higher-value products (e.g. computers) became more important in electronic and electrical equipment. Having presented a reasonable explanation for changes in commodity class 6's average value, I now turn to modeling those changes.

The most important methodology in this paper is the projection of shares (e.g., shares of commodities in final demand or total output). I stick with this approach in the modeling of commodity class 6 dynamics. Table 5.5 suggests this modeling should either project the share of sector 6c or the share of all other sectors in commodity class 6. Looking at the available CFS data, I found that the former way is the more appropriate one because sector 6c remains (almost) the same categorization in the 1977. 1993, and 1997 CFS. I project the ton-share of sector 6c to decline from 62.9% in 1997 to 46.8% in 2020.[38] This value is used in the following calculation that uses Table 5.5 as a starting point.

Calculation Overview

Projection of the share of Sector 6c in sector 6 (see Data Methodology): 46.8%

Projection for Growth of Sector 6's Transportable Output* (1997-2020): 4.23 or (ann. growth): 6.47%
Resulting Total Value of Sector 6 goods in 2020 (in 1996$million): 8,259,734

The Value per ton for the two sub-categories is assumed to remain constant at 1997 values.
*Projection performed by author, see chapter Model Output for detail.

Sector 6 Goods, Incomplete, 2020		Value (1996 $million)	Weight (1000 Tons)	Value per ton (1996$)	% in Weight
6c	Motorized and other vehicles (including parts)			5,827	46.8%
	All other sector 6			23,865	
Total		**8,259,734**			**100%**

...filling in the gaps yields:
(Figures in Italic are given from the table above)

Sector 6 Goods, aggregate, 2020		Value (1996 $million)	Weight (1000 Tons)	Value per ton (1996$)	% in Weight
6c	Motorized and other vehicles (including parts)	1,458,922	250,383	*5,827*	*46.8%*
	All other sector 6	6,800,813	284,966	*23,865*	53.2%
Total		***8,259,734***	**535,349**	**15,429**	***100%***

Resulting average annual growth of Sector 6 value per ton between 1997 and 2020: 0.91%
Source: Author. Data from 1997 CFS and own projections.

Figure 5.1 The Projection Calculation of Sector 6 Value per Ton Growth

Comparing the average commodity value of sector 6 in 2020 and 1997 yields an average annual growth rate of 0.91%. I use this number to project the per-ton value of sector 6 for the years 2000, 2005, 2010, and 2015, the result of which is shown in Table 5.7.

Commodity Value in Constant 1996$ per ton		Historical			Projection				
		1977	1993	1997	2000	2005	2010	2015	2020
6	High-Value Manufacturing Products	4,588	9,802	12,525	**12,870**	**13,467**	**14,091**	**14,745**	**15,429**

Source: Author. Historical Data from CFS. U.S. Dept. of Commerce. Projections performed by author.

Table 5.7 Projection of Sector 6 Value per Ton

The projection of sector 6's commodity value is now complete. However, the finding of shifts within sector 6 implies that the choice of transport modes within this sector is likely to change, as well. I show the projection of modal shifts within sector 6 in Chapter 9.4.6, where I use the projection of commodity weight (tons) shown in Figure 5.1 as a starting point.

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[38] See Chapter 9.4.6 for details.

5.2.3 Changes in Commodity Value – Analyzed by Transport Mode

Changes in commodity value can lead to shifts in the transport mode by which those commodities are shipped from producer to buyer. The CFS data show a trend away from rail and water towards truck and air transportation if commodity values increase. For pipelines, however, there is no clear trend derivable from data, which is due to the restricted range of goods that are transported by pipeline – petroleum and petroleum products. If the average value of those goods changes, their transportation pattern does not change (at least not if the change in commodity value is moderate) since their physical composition makes pipeline their favorable mode of transportation.

For the four transport modes aside from pipeline, I use the framework explained in the following to analyze effects of changes in commodity value on the choice of transportation modes (using the notation introduced in Chapter 4.2.3). The CFS provides the value $TC_{t,i}^{y}$ and weight $ton_{t,i}^{y}$ for each commodity *i* transported by all modes *m*. I showed in Chapter 4.2.3 how those figures are used in the model. Besides those compounded numbers, the CFS provides even more detailed data on commodity value and weight by mode and shipment. To include those detailed figures in the framework, I add the index *m* to the previous notation of commodity value and commodity weight. This adjustment gives $TC_{t,im}^{y}$ as the value and $ton_{t,im}^{y}$ as the weight of commodity *i*, transported by mode *m* in year *y*.

The 1993 CFS covers 32 commodities[39] and the 1997 CFS comprises 40 sectors. Although I compound those sectors in the 6 transportation commodity classes of my model, I do not work with the compounded figures in the analysis of changes in commodity value. The reason for this decision is that I want to make use of as much information as possible from the CFS. By adjusting all commodity values with the applicable price deflator, I get 72 figures (32 from 1993 and 40 from 1997) to proceed with the analysis.

It is important to note that there are various goods within each commodity class *i*. For example, the commodity class "Other Agricultural Products" in the 1997 CFS comprises cheap corn and wheat as well as expensive fruit and flowers, where 'cheap' and 'expensive' refer to the commodities' value per ton. My hypothesis is that more expensive goods tend to be transported by truck and air, rather than by rail and water. To support this premise, I first use the definition made in equation (4.20), which I show here again:

$$(5.1) \qquad CV_i^{\,y} = \frac{TC_{t,i}^{\,y}}{ton_{t,i}^{\,y}},$$

where CV_i stands for the average value of all goods falling into commodity category *i*.[40] Note that the year index y is not necessary because I treat data from 1993 and 1997 as if they were from the same sample. The justification behind this method is that there is no recognizable trend in commodity value or weight (analyzed by mode) between 1993 and 1997[41] and even if there were a trend, it would not matter because all that counts here is the deviation from average value (as opposed to the absolute per-ton-value). I now extend equation (5.1) to include the information about transport modes:

$$(5.2) \qquad CV_{im}^{\,y} = \frac{TC_{t,im}^{\,y}}{ton_{t,im}^{\,y}},$$

where CV_{im} denotes the per-ton-value of commodity *i*, transported by mode *m*. By this extension of the previous formula, I allow for different commodity values in different transport modes. I now define the deviation of the per-ton-value of commodity *i*, transported by mode *m* (CV_{im}), from the average value of commodity *i* (CV_i) as:

---

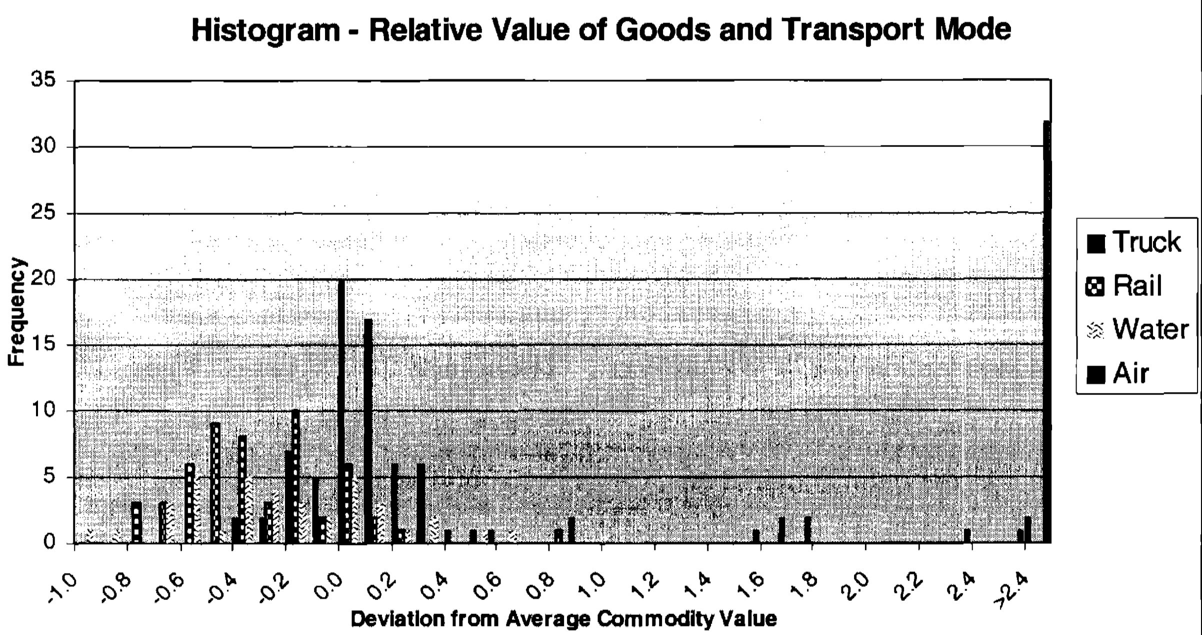
[39] Altogether, there are 35 commodities in the 1993 CFS; 3 sectors (e.g. "Miscellaneous Freight Shipments") cannot be assigned to any of the 6 commodity classes I use in my model.

[40] This is a more specific definition than the one I made in Chapter 2.2.3. However, the statement is still the same because the average value of all goods falling into commodity category *i* is the same as the value of commodity *i*, where 'commodity *i*' is a somewhat abstract notion comprising several goods.

[41] Trends in commodity value changes by mode are not derivable from CFS data. However, as shown in the previous chapter, commodity value changes by sector can be projected for commodity class 6.

$$(5.3) \qquad dev_{im} = \frac{CV_{im}}{CV_i} - 1, \quad dev_{im} \in [-1, \infty).$$

This equation enables an analysis of the effect that a commodity's value (relative to the value of goods in the same commodity class) has on the choice of transport mode for that commodity. Figure 5.2 shows the results of this study for 72 commodities obtained from the 1993 and 1997 CFS.



Source: Author. Data from 1993 and 1997 CFS. Calculation is based on commodity value per ton in constant 1996 U.S. Dollars.

Figure 5.2 Relationship between Commodity Value and Transport Mode

It is obvious in Figure 5.2 that goods whose value CV_{im} is close to the average value CV_i tend to be transported by truck. One can thus say that the 'typical' transport mode for goods is truck, or in other words, the 'average good' is shipped via road transportation. Goods whose value is about 20% to 50% below the average value of the corresponding commodity class are typically transported by railway. However, this finding is less concrete than in the case of trucks because the variance in the distribution of dev_{im} for railway is somewhat higher than for trucks. An explanation for the lower variance for truck transportation is that most goods are transported by truck when picked up from the producer or when brought to their final destination so that truck transportation is involved in a variety of shipments. Thus, the per-ton-value of all goods within a commodity class shipped by truck comes close to the average commodity value. Table 5.8 supports the analysis of commodity average value deviation.

Deviation from Average Distance - Statistical Analysis					
	Truck	Rail	Water	Air	Pipeline
Sample Size (N)	67	54	38	42	13
Average	-1.3%	-36.9%	-29.1%	1134.1%	-0.4%
Standard Deviation (StD)	17.7%	28.3%	36.4%	1613.7%	121.4%
t-statistic	(0.62)	(9.59)	(4.92)	4.55	(0.01)
t-distribution (α = 0.05)	2.00	2.00	2.02	2.02	2.18
95% Confidence Interval					
Cu	2.9%	-29.3%	-17.5%	1622.2%	65.6%
Cl	-5.6%	-44.4%	-40.7%	646.1%	-66.4%
Source: Author. Data from 1993 and 1997 CFS. Abbreviations: Cu and Cl: upper and lower value of the 95% confidence interval. α = Level of significance for N-1 degrees of freedom.					

Table 5.8 Statistical Analysis of Average Value Deviation

The value-deviation distribution of goods shipped by water has a yet higher variance than this of rail transportation. The average value of goods transported by water carriers is below the average commodity value. Although the high variance means that dev_{im} is not a reliable indicator for the choice of water transportation, one can still infer a similar pattern as for rail transport, i.e., that a higher-value goods are rather transported by truck and air than by water.

The reliability of dev_{im} as a mode-choice indicator is very different in the case of air transportation. Figure 5.2 shows that goods with high dev_{im}, i.e., goods with a value clearly above the average value of the corresponding commodity class, are in general transported by air. A high value-deviation dev_{im} is thus a clear indicator for the choice of air transportation.

The t-statistics shown in Table 5.8 imply that the null-hypothesis of zero average-commodity-value deviation cannot be rejected in the case of truck and pipeline shipments. On the other hand, the null-hypotheses that the values of rail, water, and air shipments do not differ from the average commodity value can clearly be rejected on a 5% level of significance. Note that the 95% confidence intervals for rail, water, and air shipments are a measure for how much the goods transported by those modes deviate from average commodity value of the corresponding commodity class (e.g., by how much the value of farm products shipped by air differs from the average value of farm products.)

An alternative way to analyze the dynamic effects of commodity value changes is to look at the relation between a commodity's average value and the percentage of transportation modes utilized in the shipment of this commodity. I performed this analysis for the six transport sectors used in my model. The results are shown in detail in Appendix C.I. To explain the intuition behind that approach, I show one of the figures from Appendix C.I here – the relationship between commodity value and transport mode for the case of model sector 1 (agriculture) in Figure 5.3.

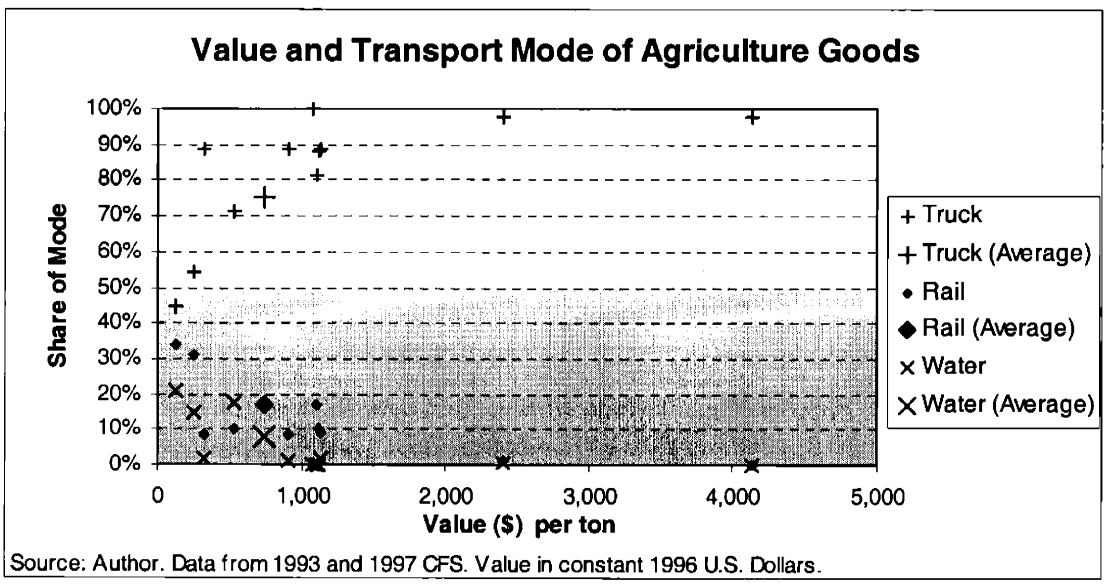


Figure 5.3 Commodity Value and Share of Transport Modes

The average numbers for the three transport modes shown in Figure 5.3 refer to model sector 1 (agriculture) as a whole, whereas all other shares and values in this figure represent sub-sectors of sector 1 (e.g., cereal grains). The three average numbers are the ones I use in the model (i.e., the average value of sector 1 goods is 735 $/ton, and the average modal shares are 75% for truck, 17% for rail, and 7.8% for water transportation.[42] The modes pipeline and air transportation are left out in Figure 5.3 because their share is negligible. It is obvious from this figure that the share of truck increases (in a log-like relationship) with increasing value of the transported good. Water and rail shares, on the other hand, decrease with increasing value so that a shift within the agriculture sector towards more valuable products leads to a growing use of truck transportation. This finding supports the conclusions drawn from Figure 5.2.

What is the effect of those findings on model dynamics? A logical conclusion is that freight transportation tends to shift from rail and water to truck and from truck to air if final and intermediate consumers favor goods with a high deviation from average value. For example, in the commodity class "Other Agricultural Products," fruit and flowers have high deviations from the average commodity value, and corn or wheat have lower deviations. If the consumption of fruit and flowers grows relatively more than the consumption of corn and wheat, air transportation will grow faster than other modes. However, this dynamic effect cannot be quantified with the available data. Consequently, I stick with the qualitative statement that, in addition to dynamic effects through fast growing high-value commodity sectors (as explained in the previous chapter), the trend away from rail and water carriers to truck and air transportation will even be increased by shifts towards high-value goods within commodity sectors. The proposition of changing consumer preference towards high-value products is supported by the fact that U.S. GDP per capita is projected to grow from about $33,000 (in constant 1996 dollars) in 2001 to over $50,000 in 2020. The purchasing power of the average consumer in the United States will thus increase dramatically, which is likely to shift final demand towards higher-value products.

5.2.4 Changes in the Choice of Transport Mode

The share of transport mode *m* in the shipment of commodity *i* is used in my model in equation (4.32). The shares b^{y}_{im} are needed to derive the weight transported by each mode.

[42] Modal share numbers are shown in Appendix C.III.

Looking at the dynamics of modal shares over time, I encounter the same problems as in the case of commodity value and average distance of shipment: The CFS data are not only poor but also hardly comparable over time, due to inconsistent methodology in the CFS. The only exception is sector 6 (high-value products), for which I have shown the intuition and data of dynamic shifts in Chapter 5.2.2. The projection of model shifts in sector 6 is based upon weight-projections performed in Chapter 5.2.2 and is shown in detail in Chapter 9.4.6. The results of this analysis show that transportation within sector 6 shifts towards truck and air transportation (see Table 9.6 on page 128). Consequently, the trend towards truck and air transportation, caused by intersectoral shifts towards high-value products, is even increased by an intra-sector-6 shift towards those modes. For all other sectors, I assume that modal shares remain constant since any projection derived from CFS data would be arbitrary. The assumption of constant b_{im}^{y} for commodity classes 1-5 is equivalent to the proposition that producers of those commodities stick with the same transport modes to ship their goods to buyers. Note, however, that the findings in Chapter 5.2.3 suggest a change in the choice of transport mode away from water and rail towards road and air. Nevertheless, I have already stated in Chapter 5.2.3 that those changes cannot be quantified.

5.2.5 Changes in the Transportation Intensity

In equation (4.21), I defined the transportation intensity t_i^y as a measure for how complex the typical transportation process of a commodity is, i.e., how many transportation modes or stops at warehouses it involves during the transportation from its origin to its destination. The transportation intensity can also be understood as the average number of trips in the shipment process of a commodity i. Values of the transportation intensity of the six model sectors are shown in Table 4.4.[43]

As was the case for average distance and commodity value, CFS data are insufficient to derive patterns for changes in the transportation intensity. But can such changes be expected? The transportation intensity t_i^y measures the complexity of a commodity's shipment process from producer to buyer. Shifts in the shipment process can occur if the infrastructure changes. Consider, for example, a factory that used to bring its goods to the nearest railway station and then shipped it by rail across the country to the buyer. If a new railroad connection is constructed, reaching to the factory's gate, goods do not need to be transported by truck, anymore, and t_i^y declines. Changes in t_i^y can also result from shifts in an industry's forward and backward linkages. For example, if an industry shifts its main input from metals to plastics, its final product becomes lighter, which may shift the favored transport mode from rail to truck. If the metal product was transported by truck and rail, and the plastics product is transported only by truck, t_i^y declines. Yet another possible cause for shifts in t_i^y is a change in consumer preferences: If buyers require a very fast delivery, producers may shift their transportation mode towards air for long distances. Air transportation, however, practically never occurs alone. Rather, it involves truck transportation to and from the airport. Consequently, the buyers' requiring faster delivery may make the shipment process more complex so that t_i^y increases.

This discussion shows that changes in the transportation intensity of commodities can be expected. However, they cannot be quantified with the present data. Thus, the transportation intensity is a constant in my model.

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[43] Note that a broadened definition of the transportation intensity is given in Chapter 9.4.2 and results of the corresponding computation are shown in Table 9.4.

6 Model Output

6.1 Economic Projections

6.1.1 GDP Projection

The business-as-usual (BAU) scenario is based upon a regression of U.S. per-capita GDP between 1950 and 1998 (in constant 1996 $). The corresponding equation is

$$GDP^{y} = 3577.4\exp(0.02222y)\,, \qquad (6.1)$$

where y is the year with 1900=0. In this equation, 0.02222 is the continuously compounded growth rate g_{cont}. The relation between the continuously compounded rate and the annually compounded growth rate g_{annual} is given by:

$$1 + g_{annual} = \lim_{n \to \infty}\left(1 + \frac{g_{cont}}{n}\right)^{n} = e^{g_{cont}}\,, \qquad (6.2)$$

where n denotes the number of time steps during which the growth occurs in a certain year. Since the growth is continuous, n approaches infinity. Re-arranging equation (6.2) and inserting the value for g_{cont} yields:

$$g_{annual} = e^{g_{cont}} - 1 = e^{0.2222} - 1 = 0.02247\,. \qquad (6.3)$$

The projection for annual per-capita GDP growth is thus 2.247%.[44] Figure 6.1 shows the historical data and the projection of U.S. GDP per capita. As outlined in more detail in the chapter Data Methodology, the projection of shares in GDP is based on per-capita GDP and the projection of intermediate multipliers uses time as a regressor. In the following, I describe the projections of economic performance and transportation demand that my model provides in the BAU scenario.

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[44] The U.S. population is projected to grow by an average annual rate of 0.65% [UN 2001]. Considering this fact, the model projects U.S. real GDP to grow by 2.91% annually between 2000 and 2020.

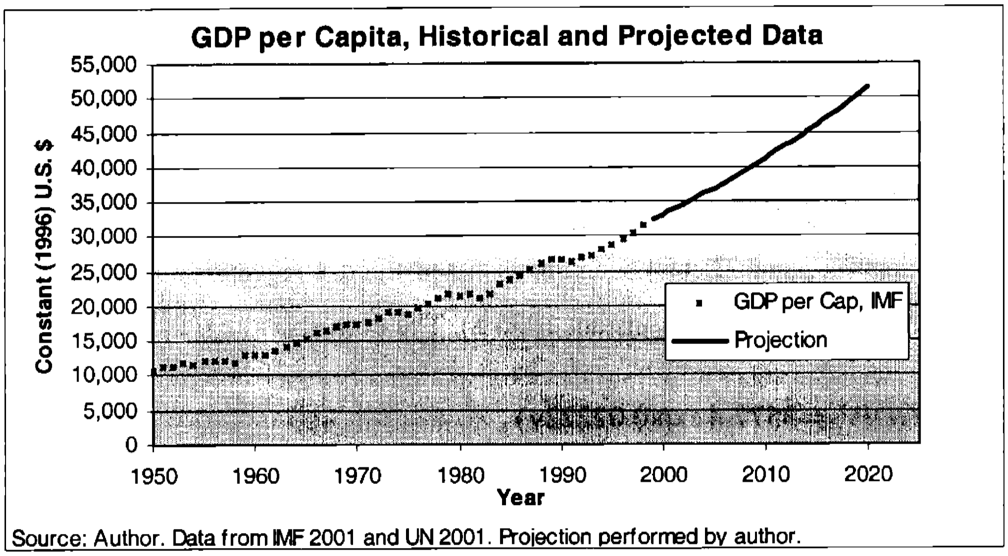

Figure 6.1 GDP per Capita – Historical Data and Projections

6.1.2 Composition of Final Demand

Having projected U.S. GDP per capita until 2020, I obtain GDP using the UN 2001 population forecast. The next step is the projection of the share s_k of each final sector k in the total final demand (GDP). Figure 6.2 shows the results of this projection. There is no indication in the data for a change in the share of personal consumption and government consumption & investment in GDP. Consequently, those shares are projected to remain constant over the next 18 years. For the shares of exports and imports in GDP, on the other hand, data strongly suggest a logarithmic growth.[45] If imports are greater than exports economists talk about a trade deficit or trade gap. The model projects that the U.S. trade deficit will grow from $187.6 billion in 1998 (last available figure from I-O tables) to $260.4 billion (in constant 1996$) in 2020. There are various political and economic interpretations of the effects of a trade deficit. The arguments reach from protectionist sentiments to optimistic outlines of the implications of an enduring trade gap [Griswold 1998]. The purpose of my study, however, is not the analysis of U.S. trade policy – I thus continue with the transportation relevant analysis; the interested reader can find more information about the ongoing discussion on the U.S. trade gap in Griswold 1998 or various financial magazines.

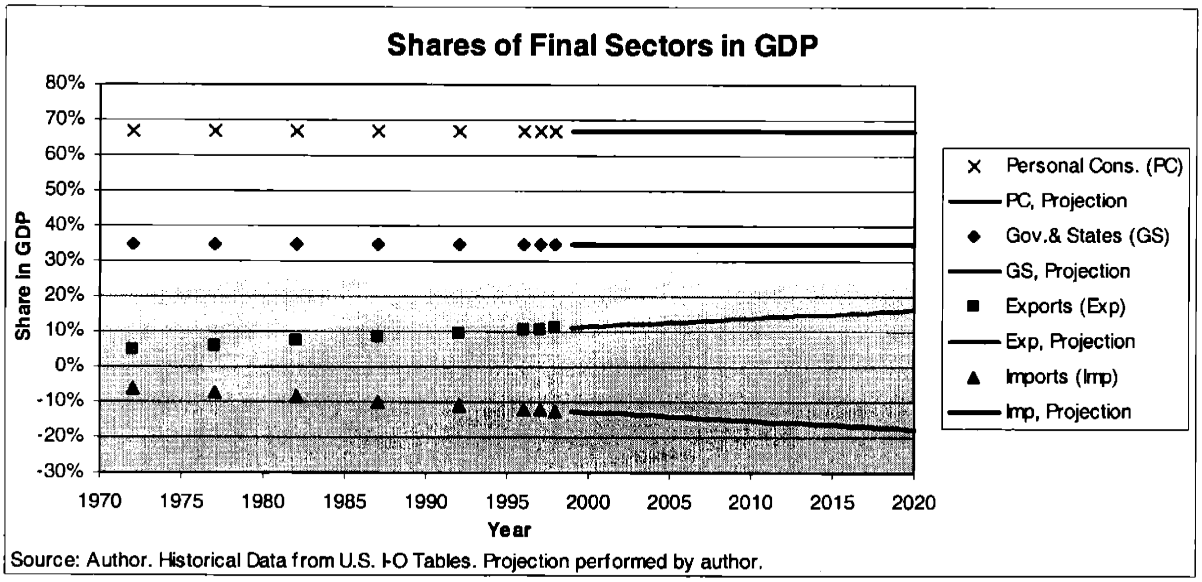

Figure 6.2 Shares of Final Sectors in GDP – Historical Data and Projections

Increasing shares of imports and exports in final demand have an interesting implication on domestic and international freight transportation demand. The demand for freight transportation effort resulting from the final demand for a dollar output of an imported or exported commodity is higher than freight transportation related to domestic demand for two reasons: (1) the share of transportable commodities is much higher in imports and exports (≈70%-80%) than in GDP (≈20%)[46] and (2) the average distance of shipment of imports and exports is larger than the average distance of domestic shipments. Therefore, the increasing share of international trade in GDP leads to an over-proportional increase in U.S. domestic freight transportation demand. This effect is analyzed in more detail in the chapter Model Extensions.

Besides the domestic implications on freight transportation, the rising share of international trade of the world's largest economy will result in a boost of worldwide air and water ship-

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[45] See Appendix B.IV for regression output.
[46] Those results can be verified by comparing Figure 6.4 with the figures in Appendix D.I.

shipments and in an increase of freight transportation in the neighboring states Canada and Mexico. The figures in Appendix D.I show that high-value transportable commodities (sector 6) will account for most of the increase in exports and imports. Since those goods are transported by air in a higher proportion than all other goods, the growing international trade of the United States will disproportionately favor air freight transport. This will also lead to an excessive impact on the environment because planes are by far the most energy-intensive transportation mode (see Table 8.1 on page 103).

As shown in Figure 4.2, the projection of total output requires (besides the shares s_k) the projection of each commodity share in the demand of final sector *k*, s_{ik} . I projected the shares of each commodity in each final sector, but showing the projections for each s_{ik} would require too much space. Instead of showing the individual shares, I, thus, depict the share of each commodity in total final demand. Those projections are shown in two charts – one for sectors producing transportable output (1-6) and one for the service sectors (7-9).

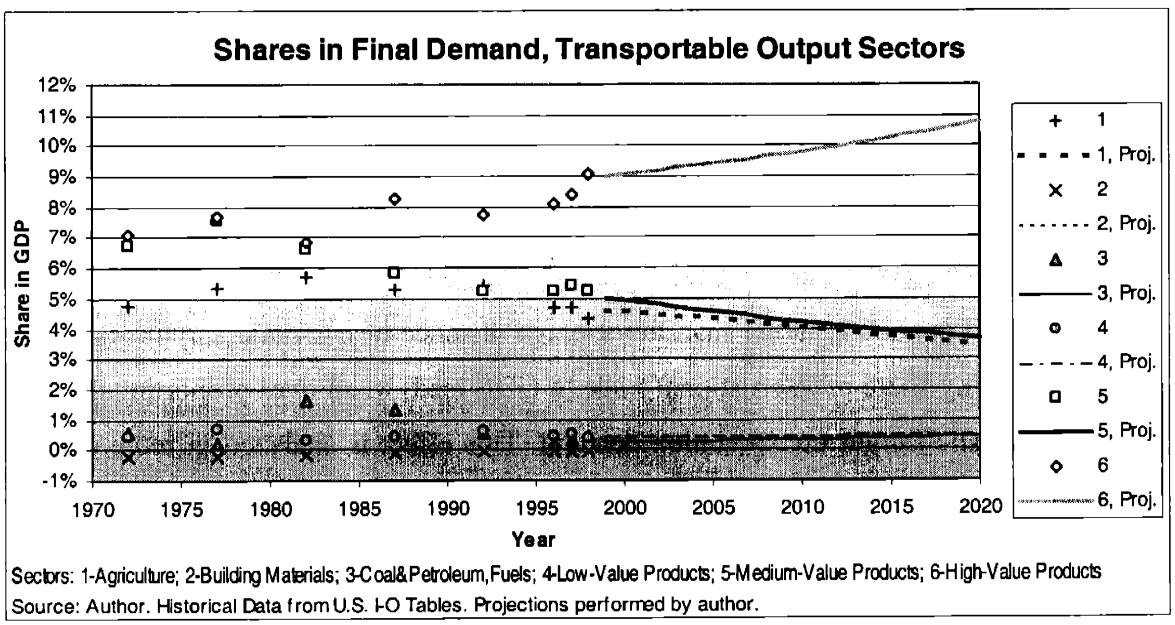


Figure 6.3 Shares of the 6 Transportable Output Sectors in Final Demand

Figure 6.3 shows that the shares of sectors 2 (building materials), 3 (energy goods), and 4 (low-value goods) remain constant or change only slightly. Sectors 1 (agriculture) and 5 (medium-value products) decline in GDP share, whereas the high-value product sector 6 increases in share. This has an interesting effect on freight transportation demand: The sectors producing relatively heavy output (i.e., the value per ton is relatively low) decrease in share or remain unchanged, whereas the share of sector 6, producing relatively light, high-value products, increases. Since final demand is the main driver of the economy, those shifts in GDP composition affect total output composition, which I show in more detail in Chapter 6.1.4.

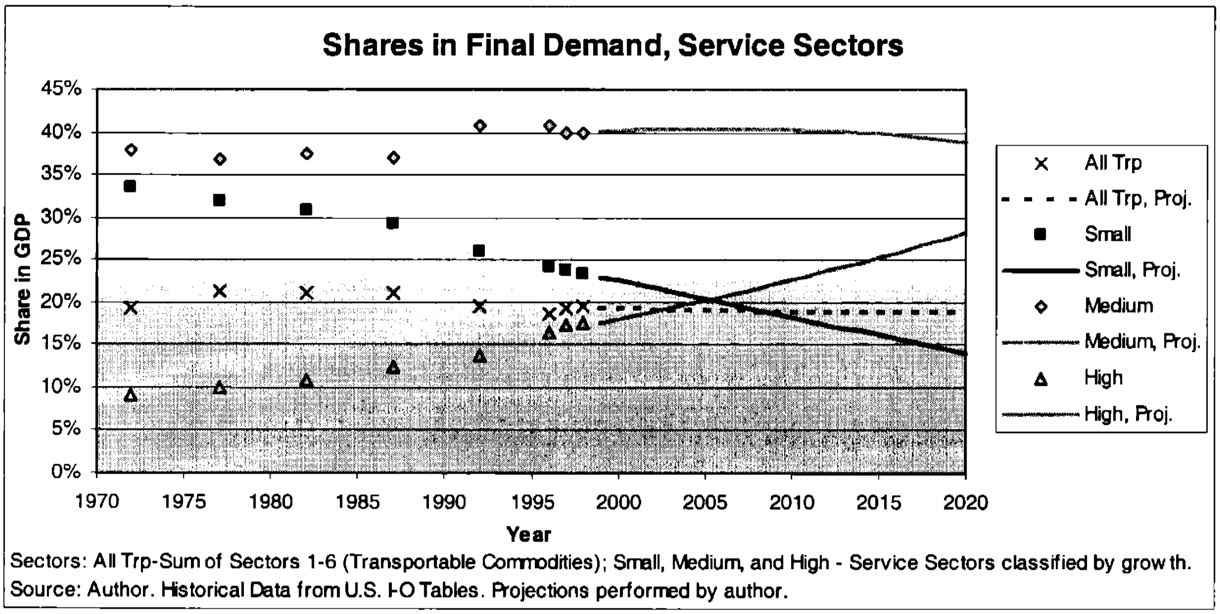


Figure 6.4 Shares of the 3 Service Sectors and Share of all Transport Sectors in GDP

Figure 6.4 shows the shares of non-transportable output (service) sectors in GDP together with the aggregated share of all transportable output sectors sectors, which remains more or less constant at a rate of 20%. One could expect that this share decreases over time under the assumption that the U.S. economy becomes increasingly service oriented. However, the historical data show that the share of transportable output sectors in the U.S. economy remained roughly constant in the last 20 years, as well. The stable share of industries producing physical outputs in the future is mainly assured by the increase in final demand for high-value products (sector 6).

The small-growth service sector and the high-growth service sector behave as expected: The share in GDP of the former decreases whereas the share of the latter increases substantially. The behavior of the medium-growth sector is intuitive, as well. Its share in GDP increases slightly until 2010 and then starts to decrease, which is reasonable if one thinks of today's medium-growth services as those sectors that are established but do not have much growth potential, anymore. They grow in absolute terms and may even increase their share in GDP in the short-run, profiting from the loss of share of low-growth sectors. But eventually they will lose share as other sectors grow faster. This is exactly what my model predicts so that this result can be seen as a verification of the underlying methodology.

Note that the projections of all shares in final demand result from the regressions of s_k and s_{ik} , so that the graphs shown in the above figures are not the result of single regressions. Consequently, the development of the medium growth-sector share does not emerge from a single regression (the shape of this curve could not be obtained by any of the functional forms I use, anyway), but is the result of a complex procedure.[47]

6.1.3 Total Output Projection

The projection of total output is performed according to equation (4.12). My model projects that total output doubles between the years 2000 and 2020. Figure 6.5 shows the development of total output and its components (i.e., the total output of transportable commodities and services) over this time period. Total output is the most important component in transportable output (see equation (4.19)). The fact that total output doubles will thus have enormous implications on U.S. freight transportation demands. I analyze those effects in Chapter 6.2. To provide a more detailed insight into the components of total output, I examine the share of the 9 sectors in the next chapter.

[47] Besides the fact that it results from the combination of several other shares, I use the share of the medium-growth sector as the resulting variable in most regressions. I explain the term "resulting variable" in Chapter 9.3.1 in equations (9.4) and (9.5) and show the corresponding regressions in Appendix B.

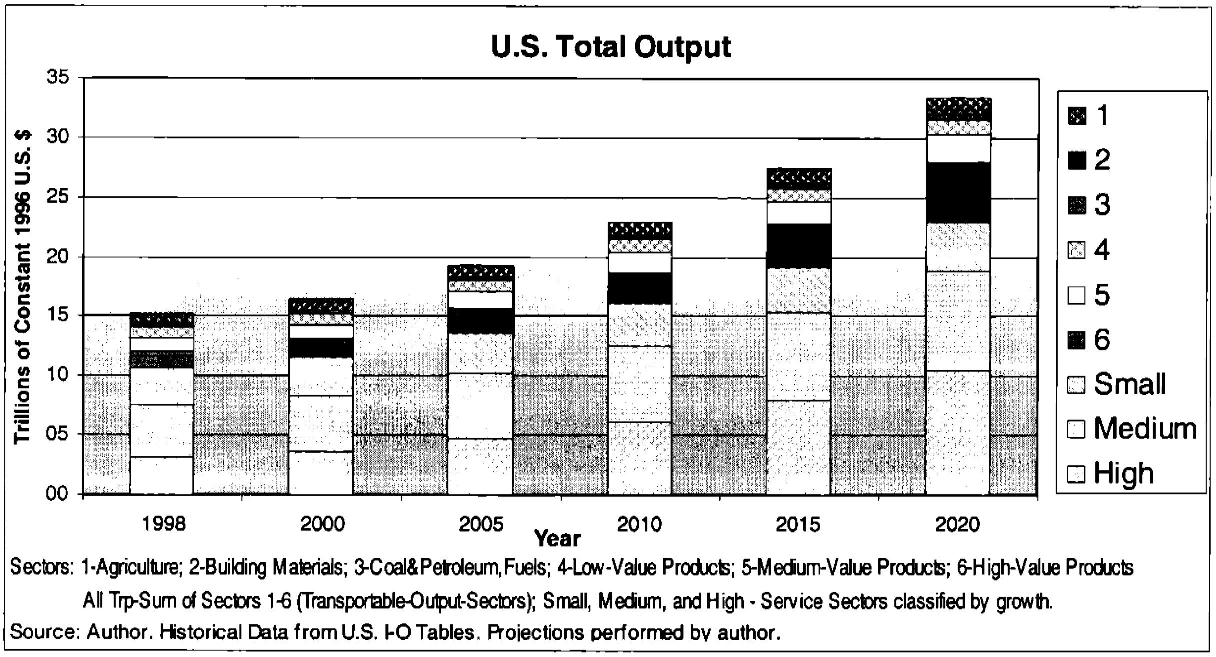


Figure 6.5 Total Output and its Components

6.1.4 Composition of Total Output

The composition of total output is derived from the projection of the total commodity output vector Y that is composed of the total output $m_{i\bullet}$ of all commodities i (as defined in equation (2.2)). To provide a better overview, the shares of commodities and services in total output are shown in two charts, one for the six transportable commodities and the other for the three service sectors.

Figure 6.6 and Figure 6.7 show that the shares in total output of transportable commodities and services, respectively, behave similar to the GDP shares. The only remarkable difference is that the share of high-value transportable products (sector 6) grows even faster in total output than in GDP, which also causes the share of all transport sectors in total output to slightly increase until 2020. I have outlined the effects of a shift from low-value products to high-value products in Chapter 6.1.2 – those effects are even stronger if the share of high-value products grows faster.

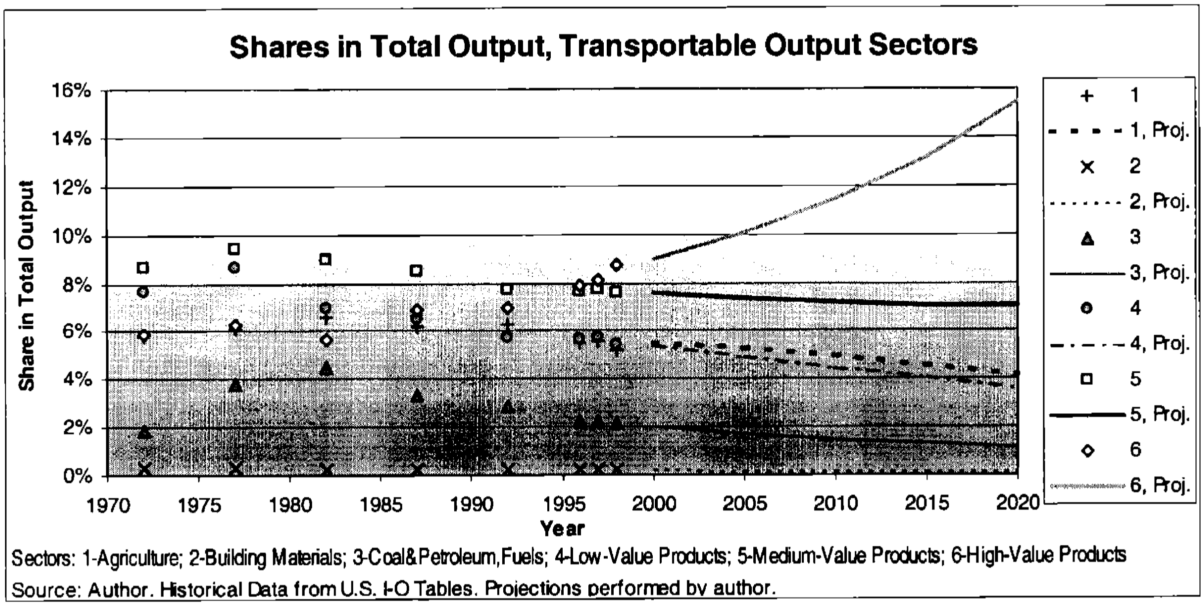


Figure 6.6 Shares of the 6 Transportable Commodities in Total Output

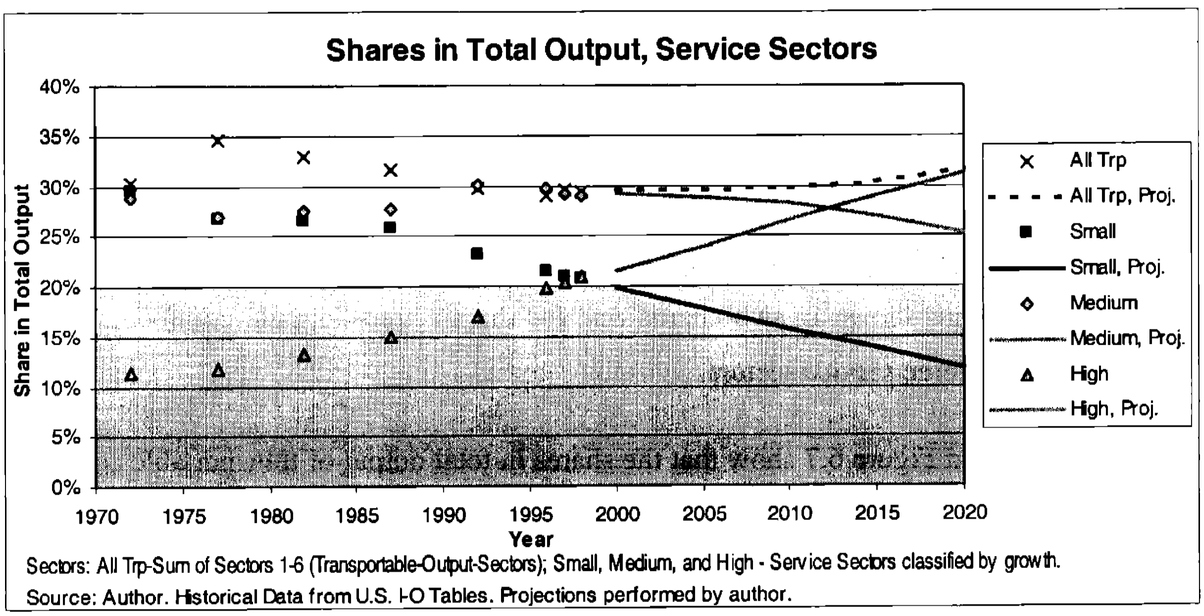


Figure 6.7 Shares of the 3 Service Sectors in Total Output

Note that the projections shown above do not result directly from the depicted historical data points. Rather, they are the result of the I-O projection procedure used in my model, which may cause projection lines to begin slightly below or above the last data point. According to the projection, the share of the medium-growth service sector in Figure 6.7 remains constant over some time and then begins to decrease. This corresponds to the intuition I gave in Chapter 6.1.2 and can thus be seen as another verification of the model and the underlying methodology. Since the shares in final demand and total output are very similar, the explanations given in Chapter 6.1.2 apply here, as well. The only addition I would like to make is that knowing the characteristics of total output is already one step closer to transportation demand. Consequently, remarks in Chapter 6.1.2 referring to freight transportation demand are now even more insightful.

6.2 Transportation Projections

Before examining the output that my model delivers for physical numbers of freight transportation demand, I would like to emphasize again that the projections are based on CFS figures that are, for some transport modes, different from other data sources. Reasons for this disparity are explained in Chapter 9.5. In the chapter Model Extensions, I show ways to make my results comparable with widely used numbers from ENO 2001. Note, however, that I corrected the most significant discrepancy by supplementing CFS figures with ENO data about crude oil transportation.[48]

6.2.1 Transportable Output

Transportable output $TC^{y}_{p,i}$ for each commodity class i is calculated according to equation (4.31) It comprises goods produced within the United States (for intermediate & final consumption and exports) and goods imported into the United States. Among all variables obtained from the economic projections, transportable output is the central one in the transformation of monetary figures of economic performance into physical figures of freight transportation demand. Figure 6.8 shows the projections for transportable output drawn from my model. Note that transportable output only includes sectors producing physical output (model sectors 1-6).

[48] The adding of crude oil shipment figures to CFS data is also explained in Chapter 9.4.3.

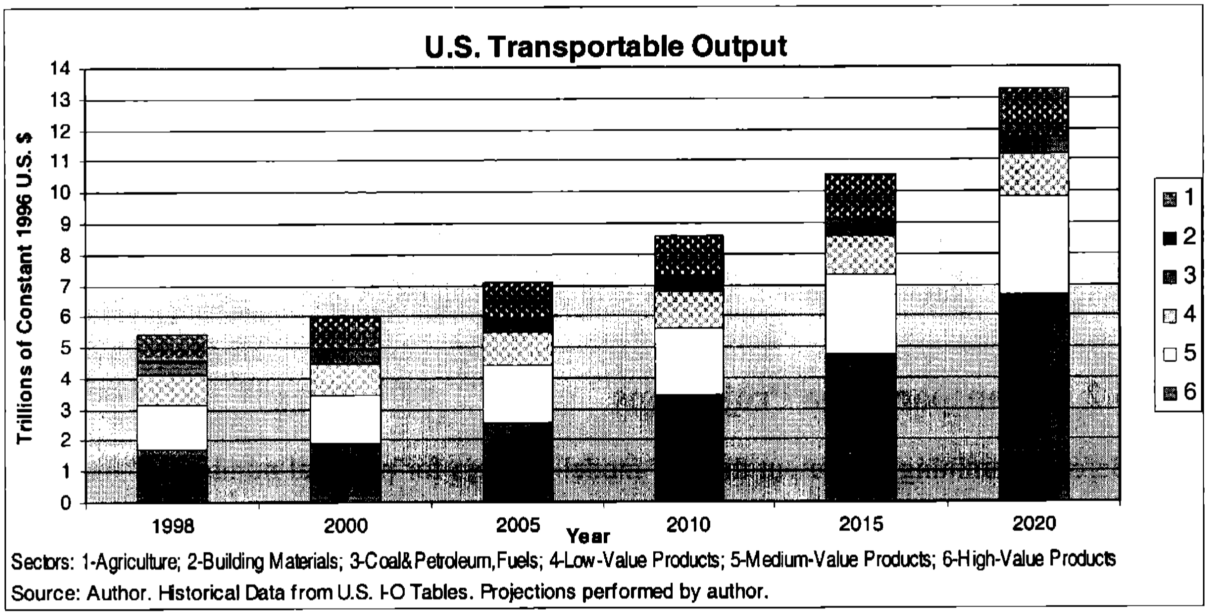
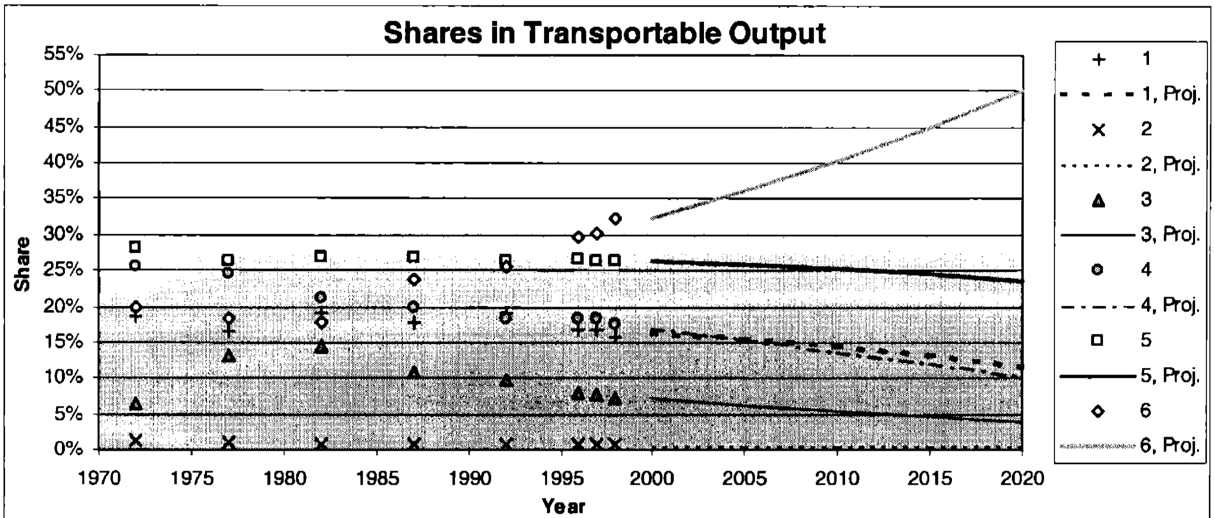


Figure 6.8 U.S. Transportable Output and its Components

A comparison of Figure 6.5 and Figure 6.8 reveals that total transportable output grows faster than total output. While total output grows by a factor of 2.20 between 1998 and 2020, total transportable output grows by 2.46 in my model. The explanation for this difference is the increasing share of transportable output sectors (1-6) in total output as visible in Figure 6.7, which is partially driven by the increasing share of imports in final demand: As outlined above, imports grow proportionally faster than total output. Moreover, the share of transportable commodities in imports (and exports) is higher than in any other final demand sector. Consequently, the addition of imports to total domestic output in the computation of transportable output (equation (4.19)) leads to a faster growth of total transportable output as compared to total commodity output. Those findings affirm my argument that commodity output, not corrected for imports, is a poor measure for the amount of commodities transported within an economy (i.e. transportable output).

Figure 6.9 visualizes in more detail the composition of transportable output.



Sectors: 1-Agriculture; 2-Building Materials; 3-Coal&Petroleum,Fuels; 4-Low-Value Products; 5-Medium-Value Products; 6-High-Value Products
Source: Author. Historical Data from U.S. I-O Tables. Projections performed by author.

Figure 6.9 The Composition of U.S. Transportable Output

Figure 6.9 shows that building materials and the medium-value-products (sectors 2 and 5) keep a relatively constant share in transportable output, while sectors 1, 3, and 4 slightly decrease in share. On the other hand, the share of the high-value-products sector in commodity output will rise dramatically. What will be the effect of this structural change in the economy on physical output and transportation demand? And what consequence does the increasing trend in total transportable output (as shown in Figure 6.8) have on freight transport demand in the United States? I will analyze those questions in the following chapters.

I compare "backwards" projections of transportable output with the corresponding historical data in Appendix D.II to verify the model.

6.2.2 Transportation Demand in Tons – By Commodity

The weight of commodity shipments $ton_{t,i}^{y}$ is obtained from transportable output $TC_{p,i}^{y}$ according to equation (4.23). This calculation represents the transformation of monetary commodity output into physical figures of transportation demand and is the centerpiece in the connection of the economic part and the transportation part in my model. Figure 6.10 shows the results that the model computes for the weight of commodities transported in the

U.S. between 1998 and 2020. The findings of this projection are described in the following. An important tool to understand the subsequent analysis is the knowledge about transport intensities t_i^y and commodity values CV_i as shown in Table 6.1.

Value of Transported Goods		**Average 1993-97**	
(in constant 1996 $ per ton)		**CVi ***	**ti ****
1	Agricultural and Food Products	734.8	1.26
2	Mining, Minerals, Sands, Stone, Waste	29.9	2.54
3	Coal, Petroleum, Fuels	142.9	1.29
4	Low-Value Intermediate and Final Products	529.1	1.26
5	Medium-Value Intermediate and Final Products	3,998.7	1.41
6	High-Value Intermediate and Final Products	11,302.7	1.00

Source: Author. Compounded data from the 1993 and 97 Commodity Flow Survey and I-O Tables.
* Commodity Values from CFS, ton figures from CFS.
** Transportation Intensity, without unit.

Table 6.1 Commodity Values and Transportation Intensities

It is an obvious result from comparing Figure 6.9 and Figure 6.10 that the total weight of transported commodities grows by far less than total transportable output. In other words, the physical transportation grows by less then the total value of transported goods. While total transportable output grows by 2.46 between 1998 and 2020, the total weight of transported commodities increases only by a factor of 1.49 between 1997 and 2020. Comparing Figure 6.9 and Figure 6.10 also reveals the cause of this difference in growth.

Figure 6.9 shows that sector 6 rapidly gains share in total transportable output over the next two decades. However, the goods produced by sector 6 (i.e. high-value products) are very light, as can be seen in Table 6.1.[49] Thus, the production of sector 6 goods leads to less transportation demand than the production of goods in other sectors. The shift towards relatively light high-value goods (dematerialization) is analyzed in detail in Chapter 6.2.6.

[49] Note that the number for sector 6's average commodity value in Table 6.1 is not the number used in my calculations. The exact value figures for sector 6 have been projected and shown in Chapter 5.2.2. Table 6.1 is merely used as a basic source to compare commodity values.

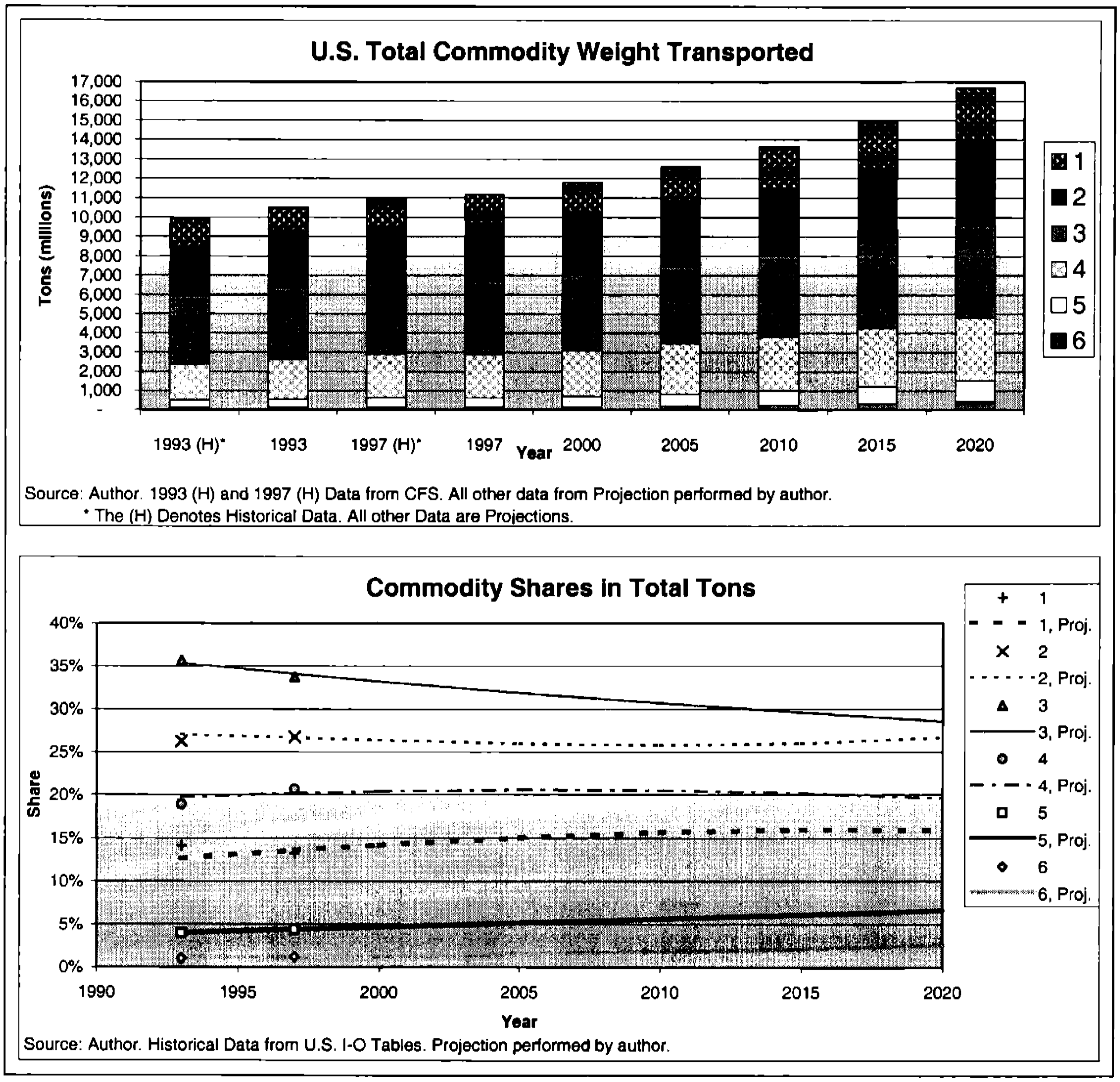


Figure 6.10 Transportation of Tons by Commodity

Another remarkable result is that building materials (sector 2) have an obsolete share in transportable output but, yet, are a very important component in the total weight of shipments. This fact is explained by the extremely low per-ton-value of building materials (see Table 6.1), which means that already a small output in dollars translates into a great physical transportation demand. The energy sector (model sector 3) loses share in transportable output as well as in the transportation of commodity weight. This finding indicates that the U.S. economy becomes less energy-transportation intensive (i.e. an x-percent increase in GDP leads to a less-than-x-percent increase in the transportation of energy goods. However, this does not necessarily mean that the U.S. economy as a whole will become less energy intensive. For example, energy utilities are considered a service sector in I-O tables so that a statement about trends in the consumption of electricity is not possible (and not wanted) in my model.

A somewhat unexpected result is that the agriculture sector gains share in commodity weight transportation. However, this result only seems strange on the first look. Figure 6.9 delivers the intuitive result that share of agricultural goods in transportable (monetary) commodity output declines. But why does the share in value decline although the share in commodity weight increases? The attentive reader knows the answer already: It lies again in the commodity value per ton. The shift towards light high-value products causes that economic growth is related to a less than proportional increase in physical transportation, i.e. the sectors that grow the most (sector 6) demand the least transportation. Thus, heavier products can gain share in the transportation of commodity weight although their share in dollar-value-output decreases. This is the case for agricultural goods, medium-value goods (sector 5), and (in the first decade of the projection) low-value products (sector 4).

Note that Figure 6.10 also includes a "backward" projection of the model, which allows the comparison between historical figures and what the model would have projected. Besides a minor overestimation of 1993 total tons, my model estimates the historical values and shares very well.

6.2.3 Transportation Demand in Tons – By Transport Mode

The computation of modal shares in total tons-transportation involves a two-step procedure. First, $ton^{y}_{t,im}$ is obtained according to equation (4.32), where $ton^{y}_{t,im}$ is the weight of commodity i transported by mode m. Second, the share b^{y}_{m} of mode m in total transport weight is calculated as follows:

$$(6.4) \qquad b^{y}_{m} = \frac{\sum_{i=1}^{6} ton^{y}_{t,im}}{\sum_{i=1}^{6} ton^{y}_{t,i}}, \forall m, y,$$

where $ton_{t,i}^{y}$ is obtained as outlined in the previous chapter. The results of this computation are visualized in Figure 6.11, which shows that all transportation modes grow in terms of tons transported. The largest increase in absolute as well as relative terms is accounted for by road transportation, while railway, pipeline, and water transportation decrease in share. Note that the share of air transport is too small to be visible in the first graph; the corresponding numbers can be seen in Appendix D.III.

The shift away from energy-efficient transport modes towards faster modes with higher energy consumption and carbon emission rates plays an important role in the analysis of environmental impacts of freight transportation. However, before proceeding with this examination, I need to compute ton-miles data because they are more closely related to energy consumption than ton numbers.

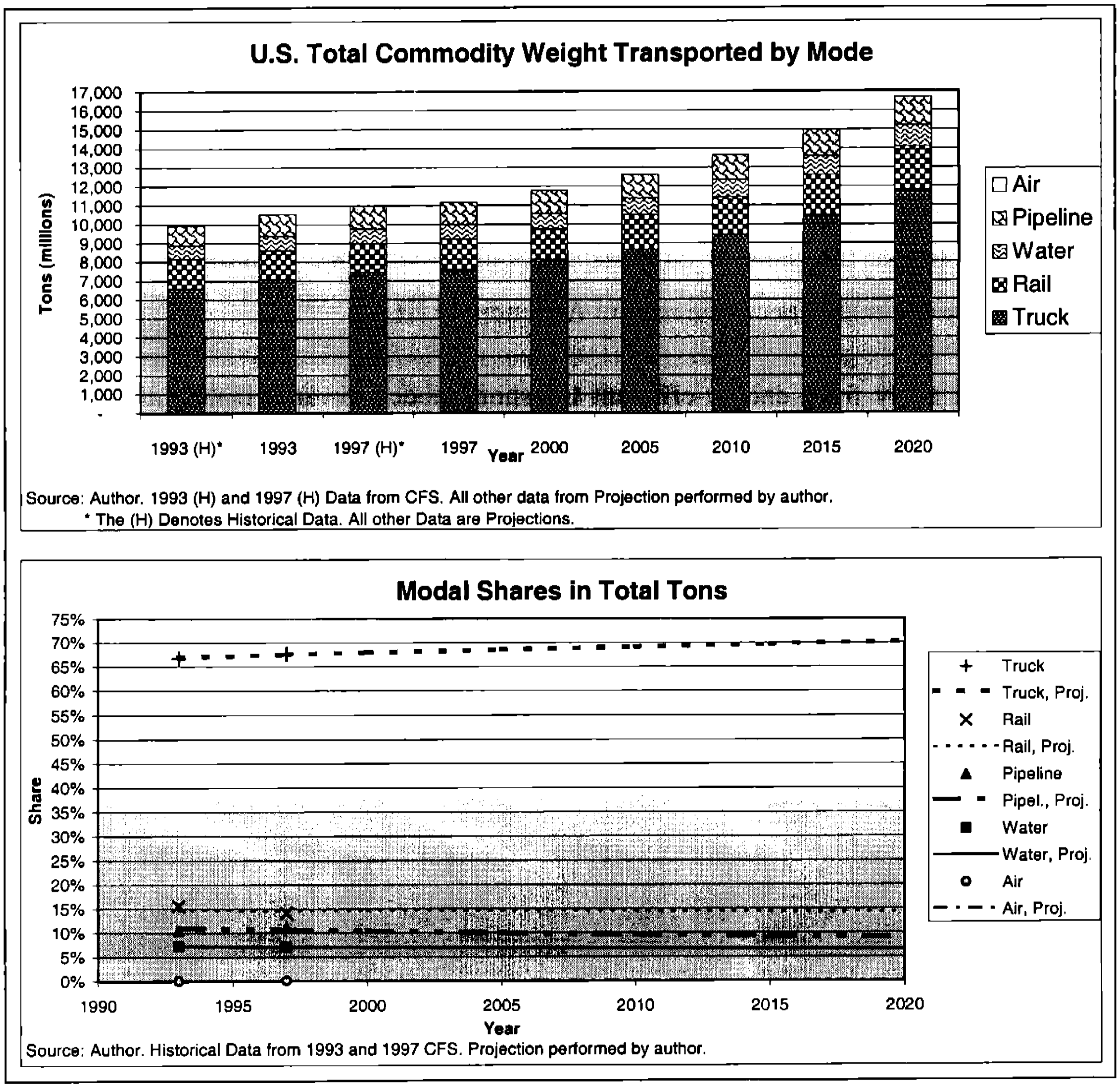


Figure 6.11 Transportation of Tons by Mode

6.2.4 Transportation Demand in Ton-Miles – By Commodity

Ton-miles of commodity shipment $(ton\text{-}miles^{y}_{im})$ are computed from ton-figures $(ton^{y}_{t,i})$ according to equation (4.29), using the average distance of shipment d^{y}_{im}. Figure 6.12 visualizes the ton-miles of shipment by commodity.

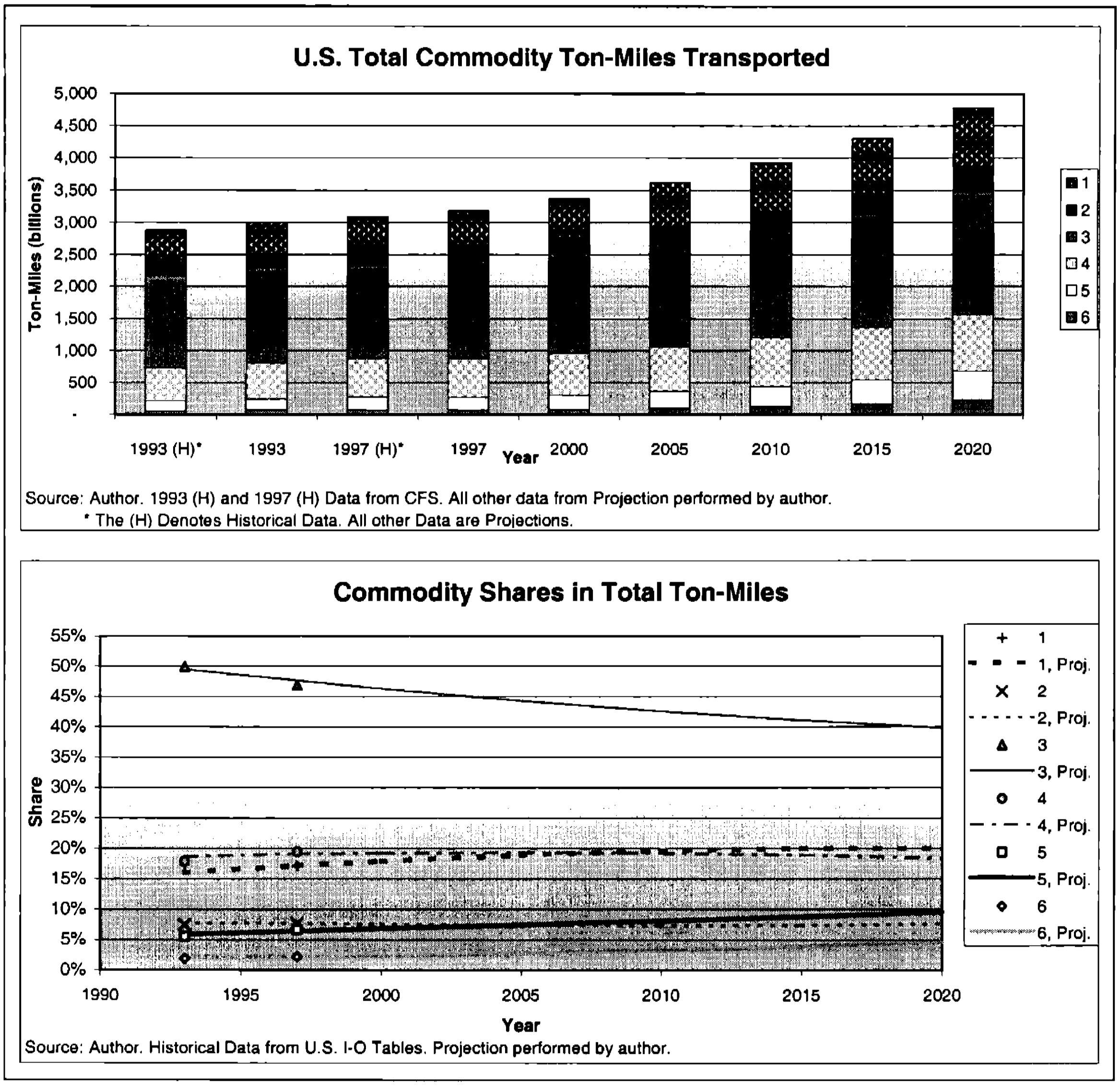


Figure 6.12 Transportation of Ton-Miles by Commodity

There is a significant difference between the shares of building materials in tons and ton-miles, which becomes obvious when comparing Figure 6.10 with Figure 6.12. Although building materials (sector 2) have a share of about 25% in total weight transported, their share in ton-miles is below 10%. The reason for this dissimilarity is that building materials are transported over relatively short distances – only around 80 miles in average, as can be seen in Appendix C.II. Energy goods (sector 3), on the other hand, are transported over relatively long distances (about 400 miles in average) so that their share in ton-miles lies notably above their share in total weight. The same result applies to sector 5 and sector 6.

Since agricultural goods are transported over longer distances than low-value products (360 miles as compared to 270 miles), their share in ton-miles exceeds the share of low-value products in my projection. Although losing share in tons and ton-miles, the by far most important sector in freight transportation remains the energy sector, which comprises coal, crude petroleum, and petroleum products.

6.2.5 Transportation Demand in Ton-Miles – By Transport Mode

The share of each transport mode m in total ton-miles in year y ($b^{y}_{m,\,ton-miles}$) is calculated according to the following equation:

$$(6.5) \qquad b^{y}_{m,\,ton-miles} = \frac{\sum_{i=1}^{6} ton - miles^{y}_{t,\,im}}{\sum_{m=1}^{5}\sum_{i=1}^{6} ton - miles^{y}_{t,\,im}}, \forall m, y,$$

which is the fraction of modal ton-miles over total ton-miles for each transport mode m. Figure 6.13 completes the analysis of my model's projection of freight transportation demand.

As was the case for commodities, there are significant differences between modal shares in tons and ton-miles. The reason for those discrepancies lies again in different average length of haul. As shown in Appendix C.II, road transportation is in average significantly shorter than the other four transport modes. This is explained by the fact that most shipments are not at their destination, yet, when they arrive at an airport or at a railway station. Rather, most goods are brought by trucks to factories, retailers, or warehouses.

While road transportation is the single most important mode in ton-transportation figures, its share in ton-miles is only half as big. Currently, railways have the highest share in ton-miles. However, my model projects that trucks will overtake the leading position in ton-miles in approximately 2005. Since ton-miles are closely related to energy consumption, this result indicates that U.S. freight transportation will in average become more energy intensive.

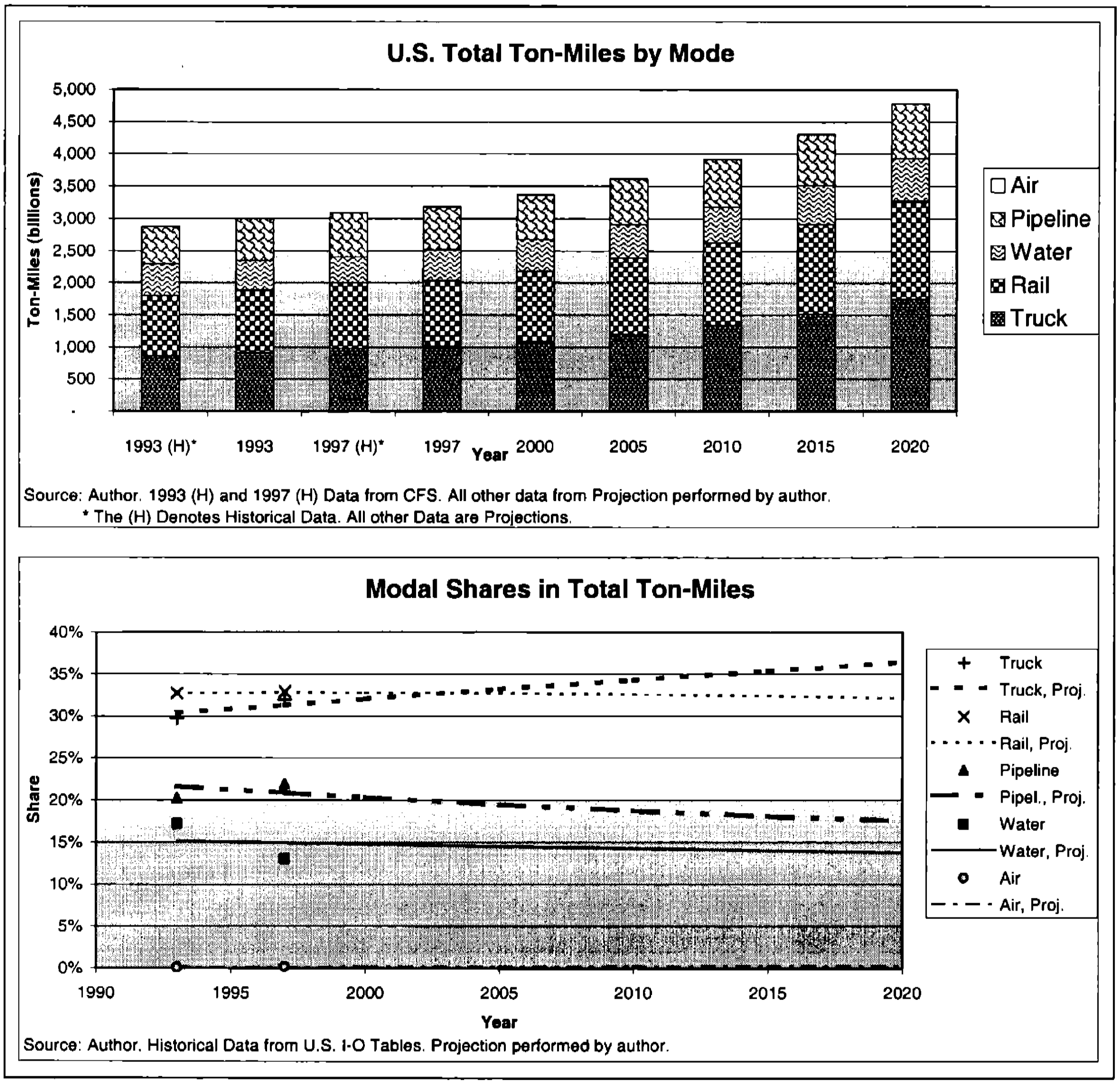


Figure 6.13 Transportation of Ton-Miles by Mode

Although the average distance of air shipments is with about 1300 miles the longest, freight aviation only has a very small share in ton-miles. To enable a better comparison between the small figures of air transportation, the projections of model shares in ton-miles are displayed in Appendix D.IV. Another interesting result, obtained by comparing Figure 6.11 and Figure 6.13 is that the share of water and pipeline transportation is significantly higher in ton-miles than in tons, which is also due to the relatively long average haul distance of those modes (about 600 and 560 miles, respectively). Altogether, shares in ton-miles are more equally distributed across transport modes than shares in tons.

6.2.6 Quantifying Dematerialization with Respect to Freight Transportation

The shift in production towards lighter goods with a higher per-ton value can be understood as a dematerialization with respect to freight transportation, i.e., an x-percent increase in GDP in the future will lead to a smaller increase in freight transportation demand than an x-percent GDP growth in the past. This effect can best be visualized by examining the average per-ton-value of all goods produced within the economy. In this analysis, I use the methodology introduced in Chapter 4.2.3. Equation (4.23) can be rearranged to yield:

$$(6.6) \qquad CV_i^y = \frac{t_i^y \times TC_{p,i}^y}{ton_{t,i}^y}, \forall i \in [1,...,6], \forall y,$$

where CV_i^y is commodity i's value per ton, t_i^y is the transportation intensity, $ton_{t,i}^y$ is the weight of transported commodity i, and $TC_{p,i}^y$ is the transportable output of commodity i in year y. However, what interests me in the quantification of dematerialization is the average value per ton of *all* products transported in the U.S. Thus, I define CV^y as the average value of all commodities shipped in the U.S. in year y and derive from equation (6.6):

$$(6.7) \qquad CV^y \equiv \frac{\sum_{i=1}^{6} t_i^y \times TC_{p,i}^y}{\sum_{i=1}^{6} ton_{t,i}^y}, \forall y,$$

which is simply the total commodity value transported divided by total commodity weight. I apply equation (6.7) to the historical data of $TC_{p,i}^y$ (obtained from I-O tables)[50] and $ton_{t,i}^y$ (obtained from CFS) in 1993 and 1997. Besides this, I also apply equation (6.7) to the projected data for 1993, 1997, and 2000-2020, where the data for 1993 and 1997 are "backwards" projections to verify the model. Figure 6.14 shows the results of this computation. A comparison of the "backwards"- projection and the historical average per-ton commodity values shows that my model fits the actual data very well. The model's

[50] The 1993 values are obtained by linear interpolation between the 1992 and 1996 I-O table because there exists no I-O table for 1993.

commodity values shows that my model fits the actual data very well. The model's projection results from a complicated process of modeling economic and transport parameters and is thus by far more than an extrapolation of the two historical data points in Figure 6.14. The fact that my model fits the historical data so well can be taken as one more verification of the underlying methodology (though it does not grant that the model correctly predicts future changes).

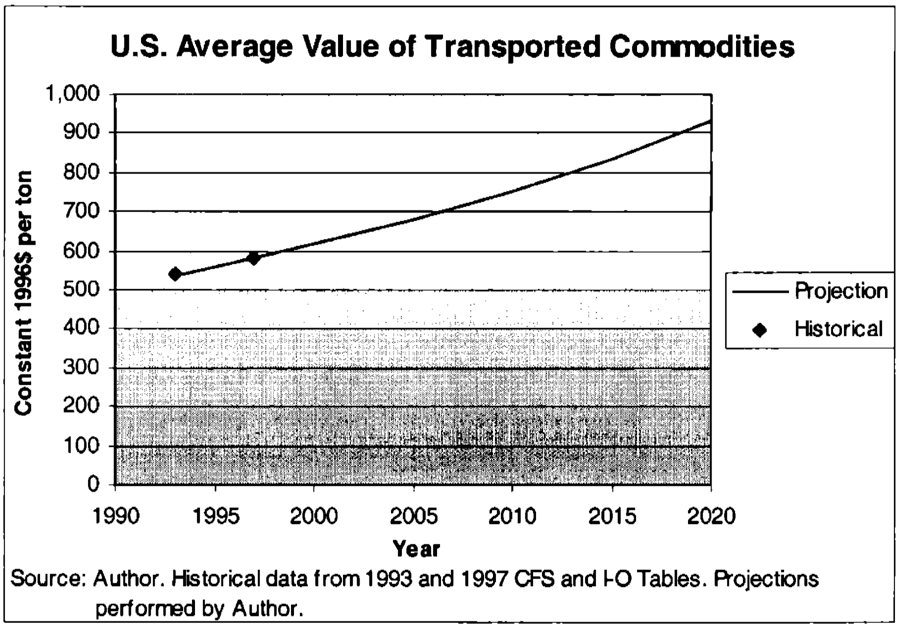


Figure 6.14 Time Trend in Average Commodity Value per Ton

Figure 6.14 shows that my model projects the average per-ton-value of transportable commodities in the United States to grow by more than one third in the next two decades. This is a clear indication for a dematerialization of the U.S. economy with respect to freight transportation demand, meaning that the same economic growth will lead to relatively less commodity weight transported in the future. Whether this finding signals environmental relief in the discussion of sustainable transportation will be analyzed in the chapter Environmental Impacts.

7 Model Extensions

7.1 Comparability with other Data Sources

7.1.1 ENO Data and CFS Data

A widely used source for U.S. Freight Transportation data is "Transportation in America", published by the ENO Transportation Foundation. Those data differ, for some modes, significantly from CFS data, i.e., CFS estimates are below the corresponding ENO figures. The major reasons for those differences are explained in Chapter 9.5. Although ENO data appear to be a more reliable source than CFS data, I could not use those data as a basis for the model because they do not provide information on commodity shipments. The only possible supplementation of CFS data was an adjustment for crude oil shipments (see Chapter 9.4). Table 7.1 shows a comparison between the adjusted CFS numbers used in the model and figures from ENO 2000.

Transportation Mode	Tons (millions)			Ton-miles (billions)			Average Distance		
	Model	ENO	%Diff	Model	ENO	%Diff	Model	ENO	%Diff
1997									
Truck	7431.8	3732.0	-50%	988.4	996.0	1%	133.0	266.9	101%
Rail	1543.7	1972.0	28%	1016.5	1421.0	40%	658.5	720.6	9%
Water	781.4	1017.0	30%	403.0	706.0	75%	515.7	694.2	35%
Air	4.1	12.9	212%	5.7	13.9	146%	1,370.8	1,077.5	-21%
Pipeline	1219.5	1108.0	-9%	678.5	617.0	-9%	556.4	556.9	0%
Source: Author. Data from CFS and ENO 2000. Crude oil transportation numbers have been added to CFS data.									

Table 7.1 Comparison of Data used in the Model and ENO Data in 1997

The interested reader can compare the numbers in Table 7.1 with the unadjusted CFS data shown in Table 9.7 on page 129. This comparison shows that the addition of crude oil shipments to CFS figures significantly lowers the difference to ENO data for water and pipeline shipments. However, differences in ton-miles of shipments remain large for all modes except truck and pipeline. It is interesting to note that ton-miles shipments for trucks are very similar in both sources although tons figures differ by 50%. Explanation lies in the difference in average distance for trucks shipments given by CFS and ENO data. I believe that CFS figures are more reasonable in this respect, because ENO data only cover intercity shipments and leave out short-range truck operations so that they potentially overestimate the average distance.

Since ton-miles data from ENO are the more widely acknowledged source, it is helpful for the future verification of my model to provide a way to relate the model with ENO data. Such a procedure is shown in the following.

7.1.2 Using the Model to Project ENO Data

One of the outputs of the model is the projection of ton-miles by transport mode until 2020. This projection involves the dynamic modeling of U.S. economic performance and transportation characteristics. The growth of ton-miles for each transport mode is thus closely related to changes in the output of transportable commodities. The model's growth projections of ton-miles are the basis to apply the model to ENO data. The corresponding equation to project ENO ton-miles transported in year *y* by mode *m* is:

$$(7.1) \qquad ton\text{-}miles_{ENO,m}^{y} = (1 + g_{m}^{y}) \times ton\text{-}miles_{ENO,m}^{y-1}, \; \forall m,$$

where $g_{m}^{y} = \dfrac{ton\text{-}miles_{Model,m}^{y}}{ton\text{-}miles_{Model,m}^{y-1}} - 1$.

In this equation, g_{m}^{y} is the growth rate of ton-miles in mode *m* in year *y* and $ton\text{-}miles_{ENO,m}^{y-1}$ denotes ENO data for the previous year. Note that this projection is not restricted to one-year steps – the growth rate of ton-miles can also be calculated for shorter or longer time-steps (e.g. for a 17-year period to project 2015 ton-miles based on 1998 ENO figures).

The application of ton-miles growth rates from the model to ENO data assumes that commodity shipments by each mode not covered by the model grow similarly to commodity shipments covered by the model. For example, equation (7.1) only delivers accurate results for rail shipments, if the 40% in ton-miles not included in the model grow similarly to the covered 1000 billion ton-miles (see Table 7.1). Since the CFS covers a wide array of goods, it provides a broad sample so that the assumption of similar growth in goods not covered is not very strong. The data to test this assumption, however, are not available.

Equation (7.1) can be used to verify the model with future data from ENO or to make the model's projection comparable to forecasts that have been developed based on ENO data. A table showing growth rates of ton-miles projected by the model is included in Appendix D.IV.

7.2 Improving the Role of Imports in the Model

In the current shape of the model, imports and exports are not given special consideration although they are related to longer transportation distances and thus higher ton-miles than goods whose production and consumption occurs domestically. A possible way to improve the model projections would be to treat imports and exports separately. For this purpose, equation (4.18) could be altered in the following way:

$$(7.2) \qquad TC^{y}_{dom,\,p,\,i} = \sum_{j=1}^{9} m^{y}_{ij} + \sum_{k=1}^{2} f^{y}_{ik}\ , \quad \forall i \in [1,\ldots,6]\,, \forall y\,,$$

where $TC^{y}_{dom,\,p,\,i}$ is the "domestic" transportable output of commodity i, produced and consumed domestically in year y, $\sum_{j=1}^{9} m^{y}_{ij}$ is the intermediate demand for i, and $\sum_{k=1}^{2} f^{y}_{ik}$ is the final demand of personal and government consumption for i. For exported and imported commodities, the following equation applies:

$$(7.3) \qquad TC^{y}_{\text{int},\,p,\,i} = \sum_{j=1}^{9} m^{y}_{ij} + f^{y}_{i3} + \left|f^{y}_{i4}\right|, \quad \forall i \in [1,\ldots,6]\,, \forall y\,,$$

where $TC^{y}_{\text{int},\,p,\,i}$ is the "international" transportable output of commodity i, exported or imported in year y, f^{y}_{i3} denotes exports, and $\left|f^{y}_{i4}\right|$ is the absolute value of imports. To transform $TC^{y}_{dom,\,p,\,i}$ and $TC^{y}_{\text{int},\,p,\,i}$ into quantities, equation (4.23) still applies. To calculate ton-miles figures, however, different average distances must be used for domestic and international goods. The corresponding equations are:

(7.4) $$ton\text{-}miles^{y}_{dom,im} = d^{y}_{dom,im} \times ton^{y}_{dom,t,im}\ ,\ \forall i \in [1,...,6]\ ,\forall y,\ \forall m$$

and

(7.5) $$ton\text{-}miles^{y}_{int,im} = d^{y}_{int,im} \times ton^{y}_{int,t,im}\ ,\ \forall i \in [1,...,6]\ ,\forall y,\ \forall m\ ,$$

where $d^{y}_{dom,im}$ is the average distance of domestic shipments of commodity i by mode m and $d^{y}_{int,im}$ is the average distance that imports and exports of commodity i are shipped *within* the United States by mode m.

From the current model, $TC^{y}_{dom,p,i}$ and $TC^{y}_{int,p,i}$ can be derived. However, the average distance of shipments for imports and exports is not available. In the present CFS methodology, imports are not tracked from the point on when they enter the U.S. This needs to be changed to enable more exact analyses of U.S. freight transportation.

7.3 Adding Data on Parcel Shipments

Parcel shipments become increasingly important in the U.S. economy, [51] since lots of shipments are small and need to be delivered fast, thus favoring truck and air transportation. Although the 1997 CFS includes parcel shipments, it does not provide detail on the underlying transport modes. If more detailed data become available, parcel shipments can easily be built into the model structure, e.g., as a 6th mode for which tons and ton-miles are computed and then assigned to the single modes.

7.4 Making Variables Time-dependent

Commodity value CV_i^y, transportation intensity t_i^y, and average distance d^{y}_{im} have the y in their index, which means that the model can deal with time-dependent functions for those variables. However, currently available data do not allow the derivation of corre-

[51] And might have gained overwhelming importance if internet-shopping had become as wide-spread as anticipated two years ago.

sponding time trends. This may become possible of the CFS does not change its methodology and provides regular data sets in the future.

7.5 Adding Detail for Intersectoral Shipments

The present model uses transportable commodity values $TC_{p,i}^{y}$ to derive quantities (tons). In this process, average values are used for commodity value, transportation intensity, and average distance. It is conceivable, however, that those values vary for shipments between different sectors. For example, shipments from agriculture to agriculture may be shorter than shipments from agriculture to the high-value-product sector. The I-O framework allows such detailed analysis, so that the model could be extended if data on intersectoral shipments were made available. The CFS gives detailed information on interregional shipments, if those data were extended to provide intersectoral shipment numbers, a more detailed freight projection would become possible.

8 Environmental Impacts

The ton-mile projections for each transport mode are the basis in the calculation of energy consumption and CO_2 emissions resulting from freight transportation in the United States. Figure 6.13 on page 95 shows the ton-mile projections; it may be interesting for the reader to compare this figure with the projections shown in the following and to see how a big share of a mode in ton-miles can be related to a small share in CO_2 emissions, and vice-versa. Note, as in Chapter 6, that the data shown here are calculated based on CFS data. Computations based upon ENO data may yield higher figures.

8.1 Freight Energy Consumption

8.1.1 Energy Intensities

The energy consumption E_m^y of each transport mode *m* in year *y* is computed from ton-mile figures according to the equation

$$(8.1) \qquad E_m^y = e_m^y \times ton\text{–}miles_m^y \quad , \forall y, \forall m ,$$

where e_m^y is the energy intensity of mode *m* in Btu per ton-mile. I obtain energy intensity figures for rail, water, and pipeline transportation from ENO 2000. For truck transportation, I include data on local shipments, as described in Chapter 9.6.1. Finally, for air transportation, I take the figure provided by Mintz 1991 and adjust it with the average annual change given for civil aviation by ENO 2000. The results of this data compilation are shown in Table 8.1.

Energy Intensity Projection		**Average %Change**					
(Figures in Btu/ton-mile)	**1998**	(1970-98)	**2000**	**2005**	**2010**	**2015**	**2020**
Truck	4,266*	-0.40%	4,232	4,148	4,066	3,985	3,906
Rail	365	-2.30%	348	310	276	246	219
Water	436	-0.80%	429	412	396	380	365
Air ***	20,776**	-0.20%	20,693	20,487	20,283	20,081	19,881
Pipeline	256	N/A	256	256	256	256	256

Source: Author. Data in 1998 and %Change numbers from ENO 2000, unless indicated otherwise.
* Calculated by Author. See table in chapter Data Methodology.
** 1991 figure is 21,670 [Mintz 1991]. This number was adjusted with an average annual growth of -0.6%, taken from DOE 2000, p.2-14.
*** Growth rates in efficiency are taken from ENO figures for civil aviation, since no data for freight efficiency are available.

Table 8.1 Energy Intensities of Freight Transport Modes

The most energy-intensive transport mode is air transportation, followed by truck, which is about five times smaller. Water, rail, and pipeline shipments are again 10, 12, and 16, respectively, times more energy efficient than truck transportation. The figures for average annual change in energy intensities reveal that rail energy efficiency increased the most, whereas air energy efficiency increased only slightly in the last 30 years. I use the average change numbers for 1970-98 to project future energy efficiencies.[52]

8.1.2 Energy Consumption by Mode

Figure 8.1 shows the modal energy consumption that my model projects for U.S. freight transportation.

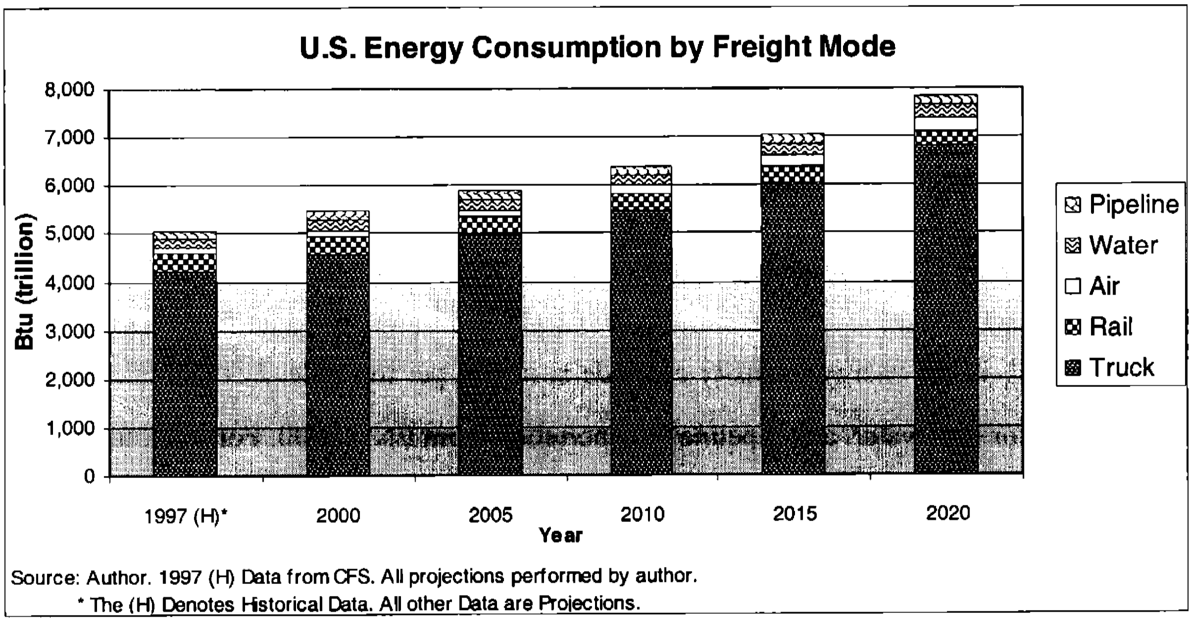


Figure 8.1 Energy Consumption of Freight Modes

The model projects total energy consumption of freight transportation to grow by 1.55 between 1997 and 2020 (the projected GDP growth is 1.99). The total weight of commodity shipments, on the other hand, is projected to grow by 1.52 in the same time period.[53] This

[52] In future studies, more comprehensive research should be conducted on the projection of freight mode energy efficiencies. There are several studies on passenger transport energy efficiencies, but the most recent one I found for freight transportation dated back to 1991 [Mintz].

[53] The underlying calculations can be verified using the figures presented in appendices D.II and E.I.

finding implies that U.S. freight transportation will become more energy-intensive, which is mainly due to the shift towards high-value products that are (1) shipped over the longest distance among all 6 commodity classes,[54] and (2) shipped by the energy-intensive modes air and road to a higher percentage than other products.

It is remarkable how much larger the share of trucks in energy consumption (≈83-86%)[55] is compared with the truck share in total ton-miles (≈32-36%, as shown in Figure 6.13). This is a result of the relatively high energy-intensity of truck shipments. On the other hand, the shares of water and pipeline transportation in energy consumption are only about 3.5-2.9% in energy consumption but about 15-13% (water) and 21-17% (pipeline) in ton-miles. This is exactly the opposite of the finding for trucks and is explained by the low energy-intensities of water and pipeline shipments. The share of rail transportation – after pipeline the second most energy-efficient transport mode – even declines from 7.1% in 1997 to 4.3%, as shown in Table 8.2.

Modal Shares in Energy Consumption		CFS	Projected Shares in Energy Consumption				
Figures in billion ton-miles		1997	2000	2005	2010	2015	2020
1	Truck	83.4%	83.7%	84.7%	85.5%	86.1%	86.6%
2	Rail	7.3%	7.1%	6.2%	5.5%	4.9%	4.3%
3	Water	3.5%	3.9%	3.7%	3.5%	3.3%	3.1%
4	Air	2.3%	2.1%	2.4%	2.6%	2.9%	3.3%
5	Pipeline *	3.4%	3.2%	3.1%	2.9%	2.8%	2.7%
Total		**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Author. Data in 1997 from CFS. Projections performed by author.
* Includes data on crude petroleum shipments from ENO 2000.

Table 8.2 Modal Shares in Freight Energy Consumption

The findings of this chapter underline again the general trend in U.S. freight transportation towards faster, but more energy-intensive, modes. In the next chapter, I examine the environmental implications of this trend in the light of carbon dioxide (CO_2) emissions.

[54] See Appendix C.II for detailed figures.
[55] The first number represents the approximate share in 1997 and the second figure is the projected share in 2020.

8.2 Carbon Dioxide Emissions

8.2.1 Calculation

Carbon Dioxide emissions can be derived from ton-mile figures by using the carbon content in the fuel that has been burnt during the shipment. An average figure is 20g Carbon per Megajoule,[56] which is the same as 0.0774g CO_2 per Btu. I use the latter number to derive CO_2 emissions from the ton-mile figures computed in the previous chapter. Note that, in a more comprehensive analysis, one could calculate separate carbon content figures for each fuel (e.g., for diesel and gasoline) and use them together with data on typical fuel usage for each transport mode (e.g., kerosene for airplanes and diesel for trucks). However, for the purpose of this paper, the calculation with the average figure is sufficient (considering that there are no big differences in the carbon content of the fuels used in transportation).

8.2.2 Global Warming

Reports from the Intergovernmental Panel on Climate Change (IPCC) warn that a continuation of current greenhouse gas emissions will very likely lead to serious environmental implications (e.g., an increase in the frequency of extreme climate events like droughts, typhoons, or floods) [IPCC 2001]. Worldwide, there are efforts to restrict greenhouse gas emissions[57] in order to mitigate global warming. The most important endeavor is the Kyoto protocol that has been boycotted by the current U.S. administration. However, it is not my intention to use this paper for a discussion of the United States' role in international environmental policy. Rather, I gave this short introduction to global warming as a preface to the following analysis of model outputs.

8.2.3 Projections and Policy Implications

The model projects U.S. freight transport carbon emissions to grow by a factor of 1.58 between 1997 and 2020, if no significant measures are undertaken to deviate from the busi-

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[56] A. Schafer 2002, personal reference.

ness-as-usual path. The transportation sector (including passenger transportation) currently accounts for about one third in U.S. carbon emissions [DOE 2000, p.3-6]. The projected increase in freight transportation related CO_2 emissions is one among many facts implying that it will become difficult for the United States to achieve its reduction aim determined in the Kyoto treaty.[58] Besides, policy measures to lower greenhouse gas emissions (e.g., by increasing the fuel economy of trucks) take time to become effective. Thus, the more time passes without measures to leave the business-as-usual path, the harder it will be for the United States to rejoin the Kyoto treaty. Which measures are the most promising to lower freight transport CO_2 emissions? To answer this question, I analyze the share of each freight transport in total carbon dioxide emissions.

As was the case for energy consumption, CO_2 emissions are largely (≈83-86%) due to truck transportation. The share of air transportation in total CO_2 emissions increases from about 2.3% to 3.3% between 1997 and 2020, according to my projections. Since emissions of aircrafts occur in the upper troposphere and lower stratosphere (9-13km altitude), they have more severe effects on global warming than emissions on the ground. Lee et. al wrote in 2001 (p. 176):

> *...the resulting impacts are unique. The fraction of these emissions that is relevant to atmospheric processes extends far beyond the radiative effects of CO_2. In fact, the mixture of exhaust species discharged from aircraft perturbs radiative forcing two or four times more than if the exhaust were CO_2 alone.*

Consequently, aircraft emissions need to be given special consideration in measures to lower CO_2 emissions. Figure 8.2 shows that, similar to the energy consumption pattern, the shares of the slower modes water, rail, and pipeline in CO_2 emissions are low (below 5% in average between 1997 and 2020 for each mode), although their share in ton-miles is relatively high (see Figure 6.13). The reason for this dissimilarity in shares is the relatively low energy-intensity of the slower transport modes, which forms one of the bases of my policy

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[57] The most important greenhouse gases are (ordered by shares in radiative forcing) CO2 (64%), Methane (19%), CFCs (10%), and N2O (6%) [IPCC 2001].

[58] In Annex B of the Kyoto Protocol, the United States accepted an emission reduction target for 2010 of 8% below its 1990 emissions.

suggestions in Chapter 8.4.

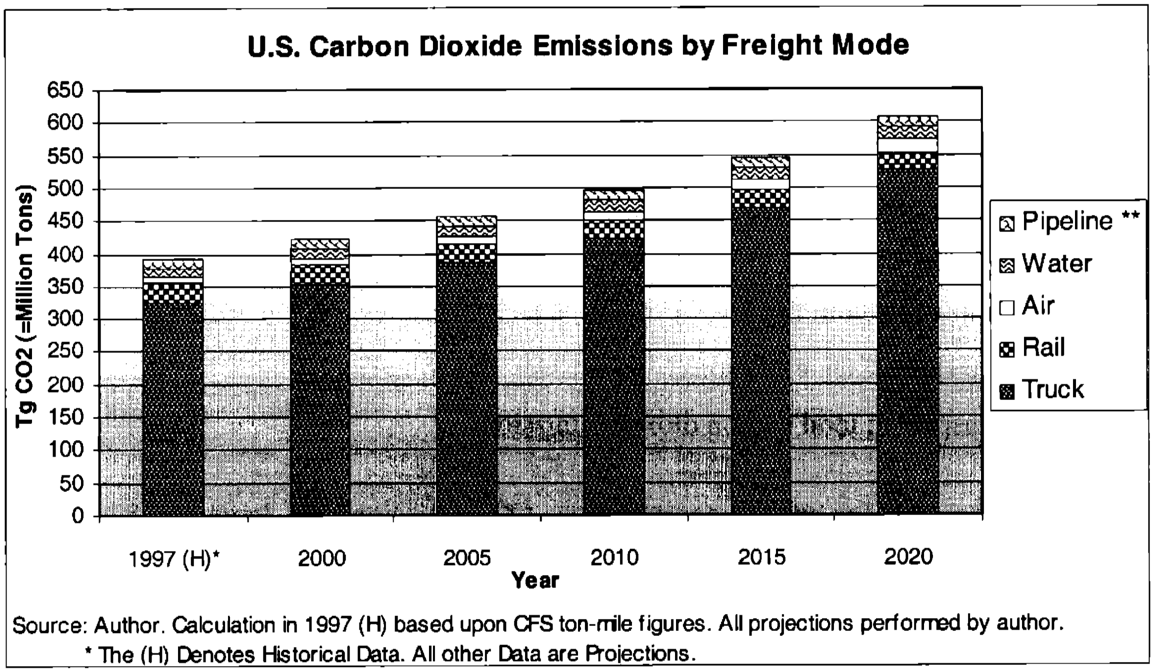

Figure 8.2 CO_2 Emissions of Freight Modes

8.3 Other Emissions

Motor vehicle exhaust and gasoline vapors are among the major sources of nitrogen oxides (NO_x) and volatile organic compounds (VOC), also known as ozone precursors. Strong sunlight and hot weather cause ground-level ozone to form in harmful concentrations in the air. Many urban areas tend to have high levels of ozone, but other areas are also subject to high ozone levels as winds carry NO_x emissions hundreds of miles away from their original sources.

Another effect to which NO_x is a main contributor (together with sulfur dioxide, SO_2) is acid rain. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds.

An important emission of transportation, that is often forgotten, is noise. My model projects a shift towards road and air transportation and those are exactly the modes with the highest noise nuisance – in the case of aircraft because the noise is very loud and in the case of trucks because the noise occurs very close to dwellings and public places.

8.4 Derived Policy Suggestions

Having observed the growth of CO_2 and other emissions, and having analyzed the reasons for modal shifts in previous chapters, I make the following propositions regarding U.S. transportation regulation:

(1) Concentrate regulatory measures on truck and air transportation: Truck and air are not only the fastest-growing transport modes, according to my projections, but they are also the most energy- and carbon-intensive ways to ship commodities. Any serious attempt of the United States to reduce greenhouse gas emissions must emphasize regulations of truck transportation. This mode accounts for about 84% of all U.S. freight transport related CO_2 emissions, and its share is projected to increase. For intercity shipments, rail transportation is a feasible alternative. The shift of long-distance shipments from truck to rail would also reduce the damage of U.S. highways caused by heavy trucks. It may be difficult, however, to reduce the even more energy-intensive local truck shipments because the last mile of a delivery is in most cases only possible by trucks. Nevertheless, the need for local shipments can be reduced by fostering the construction of railroad tracks that directly connect origin and destination areas from which many shipments result. U.S. transportation regulation must give special consideration to air freight transport, because this mode is projected to grow rapidly and because the impacts of aviation gases in the upper troposphere by far exceed the implications of ground emissions.

(2) Promote more energy-efficient modes like water, rail, and pipeline transportation: My model projects that the importance of energy-efficient transport modes will decrease over the next 20 years. This trend must be reversed in order to lower greenhouse gas emissions, acid rain, ozone levels, and noise nuisance. Ways to induce modal shifts toward water, pipeline, and rail transportation are to invest in a better infrastructure of those modes or to increase the relative price of the other modes (i.e., truck and air). However, it may be difficult to induce such shifts because supply chain management

and just-in-time inventories require fast and flexible transport modes.

(3) Try to avoid shifts towards faster modes if goods become more valuable: I have shown (e.g., in Figure 5.2) that an increase in average commodity value leads to a shift in the choice of transport modes away from water and rail to truck and air. This has its reason, among others, in the fact that the transportation margin of the commodity cost becomes less important if the overall value rises. Such a trend can be mitigated by increasing the cost of truck and air transportation (e.g., through fuel taxes that are very low in the United States). Since the slower modes are more energy efficient, they would not be hurt as much as the faster modes by increasing fuel costs, so that a modal shift (as proposed under (2)) might be generated.

9 Data Methodology

9.1 Sector Definition

9.1.1 Commodity Flow Survey Sector Classification

In order to link the economic part of the model with the transportation part (i.e., in order to transform values into quantities), identical sectors need to be defined for both parts. I use the Commodity Flow Survey (CFS) from 1997 to define the sectors and to assign each of the 41 sectors from the CFS to one of the six transportation-commodity sectors of my model.[59] The intention behind this classification is to reach intra-sector homogeneity and inter-sector differentiation of commodities (i.e., the commodities within a sector are similar in their generation of transportation demand, but they differ significantly from commodities in other sectors). Besides the six transportation sectors, there are three service sectors the classification of which I discuss later. Table 9.1 shows the model sector classification.

Model Sector Definition		Value per Ton (in 1996 $) *	Average Distance (in miles)
1	Agricultural and Food Products	734.8	360.6
2	Mining, Minerals, Sands, Stone, Waste	29.9	81.5
3	Coal, Petroleum, Fuels **	142.9	398.6
4	Low-Value Intermediate and Final Products	529.1	269.2
5	Medium-Value Intermediate and Final Products	3,998.7	414.2
6	High-Value Intermediate and Final Products	11,302.7	518.0
7	Non-Trp Small Growth (g < 1.5% / yr)	Non-Transportable Commodities (Services)	
8	Non-Trp Medium Growth (1.5% ≤ g < 4% / yr)		
9	Non-Trp High Growth (g ≥ 4% / yr)		

Source: Author. 1993 and 1997 CFS Data and ENO 2001 for Crude Petroleum and Pipeline Shipments.
Non-Trp = Non-Transportable Output Sectors; g = average annual growth of output 1972 - 1998.
* Weighted average of 1993 and 1997 CFS.
** Includes crude petroleum figures from ENO 2000 in the calculation of average distance.

Table 9.1 Model Sector Definition and Sector Characteristics

It is a straightforward process to assign the CFS sectors to the model sectors 1, 2, and 3. However, the classification of the remaining CFS sectors is more complicated. It is not obvious from some CFS sector description which goods fall into which sector. For exam-

[59] A detailed listing of all 41 sectors in the 1997 CFS can be found in Appendix A.

ple, the sector "Wood Products" could refer to a variety of very simple or high-value products. In order to achieve a matching sector classification, I split products that do not match the model sectors 1-3 into low- medium- and high-value products (model sectors 4-6). This classification is based upon the products' value per ton and, for verification, on the average distance the product is shipped. As the data in Table 9.1 show, the average distance of shipments increases with the value of the commodity. Sector 4 comprises low-value intermediate and final products with a value between $100 and $1400 per ton. Medium-value goods in sector 5 are intermediate and final products with a value between $2000 and $8500 per ton. Commodities assigned to sector 6 are high-value manufacturing products with a value above $8500 per ton. More detailed figures for average distance of shipment and value of commodities are shown in Appendix A.

9.1.2 Input-Output Sector Classification

About half of all sectors in the I-O table represent transportable commodities whereas the other half denotes non-transportable commodities, i.e., services. I classify all transportable commodities in the I-O table according to the best-matching transportation sector in my model (i.e., sectors 1-6). For example, I-O sectors 43-50 comprise various types of machinery. In the CFS, there is only one sector for machinery (CFS sector 34), and in my model specification, machinery falls into the medium-value sector. This example illustrates that I-O data are the most detailed source, followed by CFS figures. I cannot make use of this detailed information because the commodity-flow survey classification varies drastically between the 1970's and 1990's. The only reasonable way to use the CFS data is to define less detailed sectors.

After the transportable commodities have been identified and categorized, I need to classify the service sectors. Of course, it would be possible to work with one huge service sector in the economic forecast. Although this procedure would save some time in the calculations, it would waste valuable information embedded in the I-O tables. The economic projection is more accurate if the service sector is looked at in more detail. I do that by splitting the I-O service sectors into three growth categories: I categorize services according to the average annual growth of their total output (in constant 1996 dollars) between 1972 and 1997.

Sectors growing by less than 1.5% annually are termed small growth sectors. All services growing faster than 4% annual average fall into the fast-growing category, and all sectors between those growth rates are classified as medium-growth services.

Lastly, final demand sectors need to be summarized. In the 1997 I-O classification, there are 11 final demand sectors. I aggregate those sectors in the four sectors Personal Consumption (1), Government Investment and Consumption[60] (2), Exports (3), and Imports (4). The classification of I-O sectors is shown in Appendix A.III.

9.2 Implicit Price Deflators

Gross output represents the market value of an industry's production, including commodity taxes, and it differs from GDP by industry, which represents an industry's contribution to GDP. For the purpose of this study, it is important to work with constant-dollar gross output figures to correct for inflation (or deflation) in the prices of commodities. The BEA provides current-dollar and fixed-weight constant-dollar gross output estimates that are obtained from its benchmark input-output accounts. In the BEA data files, constant-dollar series for detailed industries are in millions of 1987 dollars for 1977-87, and in millions of 1996 dollars for 1987-99. Fixed-weight implicit price deflators (IPDs) are index numbers, with 1987=100.00 for 1977-87 and 1996=100.00 for 1987-99.[61]

In the gross output worksheets, BEA uses an industry classification different from the 1997 SIC basis used in I-O tables. BEA's gross output classification is more detailed, making it necessary to calculate average price deflators from several sub-sectors for the less detailed I-O classification.[62] From this adjustment I obtain gross output price deflators for each sector as classified in the I-O tables. The next step is an adjustment of the 1977-87 deflators

[60] I include all investments (private and government) in sector 2. This method provides the possibility to analyze the effects of changes in personal consumption separately.

[61] At the deflation-level of detail for which BEA provides these IPDs, chain-type IPDs are equivalent to fixed-weight IPDs.

[62] BEA does not provide price deflators in a format compatible with I-O tables, as I learnt from an inquiry with BEA staff. Consequently, if one wants to work with constant rather than current dollar figures, the best possible approach is to compute I-O compatible price deflators from BEA's gross output figures.

from 1987 as the base year to 1996 as the base year (1996=100.00). The last step is an extrapolation of the deflators back to 1972 using average price growth rates for the years 1977-1985. This procedure is necessary to allow the inclusion of 1972 I-O tables in my study.

Gross Output Implicit Price Deflators for each commodity i in year y with y_{base} as reference year work according to equation (9.1):

$$(9.1) \qquad Deflator_i^y(y_{base}) = \frac{P_i^y}{P_i^{y_{base}}}$$

where P_i^y is the current price of good i in year y and $P_i^{y_{base}}$ is the price of good i in the base- or reference year $y_{base.}$ Recall from Chapter 4.1.1 that m_{ij} is the value of commodity i consumed in the production process of the intermediate sector j and f_{ik} is the value of commodity i consumed by the final demand sector k. Re-arranging equation (9.1) and using 1996 as a reference year, I obtain the constant (1996) values of m_{ij} for according to:

$$(9.2) \qquad m_{ij}^y(1996) = \frac{P_i^{1996}}{P_i^y} \times m_{ij}^y = \frac{1}{Deflator_i^y(1996)} \times m_{ij}^y$$

where $m_{ij}^y(1996)$ the value of commodity i consumed by intermediate sector j in year y, given in constant 1996 dollars. A similar procedure is used for the final demand figures:

$$(9.3) \qquad f_{ij}^y(1996) = \frac{1}{Deflator_i^y(1996)} \times f_{ij}^y$$

where ${}_{ij}^{y}(1996)$ the value of commodity i consumed by the final demand sector k in year y, given in constant 1996 dollars. This procedure is applied to all available I-O tables between 1972 and 1998.

One problem that I encountered with price deflators is that they do not adequately correct for the huge oil price increases in the late 1970's and early 1980's. This distorts the share of sector 3 (the energy sector) in the 1977, 1982, and 1987 I-O tables, one can see that in almost all figures depicting the shares in final demand or total output. However, in the regression of sector 3's shares, I was successful in correcting for the insufficient price deflators by using the Cochrane-Orcutt procedure for autocorrelation (as described in Chapter 9.3.2).

9.3 Projection of Input-Output Coefficients

9.3.1 Specification of Functional Forms

In the regression of I-O multipliers I allow for the following functional forms: constant, linear, logarithmic, and exponential. The nonlinear functions (logarithmic and exponential) can be transformed into linear functions so that ordinary least square (OLS) estimation procedures can be applied. For the logarithmic form

$$y = a + b \ln x + \varepsilon ,$$

a linear function

$$y = a + bz + \varepsilon$$

can be created by structuring a new independent variable z whose observations are the natural logarithm of the observations on x . In this case, only the independent variable needs to be transformed. The dependent variable y can be regressed on the independent variable z using OLS estimation. The OLS estimator has its classical linear regression (CLR) model properties, the R^2 statistic retains its traditional properties and the standard hypothesis tests are valid. [Kennedy 1998, p. 97]. For the exponential form,

$$y = a \exp(bx) \varepsilon$$

the entire equation must be transformed to yield the linear function

$$\ln y = \ln a + bx + \ln \varepsilon$$

or

$$y^* = a^* + bx + \varepsilon^* ,$$

a linear function in the transformed variable y^* and x . Econometricians usually assume that this new relationship meets the CLR model assumptions. Consequently, the OLS estimates from a regression using these transformed variables have their traditional desirable properties [Kennedy 1998].

There are several econometric approaches to discover a tenable model specification, for example a method called "testing down." In this method, the initial specification is made more general (i.e., many explanatory variables are included) than the researcher expects the specification ultimately chosen to be. Various restrictions are then applied and tested, for example setting sets of coefficients equal to zero and conducting a F-test. The model is continually respecified until a number of diagnostic tests allows the researcher to conclude that the model is satisfactory. However, in my analysis of the behavior of direct requirements and shares in GDP over time, only time and GDP are relevant regressors. Although changes in the A matrix and in the composition of GDP are subject to complex economic and social mechanisms, a comprehensive analysis of the drivers in this process would go far beyond the scope of this study. Consequently, I follow a simple approach and use time as explanatory variable in the projection of direct requirements and per-capita-GDP in the projection of GDP shares.[63] I would like to emphasize again that the purpose of this paper is not a perfect forecast of the U.S. economy for the next 20 years. Rather, I hold that it is necessary to allow multipliers to change over time if historical data suggest so. The best I can do to handle those changes is to project multipliers according to the simple time- and GDP-trend analysis presented here. Feldstein (1982, p.829) makes an interesting remark about model specification:

> *In practice all econometric specifications are necessarily 'false' models... The applied econometrician, like the theorist, soon discovers from experience that a useful model is not one that is 'true' or 'realistic' but one that is parsimonious, plausible and informative.*

Since I only work with one explanatory variable, parameter specification tests are irrelevant. However, as said above, I allow for different functional forms. It is therefore neces-

[63] See below for a detailed discussion of why time is used rather than GDP in the projection of direct requirements.

sary to find the most reasonable among the four functional forms for the regression of each multiplier (direct requirement or GDP share). For the specification of the functional form, I use the following criteria:

- t-statistics. A two-tailed t-test is used with a 10% significance level.[64] If the null-hypothesis of zero slope cannot be rejected at the 10% significance level, I assume that the independent variable (i.e. the multiplier) is a constant.

- R^2-statistics. A meaningful interpretation of the R^2 statistic is valid only under the conditions that (1) the estimator in question is the OLS estimator, (2) the estimated relationship is linear,[65] and (3) the linear relationship being estimated must include a constant (intercept) term [Kennedy 1998, p. 27]. These three conditions are fulfilled by the (transformed) functional forms that I use in the regression of direct requirements on time and in the regression of GDP shares on per-capita-GDP.

For each regression, I try the functional forms (1) linear, (2) logarithmic, and (3) exponential as explained above and compare R^2 and t-statistics. Simultaneously, I analyze whether the "best" functional form makes sense from an economic point of view. For example, it would not be reasonable to assume that the personal consumption of a commodity classified as "Service, small growth" increases exponentially. Supplementary to this 'intuitive' test, I compare the regression of each multiplier with the regression of the corresponding row scalar. I am grateful to Anne Carter for this hint:[66]

> *In earlier years, we observed that coefficients tended to move in the same direction across each row of the input output table, i.e., all industries (including final demand sectors) tended to use more plastic, less steel over time. With this rationale, we computed "rowscalers", essentially time trends in the (weighted) average of all coefficients across each row.*

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[64] The relevant t-values are 1.943 and –1.943 for a t-distribution with 6 degrees of freedom. Degrees of freedom are 6 due to the formula df=N-2 for a regression with N observations, one regressor and an intercept term.

[65] Thus, the R^2 statistic only gives the percentage of the variation in the dependent variable explained *linearly* by variation in the independent variable.

[66] Anne Carter in an email conversation with the author in January 2002. Professor Anne Carter from Brandeis University has extensive experience in projecting technical coefficients [Carter 1970]

As explained in equations (4.7) and (4.9), the sum of commodity shares in each sector j must be 1. I use this fact in my regressions in the following way: The variable with the lowest t-statistics and R^2 in the regressions (i') of sector j is used as a resulting figure from all other variables according to the equations:

$$(9.4) \qquad a_{i''j}^{y} = 1 - \sum_{\substack{i=1 \\ i \neq i'}}^{I} a_{ij}^{y}, \forall j \in J, \forall y,$$

for elements of the A-matrix a_{ij}^{y} (intermediate demand), and

$$(9.5) \qquad s_{i''k}^{y} = 1 - \sum_{\substack{i=1 \\ i \neq i'}}^{I} s_{ik}^{y}, \forall k \in K, \forall y,$$

for all elements s_{ik}^{y} in final demand. This method has two advantages, (1) it makes sure that equations (4.7) and (4.9) are fulfilled and (2) it allows the verification of all other variable regressions – if the resulting projection of the share $a_{i'j}^{y}$ (or $s_{i'k}^{y}$) contradicts reasonable economic expectations, the regressions of all other variables ($a_{ij}^{y}, i \neq i'$ and $s_{ik}^{y}, i \neq i'$) are probably not realistic and must be altered. For example, if the resulting variable $a_{i'j}^{y}$ is the share of high-growth services in personal consumption, it is expected to increase over time. I also use medium-growth services in some cases as the resulting variable. In this case, I consider it a reasonable result if the corresponding share increases slightly until about 2010 and then stagnates or slowly decreases. Examples for this procedure can be seen in Appendix B.

After having found a tenable functional form, it is still essential to correct for serial correlation when working with time-series data.

9.3.2 Correction for Serial Correlation

The assumption of the OLS model that errors corresponding to different observations are uncorrelated often breaks down in time-series studies. When the error terms from adjacent time periods are correlated, econometrists speak of serial correlation. This phenomenon occurs in time-series studies when the errors associated with observations in a given time period carry over into future time periods. For example, when a model overestimates the personal consumption of agricultural goods in year y, it is likely to yield an overestimate in year $y+1$, too.

In this study, I concern myself exclusively with positive serial correlation (i.e., errors in one period are positively correlated with errors in the following period). Positive serial correlation frequently occurs in time-series studies because of the high degree of correlation over time present in the cumulative effects of omitted variables [Pindyck 1991, p.138]. In the simplified model I use, there are certainly omitted variables that would explain short-term fluctuations in multipliers so that it is indispensable to test and correct for serial correlation.

To test for first-order serial correlation,[67] I use the Durbin-Watson test (see, for example, Pindyck 1991 or Greene, 2000). The Durbin-Watson method tests the null-hypothesis that no serial correlation is present. The calculation of the Durbin-Watson statistic (DW) is based on the residuals from the OLS regression procedure. Two limits are given for the DW statistic, usually labeled d_l and d_u. A value for DW below d_l allows one to reject the null hypothesis of no serial correlation. If DW is greater than d_u, the null hypothesis is retained. The range between d_l and d_u leaves the analyst with inconclusive results. Since positive serial correlation is very likely in the I-O data set (combined with the fact that there is only one explanatory variable), I correct for serial correlation whenever I cannot reject the null hypothesis of no serial correlation (i.e., whenever DW is smaller than d_u). The sample size of I-O multipliers is very small (N=8) because relevant I-O tables are only available for eight years. Fortunately, Savin and White (1977) provide a table with the DW

[67] In first-order serial correlation, errors in one time period are correlated directly with errors in the ensuing time period.

statistic for extreme sample sizes.[68]

To correct for serial correlation, I use the Cochrane-Orcutt procedure, which is described in detail by Pindyck and Rubinfeld (1991, p. 141). Regression parameters and statistics are shown in detail in Appendix A.

9.3.3 Projection of Direct Requirements (A-Matrix)

The A matrix is used to project commodity output, which is then related to transportation demand. Since the structure of the economy changes and since my projection goes until 2020, it is reasonable to work with a dynamic model (i.e. the A matrix changes) rather than with a static A matrix from the last available year (i.e. 1998).

An important issue in projecting the A matrix is the choice of explanatory variables. Changes in direct requirements have their origin in price and substitution effects and in technological change. However, taking care of all those parameters would go far beyond the scope of this study in that it would require separate forecasts based on surveys of manufacturers and technology outlooks. Alternatively, GDP is a regressor in question. But there is no clear scientific foundation for a relation between GDP and direct requirements, as I learned from Anne Carter. She advocated the use of time as an explanatory variable:[69]

> *While we all agree that "time" is a poor excuse for an explanatory variable, I think time is preferable to GDP in this case... The beauty of sticking with time as your explanatory variable is that it's straightforward and doesn't assume that we know more than we do know about the change mechanism. I certainly agree that technical change should some day be "endogenous", i.e., explained as an integral part of the economic system. But we're not there yet, and introducing GDP [...] may be a misleading short cut.*

Having this in mind, I found that most elements in the A matrix increase or decrease linearly, exponentially, or logarithmically over time. I perform regressions for each element in the 9x9 A matrix on time and correct for autocorrelation. If t-statistics are low I use constants so that the respective multiplier does not change over time. I apply equation (9.4) as

[68] The relevant DW-values are d_l=0.763 and d_u=1.332 for N=8 and k=1 at a 5% level of significance, where k is the number of regressors excluding the intercept.
[69] Professor Anne Carter in an email conversation with the author in January 2002.

explained in Chapter 9.3.1. The output of a_{ij}^{y} regressions is shown in Appendix B.

9.3.4 Projection of Per-Capita-GDP

Gross domestic product data for the United States are available from various sources. A widely used source is the International Monetary Fund (IMF) data series. Comparing those figures with the numbers derived from I-O tables, I found only insignificant differences. From the I-O tables that I use, GDP figures can only be derived for 8 years whereas GDP numbers from IMF are available for 1950 until 1998. Consequently, my projection of per-capita GDP is based upon IMF figures. The regression clearly indicates positive serial correlation, which is corrected using the Cochrane-Orcutt procedure. Figure 9.1 shows the I-O and IMF data and the derived projection for the business-as-usual (BAU) scenario. The annual real GDP growth rate in the BAU scenario is 2.247%.

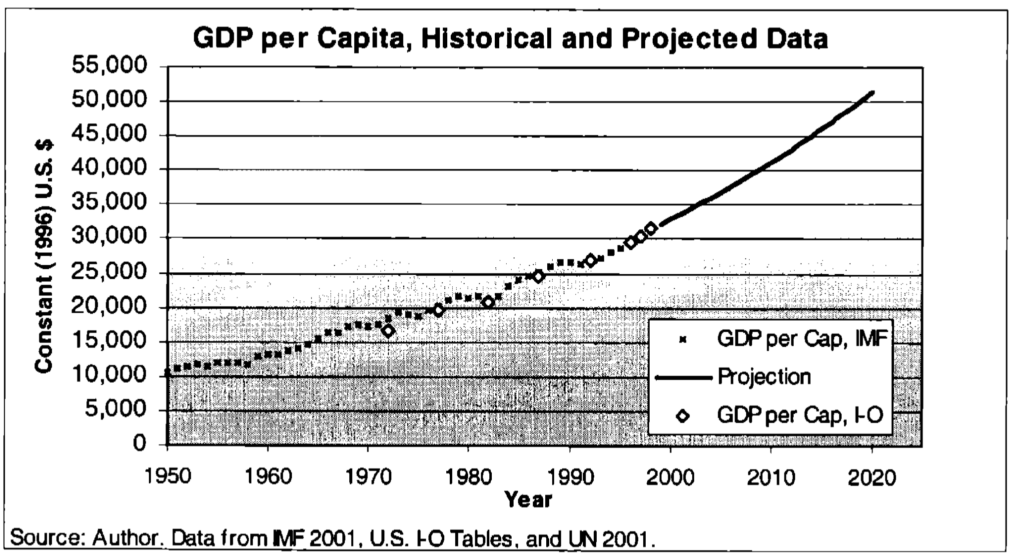

Figure 9.1 The Projection of Per-Capita-GDP

9.3.5 Projection of Shares in GDP

In the projection of the composition of final demand, I use per-capita-GDP as the explanatory variable. The use of per-capita-GDP rather than time has two reasons. First, GDP per capita is a measure for the wealth of a nation. The way in which people and government spend their money depends decisively on their budget. Second, future studies may want to analyze different growth scenarios. In order to reflect the influence of economic growth on the way in which people spend their income in each scenario, GDP shares must be set in relation to GDP growth. A regression of the GDP shares on per-capita-GDP is one way of doing so.

Except for the regressor, the methodology of GDP share (s_{ik}^{y}) projection is the same as this of a_{ij}^{y} projections. Equation (9.5) is used as explained in Chapter 9.3.1.

9.3.6 Projection of United States Population

A population forecast for the U.S. is available from the United Nations (2001). The forecast provides U.S. population figures in 5-year steps between 2000 and 2030.

9.3.7 Regression Output

The regression output, including statistical tests is summarized in the figures in Appendix A.

9.4 Determination of Transportation Variables

In the following, I refer to the notation introduced in Chapter 4.2.3.

9.4.1 Deriving Commodity Weight from CFS Data

The CFS sub-divides transportation modes into single modes and multiple modes. In the model I only use the information on single mode shipments, as shown in Table 9.2. Thus, the total tons of transportation ($ton_{t,i}^{y}$) used in the model do not include shipments by multiple and unknown modes. As Table 9.2 shows, multiple and unknown modes only make up a small share in all shipments, accounting for 2% and 3.9%, respectively. "other and unknown modes" data cannot be included in the model because they cannot be assigned to any mode. "Multiple modes", on the other hand, could be built in, but including those modes would make the model more complicated while not adding essential information. To derive environmental implications from the model, multiple modes are not useful because it is hard to assign energy consumption values. For example, it is not possible to derive energy consumption data from the information "1 million ton-miles of shipment by truck and water" because the share of each mode in this shipment is unclear.

Modes	Model Coverage	CFS Coverage	% in Total
Truck	x	x	69.4%
For-hire truck		x	
Private truck		x	
Rail	x	x	14.0%
Water	x	x	5.1%
Shallow draft		x	
Great Lakes		x	
Deep draft		x	
Air (includes truck and air)	x	x	0.0%
Pipeline	x	x	5.6%
SUB-TOTAL	ton t		
Multiple modes		x	2.0%
Parcel, US Postal Service or courier		x	
Truck and rail		x	
Truck and water		x	
Rail and water		x	
Other multiple modes		x	
Other and unknown modes		x	3.9%
TOTAL		ton* t	100.0%

Source: Author. Percentage in Total from 1997 CFS.

Table 9.2 CFS and Model Coverage of Transport Modes

In Table 9.2 I introduce a new notation: $ton\ *_t^y$ stands for total tons shipped by all modes, including multiple modes, in year y.[70] Consequently, $ton\ *_{t,i}$ denotes the shipment of commodity i by all modes, including multiple and unknown modes, in year y. This notation helps in analyzing the difference that results from excluding multiple and unknown modes in the model. Table 9.3 shows the difference between $ton_{t,i}$ (for single modes) and $ton\ *_{t,i}$. Note that the model coverage could not be increased significantly if multiple modes were included because "Other and unknown modes" are responsible for most of the difference between model and CFS data.

[70] Remember that the index t denotes 'tons transported' as opposed to 'tons produced'.

Total Tons (millions), Sum of 1993 and 1997	ton t,I	ton* t,I	Model Coverage*
Agricultural and Food Products	2,849	3,084	92.4%
Mining, Minerals, Sands, Stone, Waste	5,539	5,984	92.6%
Coal, Petroleum, Fuels	5,463	6,152	88.8%
Low-Value Intermediate and Final Products	4,139	4,347	95.2%
Medium-Value Intermediate and Final Products	883	955	92.4%
High-Value Manufacturing Products	239	283	84.3%
Source: Author. Data from 1993 and 1997 CFS * Share of tont,i in ton*t,i.			

Table 9.3 Comparison of Tons by Commodity used in the Model and CFS Data

9.4.2 A More Comprehensive Measure of the Transportation Intensity

The total tons of shipments, including multiple and "other and unknown modes", can be used to calculate a more comprehensive transportation intensity, $t*_i^y$:

$$(9.6) \qquad t*_i^y \equiv \frac{ton*_{t,i}^y}{ton_{p,i}^y}, \; t*_i^y \in [0,\infty) \;\; \forall i \in [1,...,6], \forall y .$$

Recall from equation (4.21) that $ton_{p,i}^y$ denotes tons of commodity i produced in year y. Since $ton*_{t,i}^y \geq ton_{t,i}^y$, we have $t*_i^y \geq t_i^y$. The altered transportation intensity is a bettered measure for the complexity of the shipment process of commodity i (which was explained in Chapter 4.2.3 and Chapter 5.2.5). Equation (9.6) can be rearranged using equation (4.21):

$$(9.7) \qquad t*_i^y = \frac{\dfrac{ton*_{t,i}^y}{ton_{t,i}^y} \times ton_{t,i}^y}{ton_{p,i}^y} = \frac{ton_{t,i}^y}{ton_{p,i}^y} \times \frac{ton*_{t,i}^y}{ton_{t,i}^y} = t_i^y \times \frac{ton*_{t,i}^y}{ton_{t,i}^y},$$

where $\dfrac{ton*_{t,i}^y}{ton_{t,i}^y}$ can be obtained from Table 9.3 and t_i^y has been calculated in Chapter 4.2.3. The corresponding computation yields the numbers shown in Table 9.4.

Transportation Intensity - Comparison of Methods		Average 1993-97	
(no unit)		t_I	t_I*
1	Agricultural and Food Products	1.26	1.37
2	Mining, Minerals, Sands, Stone, Waste	2.54	2.74
3	Coal, Petroleum, Fuels	1.29	1.45
4	Low-Value Intermediate and Final Products	1.26	1.32
5	Medium-Value Intermediate and Final Products	1.41	1.53
6	High-Value Intermediate and Final Products	1.00	1.18

Source: Author. Compounded data from the 1993 and 97 Commodity Flow Survey.

Table 9.4 Transportation Intensities, Computation Results of two Methods

9.4.3 Commodity Value

Data for commodity weight ($ton^{y}_{t,i}$) are obtained from the 1993 and 1997 CFS as described in the previous chapter. Since there is no clear trend in the development of commodity value between those years, I treat figures from both surveys as if they were from the same sample. This method allows the correction for errors and altered sectoral detail in the CFS. In addition to data from the 1993 and 1997 CFS, I supplement data on energy transportation (sector 3) by ENO 2000 data for crude oil shipment.[71] This adjustment is necessary because the CFS does not include crude petroleum shipments. I obtained the per-ton-values of produced commodities ($TC^{y}_{p,i}$) are obtained from 1993 and 1997 I-O figures. Since there is no I-O table for the year 1993, I linearly interpolate figures from the 1992 and 1996 I-O tables.

Having obtained $ton^{y}_{t,i}$ and $TC^{y}_{p,i}$ for 1993 and 1997, I add the data from both years and insert them into equation (4.24) to obtain the multiplier V^{y}_{i}, which I use to transform monetary values from I-O projections into physical transportation (ton) figures. The result of the V^{y}_{i} computation is shown in Table 4.4.

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[71] For crude oil shipments, only ton-mile data are available in ENO 2001. Ton data are aggregate figures for Crude & Products. To obtain disaggregate ton numbers for crude oil, I calculate the share of crude oil ton-miles in the ton-miles of Crude & Products for each mode. I then multiply those shares with the aggregate ton figures for Crude & Products to obtain disaggregate numbers for crude petroleum shipments. This approach is an approximation, assuming that the average shipment distance of crude petroleum and petroleum products is similar.

9.4.4 Shares in Transportation Modes

Shares in transportation modes b_{im}^{y} are calculated based on ton figures according to equation (4.27). Ton figures are obtained from 1993 and 1997 CFS numbers and from ENO 2000 figures for crude petroleum shipments according to the methodology outlined in the previous chapter. The results of the transportation-share computation are shown in Appendix C.

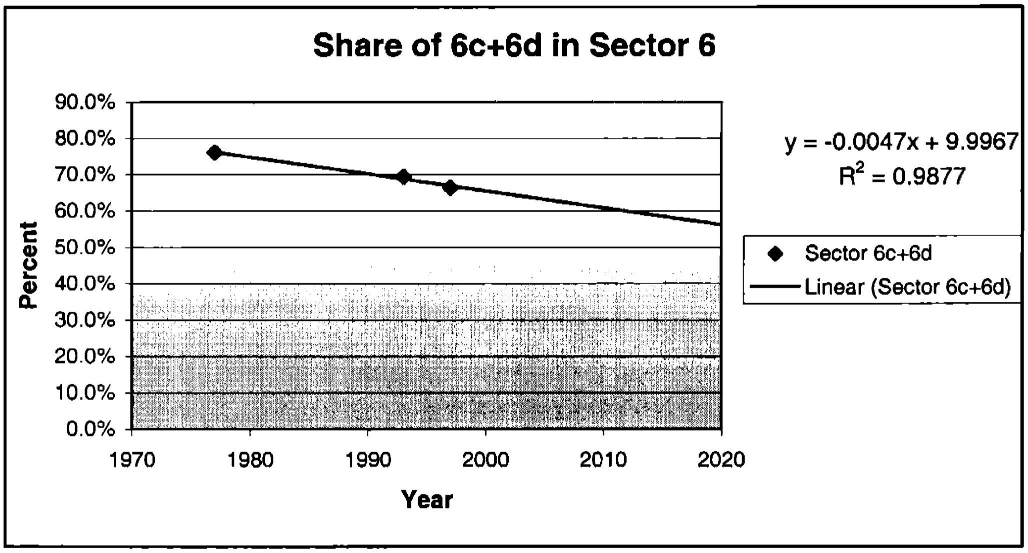
9.4.5 Average Distance of Shipment

The notation used in the following was introduced in Chapter 4.2.5. The computation of average distance of shipment d_{im}^{y} of commodity i by mode m is based on equation (4.28). The values for $ton_{i,im}^{y}$ are obtained as the sum of 1993 and 1997 CFS figures, supported by ENO 2000 data (similar to the method described in Chapter 9.4.3). Ton-miles figures are obtained from the same sources in the same manner. For pipeline transportation, CFS does not provide average distance figures. I thus use the figures provided by ENO 2000 for crude & products for all 6 sectors in 1993 and 1997. The underlying assumption is that pipeline shipments are similar in average distance across all modes. But even if this assumption were not justified, the effect on the model would be minor because practically all pipeline shipments are accounted for in sector 3, whose average distance is given by ENO data. The results of average distance calculations are shown in Appendix C.II.

9.4.6 Detailed Projection of Sector 6 Commodity Values

The following explanations refer to Chapter 5.2.2 in which I project the shares of goods within model sector 6 (high-value products). Figure 9.2 shows the projection of the share of transportation related goods (6c+6d) in sector 6. The resulting (linear) regression yields a share of 50.3% in 2020. From this share, I subtract the share of sector 6d, which I assume to remain constant at 3.5%, as no better data are available. This calculation gives 46.8% as the projected share of sector 6c within commodity class 6, which I use in my calculation in Chapter 5.2.2.

Sector 6c+6d (Transportation - Related Goods)	1977	1993	1997
Share in Total Sector 6 Weight	76.1%	69.3%	66.4%



Source: Author. Data from 1977, 1993, and 1997 CFS .

Figure 9.2 Detailed Analysis of Shares in the High-Value Products Sector

Using the projected share of 46.8% for sector 6c in the calculations depicted in Figure 5.1 in Chapter 5.2.2 yields a projection of total weight for sector 6c and total sector 6 in 2020. I use those ton-numbers in the projection of modal shares in sector 6. The computation method is shown in Table 9.5. First, I analyze the modal shares for each detailed good 6a-6f in sector 6. I then use the same method already applied in the projection of commodity value and split sector 6 into two sub-sectors (6c and "All other sector 6"), for which I have previously projected the commodity weight. Using the ton-projections for 2020, and assuming constant modal shares within the two sub-sectors of sector 6, I compute the modal shares of sector 6 (as a whole) in 2020 as shown in Table 9.5.

Sector 6 Modal Shares In Detail,1997		Weight (1000 Tons)	Modal Shares In Weight of Commodity					
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total
6a	Pharmaceutical products	9,897	99.2%	0.0%	0.0%	0.8%	0.0%	100.0%
6b	Electronic and other electrical (office) equipment	39,612	97.0%	1.1%	0.0%	1.8%	0.0%	100.0%
6c	Motorized and other vehicles (including parts)	98,074	82.7%	16.9%	0.0%	0.4%	0.0%	100.0%
6d	Transportation equipment, n.e.c.	5,477	63.0%	35.4%	0.0%	1.6%	0.0%	100.0%
6f	Precision instruments and apparatus	2,939	93.7%	0.0%	0.0%	6.3%	0.0%	100.0%
Total Tons		**155,999**	**135,554**	**18,913**	**15**	**1,516**	**-**	155,999
Sector 6 Modal Shares, aggregated, 1997		**Weight (1000 Tons)**	**Modal Shares In Weight of Commodity**					
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total
6c	Motorized and other vehicles (including parts)	98,074	82.7%	16.9%	0.0%	0.4%	0.0%	100.0%
	All other sector 6	57,925	94.0%	4.1%	0.0%	1.9%	0.0%	100.0%
Total Sector 6 (Tons and %)		**155,999**	**86.9%**	**12.1%**	**0.0%**	**1.0%**	**0.0%**	100.0%
...plugging in the values for projected tons in 2020 and assuming the same modal shares as in 1997 for the two aggregate sectors yields:								
Sector 6 Modal Shares, aggregated, 2020		**Weight (1000 Tons)**						
			[illegible]	[illegible]	[illegible]	[illegible]	Pipeline	Total
6c	Motorized and other vehicles (including parts)	250,383	82.7%	16.9%	0.0%	0.4%	0.0%	100.0%
	All other sector 6	284,966	94.0%	4.1%	0.0%	1.9%	0.0%	100.0%
Total Sector 6 (Tons and %)		**535,349**	**88.7%**	**10.1%**	**0.0%**	**1.2%**	**0.0%**	100.0%
Comparison of Modal Shares		**Weight (1000 Tons)**						
			Truck	Rail	Water	Air	Pipeline	Total
6	Total Sector 6, 1997	155,999	86.9%	12.1%	0.0%	1.0%	0.0%	100.0%
6	Total Sector 6, 2020	535,349	88.7%	10.1%	0.0%	1.2%	0.0%	100.0%
Average Annual Growth of Share			**0.09%**	**-0.80%**	**-1.28%**	**0.93%**	N/A	
Source: Author. Data from 1997 CFS and Projections performed by author.								

Table 9.5 Calculation of Modal Shares in the High-Value Products Sector

Having found the modal shares in 2020, I calculate the average annual growth of modal shares between 1997 and 2020, which are then used to compute the shares shown in Table 9.6.

Sector 6 Goods, Projection of Modal Shares, 1993 - 2020						
	Truck	Rail	Water	Air	Pipeline	Total
1993	86.5%	12.5%	0.0%	0.9%	N/A	100.0%
1997	86.9%	12.1%	0.0%	1.0%	N/A	100.0%
2000	87.2%	11.8%	0.0%	1.0%	N/A	100.0%
2005	87.6%	11.4%	0.0%	1.0%	N/A	100.0%
2010	88.0%	10.9%	0.0%	1.1%	N/A	100.0%
2015	88.4%	10.5%	0.0%	1.1%	N/A	100.0%
2020	88.7%	10.1%	0.0%	1.2%	N/A	100.0%
Source: Author. Data from 1997 CFS. Projections performed by author.						

Table 9.6 Projected Shares of Transport Modes in Sector 6

9.5 ENO Data and Commodity Flow Survey Figures

This chapter is meant to supplement Chapter 7.1.1. U.S. transportation data for all modes differ significantly across different sources. The main source I use is the Commodity Flow Survey (CFS). The CFS provides, among other things, the value, tons, and ton-miles of commodities shipped in the United States for about 40 sectors. Another widely used source for tons and ton-miles data is the ENO publication "Transportation in America." However, CFS data for total U.S. ton-miles are significantly lower than ENO data although tons-data in the CFS are higher than ENO figures. Consequently, the average distance of shipments (ton-miles per ton) is much higher in ENO tables. In road transportation, for example, the average distance of shipments in 1997 was 267 miles according to ENO and 133 miles according to CFS figures. This difference may be largely due to the fact that ENO data do not include local shipments. For water transportation, the ENO average distance figure is 694 miles in 1997 as compared to 464 miles in the CFS. In this case, ENO data are probably more accurate because the CFS does not completely cover water shipments. For rail and air transportation, differences are less significant. Figures for pipeline ton-miles are not available from CFS. Table 9.7 shows the data from those sources for 1993 and 1997.

	Tons (millions)			Ton-miles (billions)			Average Distance		
Transportation Mode	CFS	ENO	Difference	CFS	ENO	Difference	CFS	ENO	Difference
1997									
Truck	7,401.3	3732.0	-50%	986.7	996.0	1%	133.3	266.9	100%
Rail	1,542.9	1972.0	28%	1,016.0	1421.0	40%	658.5	720.6	9%
Water	550.9	1017.0	85%	255.7	706.0	176%	464.1	694.2	50%
Air	4.1	12.9	212%	5.6	13.9	146%	1,368.3	1,077.5	-21%
Pipeline	613.1	1108.0	81%	N/A	617.0	N/A	N/A	556.9	N/A
1993									
Truck	6,005.4	3061.0	-49%	831.2	861.0	4%	138.4	281.3	103%
Rail	1,551.9	1805.0	16%	944.4	1183.0	25%	608.5	655.4	8%
Water	425.9	989.0	132%	244.4	788.0	222%	573.8	796.8	39%
Air	2.0	8.7	342%	2.5	11.5	363%	1,267.1	1,326.4	5%
Pipeline	449.0	1082.0	141%	N/A	593.0	N/A	N/A	548.1	N/A
1977									
Truck	1,881.4	2143.0	14%	277.1	555.0	100%	147.3	259.0	76%
Rail	544.9	1467.0	169%	268.7	834.0	210%	493.0	568.5	15%
Water	292.4	886.0	203%	134.4	597.0	344%	459.8	673.8	47%
Air	1.4	3.6	151%	1.4	4.2	197%	983.9	1,161.1	18%
Pipeline	461.5	986.0	114%	69.3	546.0	688%	150.2	553.8	N/A
1972									
Truck	726.4	1934.0	166%	174.8	470.0	169%	240.7	243.0	1%
Rail	460.1	1531.0	233%	265.4	784.0	195%	576.8	512.1	-11%
Water	271.8	895.0	229%	187.0	603.0	222%	688.0	673.7	-2%
Air	0.7	3.3	344%	0.9	3.7	296%	1,255.7	1,121.2	-11%
Pipeline	N/A	876.0	N/A	N/A	476.0	N/A	N/A	543.4	N/A

Source: Author. Data from Commodity Flow Survey and ENO - Transportation in America 2000.

Table 9.7 Comparison of CFS and ENO Transportation Data

The fact that the CFS underestimates the ton-miles figures is explained as follows:[72]

- CFS data do not cover imports that originate outside the United States. For example, if a commodity is shipped from Montreal/Canada to Philadelphia and then from Philadelphia to Florida, only the second trip will be accounted for by CFS figures.[73] ENO data, on the other hand, rely on various sources like the Railroads Facts Book, Highway Statistics or Air Traffic statistics, thus providing a more comprehensive coverage of U.S. transport.

- Crude petroleum shipments are not included in the CFS

- Agriculture shipments originating from farms are not covered by the CFS. For example, corn harvested at a farm in Illinois and then brought to a depot in Iowa is not accounted for in the CFS. But if corn is shipped from the depot to a grain mill this trip will be picked up by the CFS.

- Shipments made by retailers are not included in the CFS. Although shipments from warehouses to retailers are covered, shipments among retailers or from retailers to customers are not accounted for. For example, the shipment of pizza dough to Tony's headquarters in Massachusetts is included in CFS data but the passing on of the dough to the single restaurants and the pizza delivery are not covered.

- Water shipments are incompletely covered by CFS data.

9.6 Energy Intensities of Freight Modes

9.6.1 Trucks

Energy intensities (per ton-mile) for trucks vary with the shipment size. Large trucks are, in general, more energy-efficient than small trucks, as Figure 9.3 visualizes.

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[72] Phone call with Mr. John L. Fowler from the U.S. Census Bureau on October 23rd 2001.

[73] One the other hand, the CFS does a good job in covering exports. The transportation of exported goods is traced to the U.S. border or to the nearest international airport.

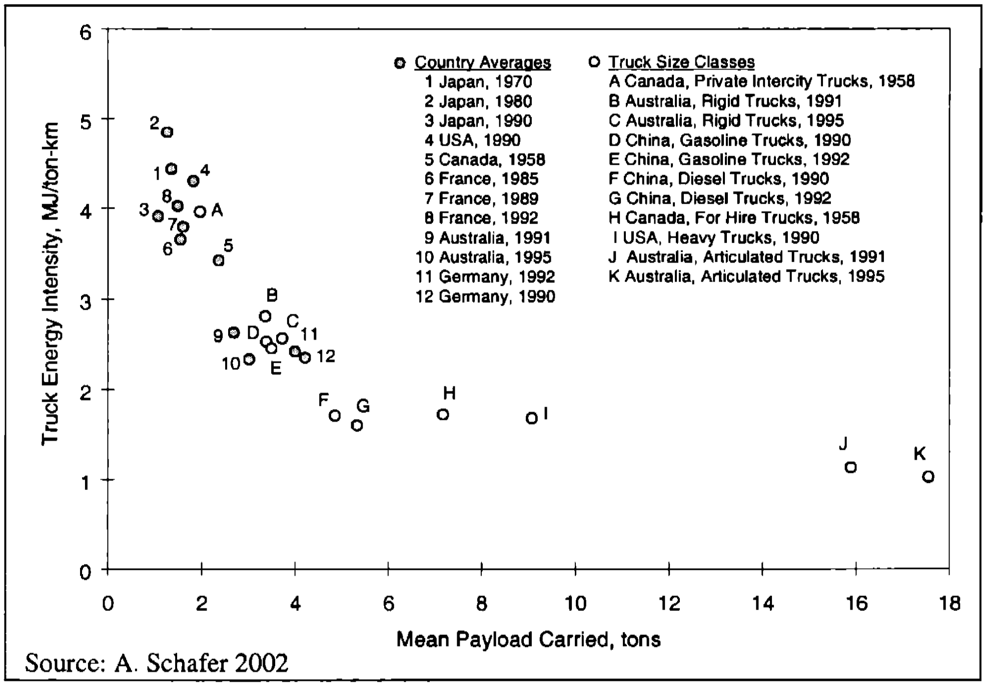

Figure 9.3 Truck Energy Intensity as a Function of Mean Carried Payload

Figure 9.3 shows that it is necessary to find a (weighted) average energy intensity of all U.S. truck shipments, in order to compute truck energy consumption from ton-miles data. For this calculation, I use ton-miles figures and energy intensities for intercity shipments and local shipments. I obtain the data for intercity shipments from ENO 2000 and I calculate the data for local shipments as follows: (1) The energy intensity for small payload (i.e., local) shipments is about 4.5 MJ/ton-km, according to Figure 9.3 (which translates into about 6800 Btu/ton-mile). (2) ENO 2000 does not provide data on local truck shipments. However, I used data on local truck shipments from BTS 1993 and found a relatively stable trend according to which local truck shipments were about 50% of intercity shipments between 1970 and 1991. I use this ratio to approximate local truck shipments as shown in Table 9.8.

Truck Calculation: (1998 Figures)	Ton-Miles (billions)	Energy Intensity (Btu/ton-mile)	Total Energy Use (trillion Btu)
Intercity Trucks	1,027	2,999	3,080
Local (smaller) Trucks **	514	6,800*	3,492
Total	**1,541**		**6,572**
Average All Freight Trucks (Btu/ton-mile):		**4,266**	

Source: Author. Data from ENO 2000, unless indicated otherwise.
* Information from personal conversation with Andreas Schafer, MIT.
** Ton-miles calculated as 50% of intercity ton-miles. See explanation in the text.

Table 9.8 Derivation of Average Energy Intensity of Truck Shipments

9.6.2 Pipelines

Energy intensities for pipeline shipments are provided by ENO 2000. However, data describing the average annual change in energy intensities are not available for this mode. Consequently, I use a constant for pipeline energy intensities in my calculations.

10 Conclusion

10.1 The Model

Economic performance, commodity output, and freight transportation demand of the United States are closely related, permitting analysts to design freight transport models that connect economic growth with transportation quantities. Several models build transportation-related variables into the economic projection, which makes them very complicated, and use prices of transportation services to transform dollar values into quantities, which makes the projections heavily dependent on fuel and labor prices. I have developed a simpler, more effective, model in which economic projections and transportation parameters are dealt with separately. I have projected the commodity output of the U.S. economy and then assumed that this output needs to be transported from producer to buyer, where the typical pattern by which a certain commodity is shipped does not change dramatically in the near term. This design makes the projections independent of the price of transportation services and, in addition, enables a separate analysis of structural change in the economy and in the freight transportation system.

Input-Output (I-O) tables are a powerful tool for examining structural changes in the economy, especially if the change of I-O multipliers is projected in the course of a dynamic analysis. I have projected GDP, I-O coefficients, and shares in final demand in the economic part of my model, from which I have derived projections of U.S. commodity output. I then defined and computed the variable "transportable output" that includes the value of all goods, in a given commodity class, circulating in the United States in a given year. The Commodity Flow Survey (CFS) provides information on shipment characteristics of transportable output. I have aggregated CFS and I-O sectors into six commodity classes ("model sectors"), and have derived transportation patterns (i.e., commodity value per ton, modal shares, and average distance) for those sectors. Besides these conventional variables, I have introduced the parameter "transportation intensity," which is a measure of how complex the typical transportation process of a commodity is, i.e., how many transportation modes or stops at warehouses are involved during the shipment from origin to destination. I then used the derived variables to compute transportation quantities from the economic projections. In various comparisons of "backwards" projections with historical data on transportable output, tons, and ton-miles, I was able to show that my model replicates the actual figures very well.

10.2 Structural Change and Its Effects on Freight Transport

According to my projections, U.S. real GDP will grow by 2.25% (annual average) over the next 20 years. Together with the projected I-O coefficients, I use those figures to analyze structural change in the U.S. economy. Imports and exports are projected to grow faster than GDP, with imports increasing slightly more, so that the U.S. trade deficit rises. Since international trade creates more freight transportation demand than domestic production and consumption, the growth of imports and exports will lead to a more than proportional increase in shipment activity.

High-value products will, according to my model, increase their share in transportable output from about 32% in 1998 to over 50% in 2020. This dramatic increase occurs because high-value products become more important in final and intermediate consumption due to rising income and structural change. On the other hand, coal and petroleum, agricultural products, low-value products, and medium-value products decline in share, and building materials maintain a relatively constant share in transportable output. Since high-value products are primarily shipped by the fast transport modes, truck and air, the change towards high-value products in the U.S. economy will lead to a shift away from energy-efficient modes (i.e., rail, water, and pipeline) to energy-intensive air and truck transportation.

Besides the intersectoral change in the U.S. economy, I have analyzed intrasector dynamics of 72 commodity sectors and found that within each commodity class (e.g., "Other Agricultural Products"), relatively valuable goods (e.g., fruit and flowers) tend to be transported by truck and air, whereas lower-value products (e.g., corn and wheat) tend to be shipped by rail and water. As a result, intrasector shifts towards truck and air will occur if consumers buy more valuable commodities, which is likely since per-capita GDP is projected to grow from about $33,000 (in constant 1996 dollars) in 2001 to over $50,000 in 2020, giving more purchasing power to the average consumer.

10.3 Ton and Ton-Mile Projections

In absolute terms, all six commodity sectors are projected to grow 1997 and 2020. While GDP will increase by a factor of 2.0, according to my model, total transportable output will grow by 2.46, and total tons and ton-miles will increase by 1.49 and 1.55, respectively. However, the sectors grow at different rates so that their shares, as well as modal shares, in tons and ton-miles, change. Although high-value products account for the largest dollar value in transportable output among the six model sectors, their share in transported commodity weight is the smallest (≈1% in 1997, rising to 2.6% in 2020). Energy-related shipments (e.g., coal, petroleum, and fuel) have the highest share in commodity weight, but their share is projected to decrease from the current 33 to about 28% in 2020. The shares of building materials, low-value products, and agricultural goods remain relatively constant at 26%, 20%, and 15%, respectively. Medium-value products are projected to increase their contribution to shipment weight from the current 5 to over 7%.

Similar shares are projected for ton-miles with two exceptions. First, the share of energy-related goods in ton-miles (46-40%)[74] is higher than the corresponding share in tons due to the relatively long average distance of coal and petroleum shipments. Second, the share of building materials in ton-miles (7.6-7.5%) is lower than their share in tons, because of the short distances of shipments.

The share of truck transport in commodity weight (68-70%) is the highest, followed by rail (15-14%), pipeline (11-9%), water (7-6%), and air (0.03-0.06%). In ton-miles, trucks (31-36%) are projected to take over the leading role from railway (33-32%) in 2005. The shares of water (15-14%) and pipeline (21-18%) in ton-miles decrease, whereas air transportation is projected to increase its share from 0.15 to 0.27% in 2020.

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[74] The first value in parenthesis is the share in 1997 (from CFS), the second is the projected share in 2020.

10.4 Environmental Impacts and Policy Recommendations

My projections show that the average value of all shipments in the United States will increase from the current \$600/ton to over \$900/ton (in constant 1996 dollars) in 2020. This is a clear indication of ongoing dematerialization with respect to freight transportation, meaning that the same economic growth will lead to relatively less commodity weight transported in the future. However, the increasing average value of U.S. commodities is mainly due to the shift towards high-value products, whose shipments have, on average, the largest environmental impact among the six sectors I analyzed.

My model projects U.S. freight transport energy consumption and carbon emissions to grow by a factor of 1.58 between 1997 and 2020, which is one among many facts implying that it will become difficult for the United States to achieve its reduction aim determined in the Kyoto treaty (provided that the United States wants to rejoin the international climate regime in the future). In terms of energy consumption and CO_2 emissions, trucks account for the greatest share (83-86%), followed by water, rail, and pipeline (each below 5%) and air (2.3-3.3%). Since emissions of aircraft occur in the upper troposphere and lower stratosphere (9-13km altitude), their radiative forcing is about two to four times larger compared with emissions on the ground [Lee et al. 2001, p. 176]. Besides the emission of greenhouse gases, the projected increase in freight transportation will also have adverse effects on acid rain, ozone levels, noise nuisance, and road abrasion.

As a consequence of the observed growth in CO_2 and other emissions, and having analyzed the reasons for modal shifts, I make the following propositions regarding U.S. transportation regulation: (1) Concentrate regulatory measures on truck and air transportation. These are not only the fastest-growing transport modes, but they are also the most energy- and carbon-intensive ways to ship commodities. (2) Promote more energy-efficient modes, i.e., water, rail, and pipeline transportation, and, in addition, try to avoid shifts towards faster modes if goods become more valuable. Ways to induce modal shifts toward water, pipeline, and rail transportation are investing in a better infrastructure of those modes or increasing the relative price of the other modes (i.e., truck and air). However, it may be difficult to induce such shifts because supply-chain management and just-in-time inventories require fast and flexible transport modes.

10.5 Future Research and Extensions of the Model

CFS data differ, for some transport modes, significantly from figures provided by other sources (e.g., ENO). Main reasons for these dissimilarities are the incomplete coverage of imports, retail and farm shipments, water transport, as well as the fact that crude oil shipments are not included in the CFS. I have corrected the last point by including crude petroleum shipments from ENO data in the model, and I have shown a way to make projections of my model comparable with other data sources. The Bureau of Economic Analysis should extend the coverage of future Commodity Flow Surveys to the areas I have mentioned. In the event that better data become available, I have outlined how to give special consideration to imports and exports in the model, and how to add detail for parcel shipments.

With the current data, I could project intrasector dynamics only for high-value commodities. For the other five model sectors, commodity values and commodity shares are constants, at present. However, these constant relationships are likely not to hold in reality, because I have shown a significant intrasector trend towards truck and air transport if commodity values increase. This qualitative finding needs to be quantified for the remaining five model sectors in future research. The variable "transportation intensity" transforms the value of produced transportable output into shipped transportable output, thereby accounting for the complexity of a given commodity's shipment process. Both variables that I have introduced, "transportable output" and "transportation intensity," are important tools for analysts and planners in the derivation of freight transport demand from economic performance and in the examination of shipment processes. My model provides an effective framework for analyzing and projecting freight transportation demand, and future research should focus on filling the gaps that remain due to data restrictions.

APPENDICES

A Definition of Sectors

A.I Model Sector Definition and Derivation

The classification of model sectors is explained in the chapter Data Methodology. Value per ton and average distance of shipment for the model sectors are shown in Table A.1. Although I showed this table in Chapter 4.1.1, I present it here again to enable a comparison between the compounded model sector figures and the original, more detailed, CFS data.

Model Sector Definition		Value per Ton (in 1996 $) *	Average Distance (in miles)
1	Agricultural and Food Products	734.8	360.6
2	Mining, Minerals, Sands, Stone, Waste	29.9	81.5
3	Coal, Petroleum, Fuels **	142.9	398.6
4	Low-Value Intermediate and Final Products	529.1	269.2
5	Medium-Value Intermediate and Final Products	3,998.7	414.2
6	High-Value Intermediate and Final Products	11,302.7	518.0
7	Non-Trp Small Growth ($g < 1.5\%$ / yr)	Non-Transportable Commodities (Services)	
8	Non-Trp Medium Growth ($1.5\% \leq g < 4\%$ / yr)		
9	Non-Trp High Growth ($g \geq 4\%$ / yr)		

Source: Author. 1993 and 1997 CFS Data and ENO 2001 for Crude Petroleum and Pipeline Shipments.
Non-Trp = Non-Transportable Output Sectors; g = average annual growth of output 1972 - 1998.
* Weighted average of 1993 and 1997 CFS.
** Includes crude petroleum figures from ENO 2000 in the calculation of average distance.

Table A.1 Model Sector Definition and Sector Characteristics

A.II Commodity Flow Survey Sectors and Model Sectors

First, I assign commodities to sectors 1-3. I then classify commodities that do not fit into those sectors as model sectors 4-6 according to the procedure described in the chapter Data Methodology.[75] Table A.2 shows the CFS classification and characteristics of corresponding commodities.

[75] Note that there are two minor exceptions from the methodology described: (1) articles of base metal (CFS sector 33) are assigned to model sector 4 although their value is higher than $1400 per ton and (2) vehicle parts (CFS sector 36) are classified as model sector 6 although their value is lower than $8500 per ton. Those exemptions were necessary to achieve consistency with I-O table classification.

	Commodity Flow Survey (CFS) Sectors (1997)	Value per Ton ($)	Avg. Distance	Model Sectors
1	Live animals and live fish	1,042	253	1
2	Cereal grains	122	410	1
3	Other agricultural products	508	400	1
4	Animal feed and products of animal origin	304	213	1
5	Meat, fish, seafood, and their preparations	2,312	458	1
6	Milled grain products and preparations, and bakery products	1,069	472	1
7	Other prepared foodstuffs and fats and oils	873	313	1
8	Alcoholic beverages	1,085	343	1
9	Tobacco products	13,661	245	1
10	Monumental or building stone	172	93	2
11	Natural sands	10	58	2
12	Gravel and crushed stone	6	51	2
13	Nonmetallic minerals	48	222	2
14	Metallic ores and concentrates	139	526	2
15	Coal	21	446	3
17	Gasoline and aviation turbine fuel	225	142	3
18	Fuel oils	196	106	3
19	Coal and petroleum products	158	172	3
20	Basic chemicals	539	462	4
21	Pharmaceutical products	22,678	564	6
22	Fertilizers	153	243	4
23	Chemical products and preparations	2,276	489	5
24	Plastics and rubber	2,138	530	5
25	Logs and other wood in the rough	41	76	2
26	Wood products	384	294	4
27	Pulp, newsprint, paper, and paperboard	700	549	4
28	Paper or paperboard articles	1,338	299	4
29	Printed products	3,335	292	5
30	Textiles, leather, and articles of textiles or leather	8,266	538	5
31	Nonmetallic mineral products	120	100	4
32	Base metal in primary or semifinished forms and in finished basic shapes	851	350	4
33	Articles of base metal	2,133	457	4
34	Machinery	8,356	542	5
35	Electronic and other electrical equipment and components and office equipment	21,955	683	6
36	Motorized and other vehicles (including parts)	5,822	468	6
37	Transportation equipment	23,587	686	6
38	Precision instruments and apparatus	53,741	738	6
39	Furniture, mattresses and mattress supports, lamps, lighting fittings, and...	4,885	581	5
40	Miscellaneous manufactured products	3,741	354	5
41	Waste and scrap	184	226	2

Source: Author. Sector Names from 1997 CFS.

Table A.2 CFS Sectors and Characteristics

A.III I-O Sectors and Model Sectors

Table A.3 shows the I-O sectors, their growth rates, and their corresponding model sector number. Note that I assume that all service sectors for which an output growth rate could not be derived from I-O tables fall into the medium-growth sector.

I-O Sector Definition		Model Sector	% Growth *
1	Livestock and livestock products	1	0.47
2	Other agricultural products	1	4.15
3	Forestry and fishery products	1	N/A
4	Agricultural, forestry, and fishery services	High	4.88
5+6	Metallic ores mining	2	2.98
7	Coal mining	3	4.57
8	Crude petroleum and natural gas	3	2.40
9+10	Nonmetallic minerals mining	2	0.91
11	New construction	Small	1.42
12	Maintenance and repair construction	Small	1.42
13	Ordnance and accessories	6	-0.16
14	Food and kindred products	1	2.28
15	Tobacco products	1	2.68
16	Broad and narrow fabrics, yarn and thread mills	5	-0.38
17	Miscellaneous textile goods and floor coverings	5	0.90
18	Apparel	5	-1.01
19	Miscellaneous fabricated textile products	5	2.09
20+21	Lumber and wood products	4	2.18
22+23	Furniture and fixtures	5	1.72
24	Paper and allied products, except containers	4	3.18
25	Paperboard containers and boxes	4	2.38
26A	Newspapers and periodicals	5	4.22
26B	Other printing and publishing	5	4.31
27A	Industrial and other chemicals	4	3.44
27B	Agricultural fertilizers and chemicals	4	2.14
28	Plastics and synthetic materials	5	4.19
29A	Drugs	6	4.26
29B	Cleaning and toilet preparations	5	1.38
30	Paints and allied products	5	2.29
31	Petroleum refining and related products	3	3.44
32	Rubber and miscellaneous plastics products	5	3.09
33+34	Footwear, leather, and leather products	5	3.09
35	Glass and glass products	4	0.37
36	Stone and clay products	4	0.42
37	Primary iron and steel manufacturing	4	-0.92
38	Primary nonferrous metals manufacturing	4	0.10
39	Metal containers	4	0.75
40	Heating, plumbing, and fabricated structural metal products	5	0.91
41	Screw machine products and stampings	5	0.98
42	Other fabricated metal products	4	0.75
43	Engines and turbines	5	1.26
44+45	Farm, construction, and mining machinery	5	1.11
46	Materials handling machinery and equipment	5	1.11
47	Metalworking machinery and equipment	5	2.14
48	Special industry machinery and equipment	5	2.35
49	General industrial machinery and equipment	5	1.85
50	Miscellaneous machinery, except electrical	5	3.86
51	Computer and office equipment	6	10.36
52	Service industry machinery	6	3.07
53	Electrical industrial equipment and apparatus	6	2.38
54	Household appliances	6	1.52

(continued on next page)

I-O Sector Definition		Model Sector	Growth
55	Electric lighting and wiring equipment	5	3.15
56	Audio, video, and communication equipment	6	3.58
57	Electronic components and accessories	6	8.60
58	Miscellaneous electrical machinery and supplies	5	4.80
59A	Motor vehicles (passenger cars and trucks)	6	2.09
59B	Truck and bus bodies, trailers, and motor vehicles parts	6	2.38
60	Aircraft and parts	6	2.75
61	Other transportation equipment	6	-0.17
62	Scientific and controlling instruments	6	12.79
63	Ophthalmic and photographic equipment	6	5.00
64	Miscellaneous manufacturing	5	5.96
65A	Railroads and related services; passenger ground transportation	Small	1.15
65B	Motor freight transportation and warehousing	Medium	2.33
65C	Water transportation	Small	1.41
65D	Air transportation	High	4.91
65E	Pipelines, freight forwarders, and related services	Medium	3.24
66	Communications, except radio and TV	High	6.05
67	Radio and TV broadcasting	Small	-6.03
68A	Electric services (utilities)	Medium	2.48
68B	Gas production and distribution (utilities)	Small	-0.55
68C	Water and sanitary services	Medium	2.04
69A	Wholesale trade	High	4.09
69B	Retail trade	Medium	3.09
70A	Finance	High	4.92
70B	Insurance	Small	0.54
71A	Owner-occupied dwellings	Small	1.43
71B	Real estate and royalties	Small	1.34
72A	Hotels and lodging places	Medium	1.53
72B	Personal and repair services (except auto)	Small	0.47
73A	Computer and data processing services, including own-account	High	7.95
73B	Legal, engineering, accounting, and related services	Medium	1.52
73C	Other business and professional services, except medical	High	4.06
73D	Advertising	Small	0.23
74	Eating and drinking places	Medium	1.88
75	Automotive repair and services	Medium	3.29
76	Amusements	High	5.44
77A	Health services	Medium	3.19
77B	Educational and social services, and membership organizations	Medium	3.33
78	Federal Government enterprises	Medium	2.29
79	State and local government enterprises	High	5.01
80	Noncomparable imports	Medium	N/A
81	Scrap, used and secondhand goods	2	N/A
82	General government industry	Medium	N/A
83	Rest of the world adjustment to final uses	Medium	N/A
84	Household industry	Small	-6.08
85	Inventory valuation adjustment	Medium	N/A
VA	Value added	VA	

Source: Author. Sector names and numbers from 1997 U.S. I-O table.
* Average annual growth of sectoral output between 1972 and 1997.

Table A.3 I-O Sectors and Average Annual Growth (1972-1997)

A.IV Final Demand Sectors

Table A.4 shows the definition of final demand sectors in the 1997 I-O framework and their corresponding sector number in the model.

Final Demand Sector Definition (based on 1997 I-O classification)		
I-O Sector Definition		**Model Sector**
91	Personal Consumption Expenditures	1
92	Gross Private Domestic Investment	2
93	Change in Private Inventories	2
94	Exports of Goods and Services	3
95	Imports of Goods and Services	4
96 C	Fed. Gov. Consumption: National Defense	2
96 I	Fed. Gov. Investment: National Defense	2
97 C	Fed. Gov. Consumption: Non-Defense	2
97 I	Fed. Gov. Investment: Non-Defense	2
98C+99C	State and Local Gov. Consumption	2
98I+99I	State and Local Gov. Investment	2
Source: Author. Sector names and numbers from 1997 U.S. I-O table.		

Table A.4 Final Demand Sector Definition

B Economic Model – Regression Output

B.I Functional Forms

The functional forms used in the projection of GDP composition and multipliers are shown in Table B.1. In the notation used in this chapter, y is the independent variable and x is the explanatory variable.

Functional Form	Abbreviation	Equation used in Projection
Constant	Const	$y = a$
Linear	Linear	$y = a + bx$
Logarithmic	Log	$y = a + b \ln x$
Exponential	Exp	$y = a \exp(bx)$

Table B.1 Functional Forms

B.II Regression of GDP per Capita

Per-capita-GDP is regressed on time using IMF data series. The regression output is shown in Table B.2.

	Regression Type	Explanatory Variable	Durbin-Watson Statistic	Correct for Autocorrelation?	R square	Function Parameters			
						a	t-stat (a)	b	t-stat (b)
Per-Capita-GDP Regression									
GDP per capita in constant 1996 U.S. Dollar	Exp	Time (1900=0)	0.547	Yes	0.93	3,577.4	122.01	0.0222	25.70

Source: Author. Relevant values for the Durbin-Watson statistic: dl=1.503, du=1.585.

Table B.2 Per-Capita-GDP Regression

B.III Regression of Direct Requirements (A-Matrix)

In the regression of direct requirements a_{ij} I use time as explanatory variable. I corrected for autocorrelation whenever the Durbin-Watson statistic is smaller than the upper bound value, i.e., if the null hypothesis of no serial correlation cannot be rejected. Table B.3 shows the regression output.

		Regression Type	Explanatory Variable	Durbin-Watson Statistic	Correct for Autocorrelation?	R square	Function Parameters: a	t-stat (a)	b	t-stat (b)
Agricultural and Food Products (j=1)										
	Agricultural and Food Products	Log	Time (1970=0)	2.423	No	0.87	0.256	16.88	0.034	6.22
	Mining, Minerals, Sands, Stone, Waste	Log	Time (1970=0)	2.782	No	0.84	0.001	8.43	(0.000)	(5.66)
	Coal, Petroleum, Fuels	Const *					0.009			
	Low-Value Intermediate and Final Products	*(results)*								
a^y_{i1}	Medium-Value Intermediate and Final Products	Log	Time (1970=0)	1.835	No	0.94	0.014	14.32	0.003	9.35
	High-Value Intermediate and Final Products	Const					0.003			
	Non-Trp Small Growth	Log	Time (1970=0)	1.336	No	0.97	0.102	43.01	(0.011)	(13.33)
	Non-Trp Medium Growth	Exp	Time (1970=0)	1.722	No	0.63	0.053	(53.21)	(0.009)	
	Non-Trp High Growth	Exp	Time (1970=0)	1.465	No	0.89	0.065	(57.96)	0.016	6.84
	Value Added	Log	Time (1970=0)	1.455	No	0.85	0.418	29.59	(0.030)	(5.87)
Mining, Minerals, Sands, Stone, Waste (j=2)										
	Agricultural and Food Products	Linear	Time (1970=0)	2.150	No	0.60	0.000	4.41	(0.000)	(3.02)
	Mining, Minerals, Sands, Stone, Waste	Linear	Time (1970=0)	2.442	No	0.50	0.031	2.08	0.002	2.44
	Coal, Petroleum, Fuels	Const *					0.032			
	Low-Value Intermediate and Final Products	Const					0.056			
a^y_{i2}	Medium-Value Intermediate and Final Products	Const					0.073			
	High-Value Intermediate and Final Products	Const					0.006			
	Non-Trp Small Growth	Log	Time (1970=0)	2.541	No	0.91	0.145	14.00	(0.029)	(7.80)
	Non-Trp Medium Growth	Const					0.100			
	Non-Trp High Growth	Const					0.067			
	Value Added	*(results)*								
Coal, Petroleum, Fuels (j=3)										
	Agricultural and Food Products	Linear	Time (1970=0)	1.174	Yes	0.84	(0.000)	(2.88)	0.000	5.62
	Mining, Minerals, Sands, Stone, Waste	Const					0.002			
	Coal, Petroleum, Fuels	Log	Time (1970=0)	2.323	No	0.49	0.254	4.10	0.054	2.41
	Low-Value Intermediate and Final Products	Const					0.026			
a^y_{i3}	Medium-Value Intermediate and Final Products	Const					0.016			
	High-Value Intermediate and Final Products	Exp	Time (1970=0)	1.825	No	0.61	0.002	(46.41)	(0.021)	(3.04)
	Non-Trp Small Growth	*(results)*								
	Non-Trp Medium Growth	Const					0.055			
	Non-Trp High Growth	Exp	Time (1970=0)	1.109	Yes	0.85	0.025	(72.78)	0.025	10.75
	Value Added	Log	Time (1970=0)	1.690	No	0.48	0.508	6.10	(0.069)	(2.26)
Low-Value Intermediate and Final Products (j=4)										
	Agricultural and Food Products	Log	Time (1970=0)	1.703	No	0.95	0.002	2.50	0.004	10.37
	Mining, Minerals, Sands, Stone, Waste	Linear	Time (1970=0)	3.148	No	0.97	0.040	83.60	(0.000)	(15.04)
	Coal, Petroleum, Fuels	Log	Time (1970=0)	1.309	Yes	0.54	0.032	7.62	(0.004)	(2.64)
	Low-Value Intermediate and Final Products	*(results)*								
a^y_{i4}	Medium-Value Intermediate and Final Products	Log	Time (1970=0)	1.784	No	0.82	0.032	12.18	0.005	5.18
	High-Value Intermediate and Final Products	Exp	Time (1970=0)	1.669	No	0.78	0.002	(71.43)	0.019	4.58
	Non-Trp Small Growth	Linear	Time (1970=0)	2.413	No	0.96	0.078	38.41	(0.001)	(12.40)
	Non-Trp Medium Growth	Log	Time (1970=0)	3.125	No	0.62	0.057	10.73	0.006	3.12
	Non-Trp High Growth	Linear	Time (1970=0)	1.888	No	0.83	0.052	9.03	0.002	5.36
	Value Added	Log	Time (1970=0)	2.228	No	0.43	0.422	21.97	(0.015)	(2.13)
Medium-Value Intermediate and Final Products (j=5)										
	Agricultural and Food Products	Linear	Time (1970=0)	2.315	No	0.50	0.005	6.56	0.000	2.45
	Mining, Minerals, Sands, Stone, Waste	Log	Time (1970=0)	2.399	No	0.98	0.003	22.84	(0.001)	(16.89)
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	1.278	Yes	0.82	0.011	(28.45)	(0.042)	(5.24)
	Low-Value Intermediate and Final Products	Linear	Time (1970=0)	2.815	No	0.43	0.159	40.38	(0.000)	(2.14)
a^y_{i5}	Medium-Value Intermediate and Final Products	Const					0.208			
	High-Value Intermediate and Final Products	Exp	Time (1970=0)	2.171	No	0.84	0.008	(62.78)	0.024	5.66
	Non-Trp Small Growth	Log	Time (1970=0)	1.447	No	0.94	0.077	23.58	(0.012)	(9.73)
	Non-Trp Medium Growth	Exp	Time (1970=0)	2.207	No	0.60	0.056	(115.72)	(0.004)	(3.02)
	Non-Trp High Growth	Linear	Time (1970=0)	1.983	No	0.69	0.061	10.68	0.001	3.66
	Value Added	*(results)*								
High-Value Manufacturing Products (j=6)										
	Agricultural and Food Products	Const					0.001			
	Mining, Minerals, Sands, Stone, Waste	Log	Time (1970=0)	1.524	No	0.81	0.002	10.73	(0.001)	(7.75)
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	1.173	Yes	0.81	0.008	(19.17)	(0.062)	(5.00)
	Low-Value Intermediate and Final Products	Linear	Time (1970=0)	1.357	No	0.85	0.133	17.36	(0.002)	(5.89)
a^y_{i6}	Medium-Value Intermediate and Final Products	Log	Time (1970=0)	3.621	No	0.40	0.099	14.60	0.005	2.01
	High-Value Intermediate and Final Products	Linear	Time (1970=0)	1.349	No	0.92	0.118	10.37	0.005	8.15
	Non-Trp Small Growth	Log	Time (1970=0)	2.649	No	0.65	0.059	17.63	(0.007)	(5.82)
	Non-Trp Medium Growth	*(results)*								
	Non-Trp High Growth	Linear	Time (1970=0)	2.837	No	0.79	0.058	7.91	0.002	4.78
	Value Added	Exp	Time (1970=0)	1.090	Yes	0.47	0.565	(3.46)	(0.017)	(2.33)

(continued on next page)

(Table B.3 continued)

		Regression Type	Explanatory Variable	Durbin-Watson Statistic	Correct for Autocorrelation?	R square	Function Parameters a	t-stat (a)	b	t-stat (b)
Non-Trp Small Growth (*j*=7)										
	Agricultural and Food Products	Linear	Time (1970=0)	1.871	No	0.52	0.000	0.21	0.000	2.55
	Mining, Minerals, Sands, Stone, Waste	Const					0.002			
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	1.279	Yes	0.46	0.033	(29.86)	(0.013)	(2.27)
a^{y}_{i7}	Low-Value Intermediate and Final Products	Linear	Time (1970=0)	2.726	No	0.68	0.062	19.53	(0.001)	(3.58)
	Medium-Value Intermediate and Final Products	Const					0.042			
	High-Value Intermediate and Final Products	Exp	Time (1970=0)	1.243	Yes	0.52	0.007	(25.85)	0.023	2.55
	Non-Trp Small Growth	Exp	Time (1970=0)	1.174	Yes	0.68	0.229	(9.25)	(0.025)	(3.57)
	Non-Trp Medium Growth	Const					0.070			
	Non-Trp High Growth	Exp	Time (1970=0)	1.581	No	0.99	0.043	(144.67)	0.024	21.48
	Value Added	*(results)*								
Non-Trp Medium Growth (*j*=8)										
	Agricultural and Food Products	Const					0.023			
	Mining, Minerals, Sands, Stone, Waste	Const					0.000			
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	1.332	Yes	0.98	0.042	(52.84)	(0.057)	(19.65)
a^{y}_{i8}	Low-Value Intermediate and Final Products	Log	Time (1970=0)	1.118	Yes	0.65	0.051	4.62	(0.012)	(3.37)
	Medium-Value Intermediate and Final Products	Log	Time (1970=0)	1.495	No	0.68	0.008	3.07	0.003	3.56
	High-Value Intermediate and Final Products	Linear	Time (1970=0)	0.840	Yes	0.88	(0.005)	(1.71)	0.001	6.74
	Non-Trp Small Growth	Log	Time (1970=0)	0.911	Yes	0.90	0.265	11.23	(0.062)	(7.31)
	Non-Trp Medium Growth	Const					0.071			
	Non-Trp High Growth	Linear	Time (1970=0)	0.820	Yes	0.82	0.021	1.95	0.002	5.27
	Value Added	*(results)*								
Non-Trp High Growth (*j*=9)										
	Agricultural and Food Products	Log	Time (1970=0)	2.042	No	0.66	0.002	6.86	0.000	3.45
	Mining, Minerals, Sands, Stone, Waste	Linear	Time (1970=0)	2.023	No	0.81	0.000	3.66	(0.000)	(5.05)
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	0.987	Yes	0.94	0.154	(7.34)	(0.107)	(9.57)
	Low-Value Intermediate and Final Products	Const					0.012			
a^{y}_{i9}	Medium-Value Intermediate and Final Products	Log	Time (1970=0)	1.357	No	0.48	0.010	3.79	0.002	2.37
	High-Value Intermediate and Final Products	Exp	Time (1970=0)	0.907	Yes	0.83	0.004	(19.10)	0.068	5.42
	Non-Trp Small Growth	Log	Time (1970=0)	1.937	No	0.91	0.116	24.90	(0.013)	(7.76)
	Non-Trp Medium Growth	Linear	Time (1970=0)	3.541	No	0.85	0.106	25.88	(0.001)	(5.86)
	Non-Trp High Growth	Linear	Time (1970=0)	2.827	No	0.88	0.093	9.38	0.003	6.61
	Value Added	*(results)*								
ALL Intermediate Sectors (Row-scaler)										
	Agricultural and Food Products	Linear	Time (1970=0)	1.249	Yes	0.55	0.040	12.12	(0.000)	(2.73)
	Mining, Minerals, Sands, Stone, Waste	Log	Time (1970=0)	2.755	No	0.89	0.005	14.76	(0.001)	(7.02)
	Coal, Petroleum, Fuels	Exp	Time (1970=0)	1.175	Yes	0.95	0.051	(47.30)	(0.034)	(11.03)
	Low-Value Intermediate and Final Products	Exp	Time (1970=0)	2.259	No	0.87	0.082	(49.13)	(0.016)	(6.21)
	Medium-Value Intermediate and Final Products	Linear	Time (1970=0)	1.217	Yes	0.78	0.062	24.50	(0.001)	(4.81)
	High-Value Intermediate and Final Products	Linear	Time (1970=0)	0.868	Yes	0.73	0.002	0.22	0.001	4.00
	Non-Trp Small Growth	Exp	Time (1970=0)	1.614	No	0.86	0.106	(62.70)	(0.011)	(6.16)
	Non-Trp Medium Growth	Linear	Time (1970=0)	2.502	No	0.32	0.069	67.65	(0.000)	(1.68)
	Non-Trp High Growth	Linear	Time (1970=0)	0.922	Yes	0.94	0.032	5.02	0.003	9.89
	Value Added	*(results)*								

Source: Author. Relevant values for the Durbin-Watson statistic: dl=0.763, du=1.332. Relevant values for the t-statistic (10% significance): 1.943 and –1.943.
* The constant is the average value of the years 1992-1998. Prior years are not included due to large deviations following the oil crisis.
Abbreviations: Const=Constant; Log=Logarithmic; Exp=Exponential; Non-Trp = Non-Transportable Output Sectors

Table B.3 Direct Requirement Regression Output

B.IV Regression of Shares in Final Demand

In the regression of the final demand components s_k and s_{ik}, per-capita-GDP is the regressor. Again, I correct for autocorrelation whenever the Durbin-Watson statistic is smaller than the upper bound value. Table B.4 shows the regression output.

		Regression Type	Explanatory Variable	Durbin-Watson Statistic	Correct for Autocorrelation?	R square	Function Parameters			
							a	t-stat (a)	b	t-stat (b)
Shares of the four Sectors in Total Final Demand										
s^{y}_{k}	Personal Consumption	Const					0.666			
	Gov. and States: Investm.&Consumption	*(Results)*								
	Exports	Log	GDP per cap, $ thousand	2.656	No	0.86	(0.258)	(9.28)	0.106	12.25
	Imports	Log	GDP per cap, $ thousand	2.789	No	0.96	0.248	8.19	(0.108)	(11.41)
Shares in Personal Consumption										
s^{y}_{i1}	Agricultural and Food Products	Exp	GDP per cap, $ thousand	1.358	No	0.52	0.086	(28.34)	(0.009)	(2.53)
	Mining, Minerals, Sands, Stone, Waste	Linear	GDP per cap, $ thousand	2.238	No	0.47	0.002	1.64	0.000	2.31
	Coal, Petroleum, Fuels	Const *					0.013			
	Low-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	1.244	Yes	0.89	0.021	11.44	(0.004)	(7.02)
	Medium-Value Intermediate and Final Products	Const					0.081			
	High-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	1.482	No	0.42	0.028	2.50	0.007	2.08
	Non-Trp Small Growth	Exp	GDP per cap, $ thousand	1.542	No	0.98	0.510	(28.22)	(0.030)	(32.07)
	Non-Trp Medium Growth	*(Results)*								
	Non-Trp High Growth	Linear	GDP per cap, $ thousand	1.375	No	0.95	0.025	2.37	0.004	10.19
Shares in Gov. and States: Investm.&Consumption										
s^{y}_{i2}	Agricultural and Food Products	Const					0.007			
	Mining, Minerals, Sands, Stone, Waste	Const					(0.014)			
	Coal, Petroleum, Fuels	Const *					0.007			
	Low-Value Intermediate and Final Products	Const					0.014			
	Medium-Value Intermediate and Final Products	Const					0.077			
	High-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	2.631	No	0.90	(0.231)	(4.42)	0.121	7.41
	Non-Trp Small Growth	Exp	GDP per cap, $ thousand	2.075	No	0.89	0.533	(8.22)	(0.021)	(7.02)
	Non-Trp Medium Growth	*(Results)*								
	Non-Trp High Growth	Linear	GDP per cap, $ thousand	1.521	No	0.89	(0.053)	(2.53)	0.006	7.05
Shares in Exports										
s^{y}_{i3}	Agricultural and Food Products	Exp	GDP per cap, $ thousand	1.624	No	0.69	0.216	(5.72)	(0.038)	(3.66)
	Mining, Minerals, Sands, Stone, Waste	Exp	GDP per cap, $ thousand	2.615	No	0.95	0.105	(11.47)	(0.079)	(10.32)
	Coal, Petroleum, Fuels	Exp **	GDP per cap, $ thousand	1.086	Yes	0.77	0.073	(10.70)	(0.034)	(4.50)
	Low-Value Intermediate and Final Products	Exp	GDP per cap, $ thousand	1.754	No	0.90	0.228	(13.78)	(0.032)	(7.52)
	Medium-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	2.078	No	0.54	0.393	4.55	(0.072)	(2.68)
	High-Value Intermediate and Final Products	Linear	GDP per cap, $ thousand	1.862	No	0.92	0.057	2.39	0.008	8.47
	Non-Trp Small Growth	Log	GDP per cap, $ thousand	2.482	No	0.84	0.342	7.13	(0.083)	(5.52)
	Non-Trp Medium Growth	*(Results)*								
	Non-Trp High Growth	Log	GDP per cap, $ thousand	1.993	No	0.88	(0.178)	(3.88)	0.104	8.87
Shares in Imports										
s^{y}_{i4}	Agricultural and Food Products	Const					0.056			
	Mining, Minerals, Sands, Stone, Waste	Exp	GDP per cap, $ thousand	1.449	No	0.79	0.157	(2.83)	(0.121)	(4.74)
	Coal, Petroleum, Fuels	Exp ***	GDP per cap, $ thousand	2.149	No	0.51	0.235	(3.82)	(0.030)	(2.48)
	Low-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	1.372	No	0.92	0.509	11.81	(0.115)	(8.57)
	Medium-Value Intermediate and Final Products	*(Results)*								
	High-Value Intermediate and Final Products	Log	GDP per cap, $ thousand	1.638	No	0.95	(0.718)	(7.19)	0.313	10.33
	Non-Trp Small Growth	Log	GDP per cap, $ thousand	1.948	No	0.88	0.072	3.95	(0.021)	(3.61)
	Non-Trp Medium Growth	Exp	GDP per cap, $ thousand	2.621	No	0.97	0.861	(1.25)	(0.064)	(13.54)
	Non-Trp High Growth	Linear	GDP per cap, $ thousand	1.476	No	0.90	(0.047)	(9.12)	0.001	7.32

Source: Author. Relevant values for the Durbin-Watson statistic: dl=0.763, du=1.332 Relevant values for the t-statistic (10% significance): 1.943 and –1.943.

* The constant is the average value of the years 1992-1998. Prior years are not included due to large deviations following the oil crisis.

** The regression is targeted towards 1% for a GDP per capita of $60,000. Without this correction, negative values would result for high GDP figures

*** The regression is targeted towards 5% for a GDP per capita of $60,000 for the reason mentioned above and based on the assumption that the U.S. Petroleum share in imports will not decrease rapidly.

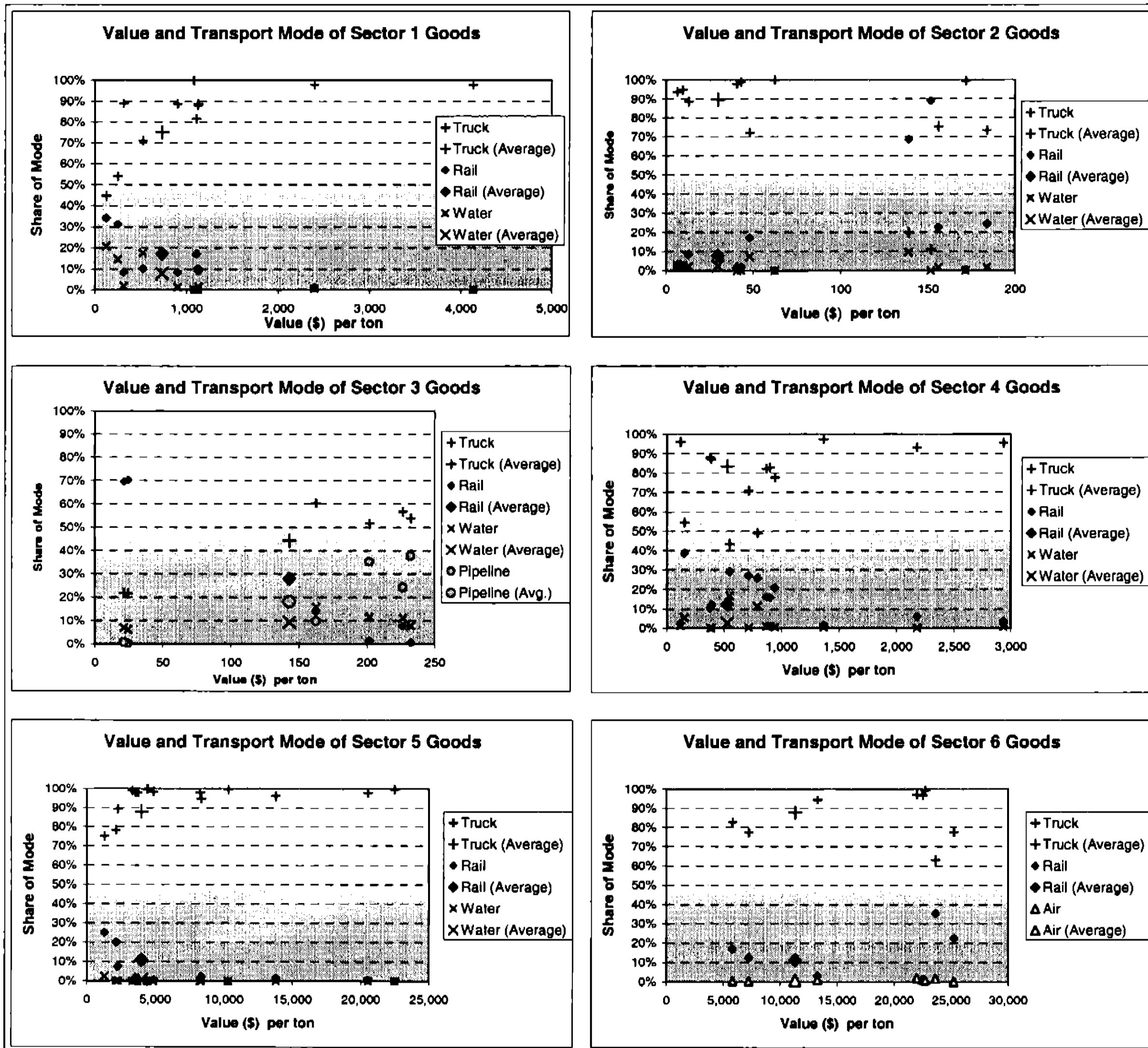
Abbreviations: Const=Constant; Log=Logarithmic; Exp=Exponential; Non-Trp = Non-Transportable Output Sectors

Table B.4 Shares in Final Demand – Regression Output

C Transportation Variables

C.I Commodity Value per Ton

The commodity value per ton for each of the six transportation commodity sectors used in the model is shown in Figure C.1.



Source: Author. Data from 1993 and 1997 CFS. Commodity value per ton in constant 1996 U.S. Dollars.

Figure C.1 Commodity Value per ton and Transport Modes

Pipeline is left out in all sectors, except sector 3, due to its low share. The same counts for Air transportation, which is only represented for sector 6. The average per-ton-value for each commodity sector with the corresponding modal share is indicated by bigger dots.

C.II Average Distance of Shipment

The computation of average distance of shipments by mode and commodity is shown in Table C.1. Average distance $d^{\,y}_{im}$ is obtained from ton and ton-miles data according to equation (4.28).

(Thousands of Tons) - 1993+1997		Truck	Rail	Water	Air	Pipeline	SUM
1	Agricultural and Food Products	2,137,544	488,088	221,845	452	876	**2,848,805**
2	Mining, Minerals, Sands, Stone, Waste	4,972,797	430,797	127,038	39	8,441	**5,539,112**
3	Coal, Petroleum, Fuels *	2,489,047	1,530,927	1,036,984	13	2,182,004	**7,238,976**
4	Low-Value Intermediate and Final Products	3,457,157	514,480	110,871	1,802	54,777	**4,139,088**
5	Medium-Value Intermediate and Final Products	775,983	96,330	5,937	2,194	2,764	**883,207**
6	High-Value Intermediate and Final Products	209,710	27,001	71	1,932	-	**238,714**
	SUM	**14,042,238**	**3,087,624**	**1,502,746**	**6,432**	**2,248,862**	**20,887,901**
Millions of Ton-Miles - 1993+1997		**Truck**	**Rail**	**Water**	**Air**	**Pipeline ****	**SUM**
1	Agricultural and Food Products	458,405	397,067	170,285	1,002	487	**1,027,247**
2	Mining, Minerals, Sands, Stone, Waste	257,498	135,016	54,313	52	4,697	**451,576**
3	Coal, Petroleum, Fuels *	139,851	918,113	603,355	19	1,224,119	**2,885,457**
4	Low-Value Intermediate and Final Products	602,421	414,411	64,423	2,276	30,699	**1,114,229**
5	Medium-Value Intermediate and Final Products	287,223	69,505	4,690	2,875	1,560	**365,854**
6	High-Value Intermediate and Final Products	97,812	23,358	18	2,460	-	**123,648**
	SUM	**1,843,211**	**1,957,470**	**897,084**	**8,684**	**1,261,563**	**5,968,011**
Average Distance 1993-97		**Truck**	**Rail**	**Water**	**Air**	**Pipeline ****	**Commodity Average**
1	Agricultural and Food Products	214.5	813.5	767.6	2,217.7	556.4	360.6
2	Mining, Minerals, Sands, Stone, Waste	51.8	313.4	427.5	1,335.2	556.4	81.5
3	Coal, Petroleum, Fuels *	56.2	599.7	581.8	1,456.2	561.0	398.6
4	Low-Value Intermediate and Final Products	174.3	805.5	581.1	1,262.9	560.4	269.2
5	Medium-Value Intermediate and Final Products	370.1	721.5	790.0	1,310.6	564.6	414.2
6	High-Value Intermediate and Final Products	466.4	865.1	252.3	1,273.3	N/A	518.0
	Modal Average	131.3	634.0	597.0	1,350.2	561.0	-

Source: Author. Compounded data from the 1997 Commodity Flow Survey.
* Includes data for crude petroleum shipment from ENO 2000.
** Includes data for average distance of shipments by pipeline from ENO 2000.

Table C.1 The Calculation of Average Shipment Distance by Commodity and Mode

C.III Shares in Transportation Modes

The shares of modes *m* in the transportation of commodities *i* is shown in Table C.2. Note that modal shares in sector 6 change over time as shown in Table 9.6.

Means of Transport - Average 1993-97		Truck	Rail	Water	Air	Pipeline	SUM
1	Agricultural and Food Products	75.0%	17.1%	7.8%	0.0%	0.0%	**100.0%**
2	Mining, Minerals, Sands, Stone, Waste	89.8%	7.8%	2.3%	0.0%	0.2%	**100.0%**
3	Coal, Petroleum, Fuels *	34.4%	21.1%	14.3%	0.0%	30.1%	**100.0%**
4	Low-Value Intermediate and Final Products	83.5%	12.4%	2.7%	0.0%	1.3%	**100.0%**
5	Medium-Value Intermediate and Final Products	87.9%	10.9%	0.7%	0.2%	0.3%	**100.0%**
6	High-Value Manufacturing Products	87.8%	11.3%	0.0%	0.8%	0.0%	**100.0%**

Source: Author. Compounded data from the 1997 Commodity Flow Survey.
* Includes data for crude petroleum shipment from ENO 2000.

Table C.2 Transportation Shares by Commodity and Mode

D Model Output

Appendix D is meant to supplement Chapter 6, which includes references to the figures shown here. Appendix D is not a complete listing of model output since the most important projection graphs have already been shown in Chapter 6.

D.I Exports and Imports

The magnitude and composition of U.S. exports and imports is shown in Figure D.1 and Figure D.2.

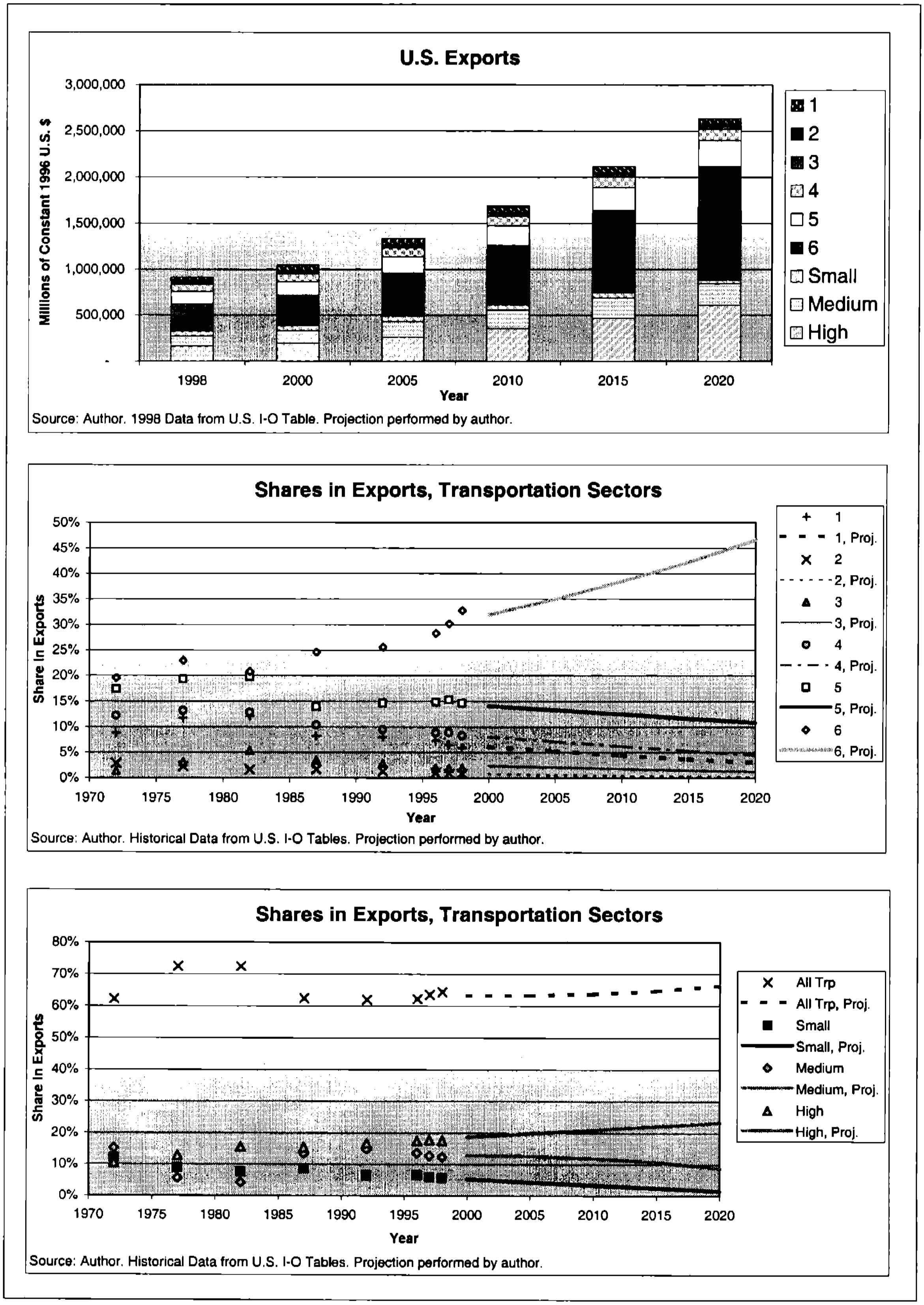


Figure D.1 U.S. Exports, Historical Figures and Projections

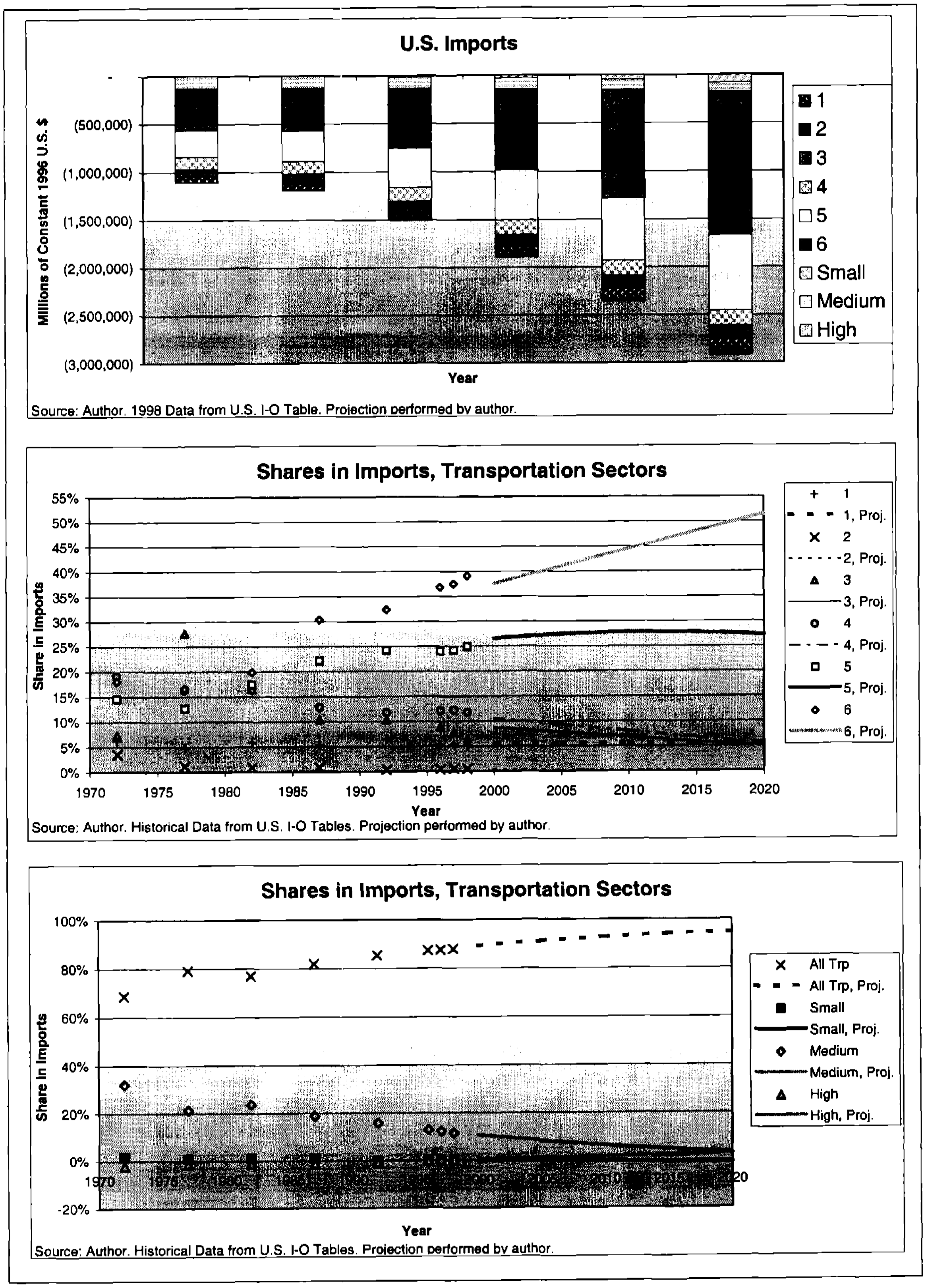


Figure D.2 U.S. Imports, Historical Figures and Projections

D.II Model Verification

Transportable output is the most important figure projected by the economic model. To verify my model, I thus compare historical figures of transportable output with "backwards" projections. Figure D.3 shows the results of this analysis. There are some differences between model output and historical data in 1972 and 1977. From 1982 on, however, the model replicates historical figures very well.

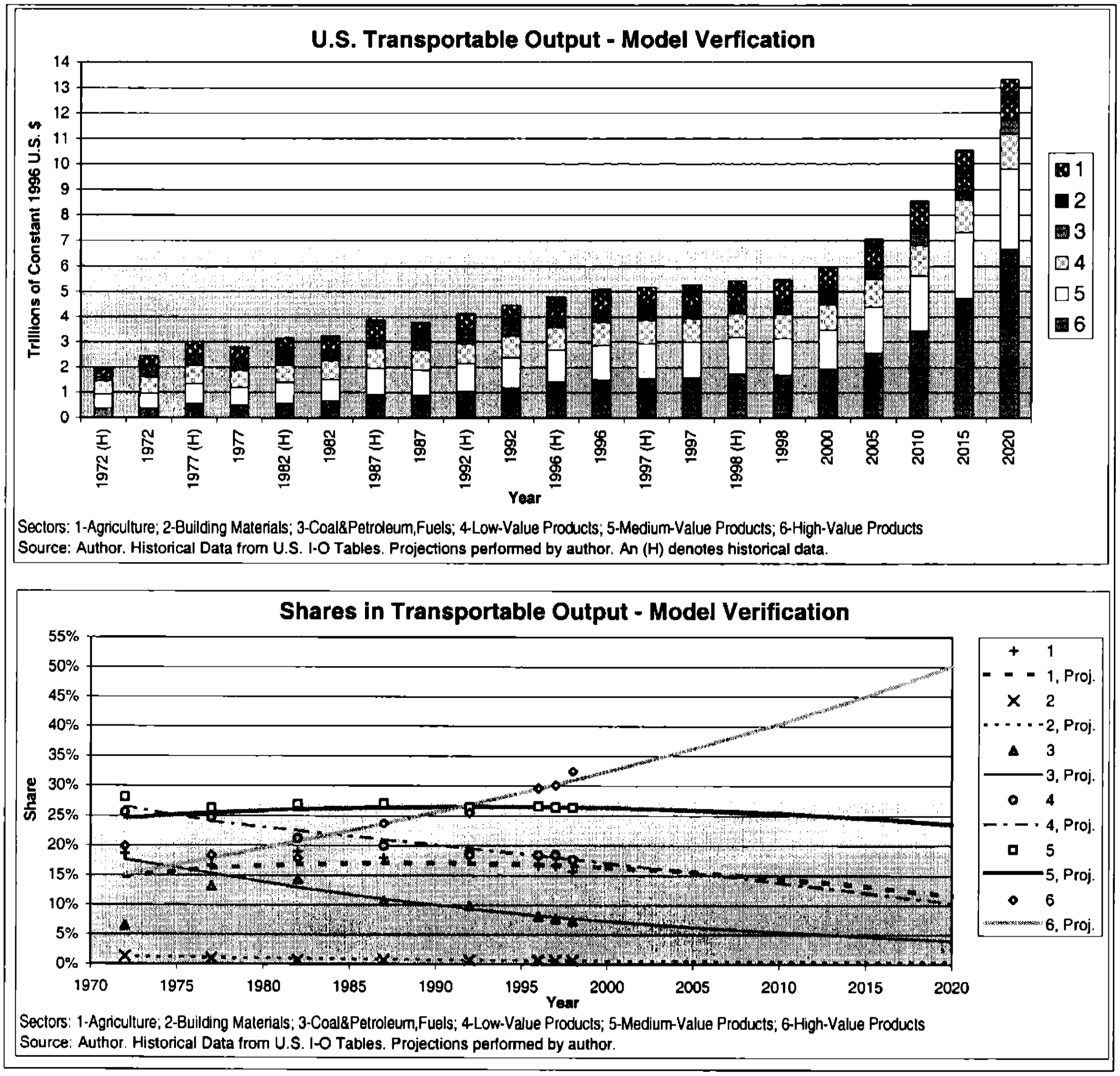


Figure D.3 Transportable Output – Model Verification

D.III Transportation Demand in Tons – By Transport Mode

Table D.1 shows historical numbers and projections of commodity weight in tons by transport mode. For 1993 and 1997, model "backwards" projections can be compared with actual figures.

Tons (millions) by Mode		**Historical**	**Projected**	**Historical**						
		1993 (H)*	1993	1997 (H)*	1997	2000	2005	2010	2015	2020
1	Truck	6,610.4	7,046.8	7,431.8	7,553.6	8,017.9	8,646.5	9,408.4	10,360.2	11,575.5
2	Rail	1,543.9	1,566.1	1,543.7	1,672.5	1,770.1	1,899.4	2,051.7	2,232.9	2,450.8
3	Water	721.3	768.6	781.4	815.1	857.5	911.6	975.7	1,051.4	1,141.2
4	Air	2.3	3.3	4.1	3.7	4.2	5.1	6.3	7.8	9.9
5	Pipeline	1,029.4	1,173.6	1,219.5	1,226.8	1,278.0	1,338.2	1,412.4	1,501.6	1,607.9
Total		**9,907.3**	**10,558.5**	**10,980.6**	**11,271.8**	**11,927.8**	**12,800.8**	**13,854.5**	**15,153.9**	**16,785.4**
Source: Author. Historical Data from 1993 and 1997 CFS. Projections Performed by Author. * The (H) denotes Historical Data.										

Modal Shares in Tons Transported		**Historical**		**Projected**						
		1993	1997	1993	1997	2000	2005	2010	2015	2020
1	Truck	66.72%	67.68%	66.74%	67.01%	67.22%	67.55%	67.91%	68.37%	68.96%
2	Rail	15.58%	14.06%	14.83%	14.84%	14.84%	14.84%	14.81%	14.73%	14.60%
3	Water	7.28%	7.12%	7.28%	7.23%	7.19%	7.12%	7.04%	6.94%	6.80%
4	Air	0.02%	0.04%	0.03%	0.03%	0.04%	0.04%	0.05%	0.05%	0.06%
5	Pipeline	10.39%	11.11%	11.12%	10.88%	10.71%	10.45%	10.19%	9.91%	9.58%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Source: Author. Historical Data from 1993 and 1997 CFS. Projections Performed by Author.										

Table D.1 Transportation Demand in Tons by Transport Mode

D.IV Transportation Demand in Ton-Miles – By Transport Mode

Table D.2 shows historical numbers and projections of ton-miles by transport mode. For 1993 and 1997, model "backwards" projections can be compared with actual figures.

Ton-Miles (billions) by Mode		**Historical**	**Projected**	**Historical**						
		1993 (H)*	1993	1997 (H)*	1997	2000	2005	2010	2015	2020
1	Truck	854.8	905.9	988.4	996.3	1,083.1	1,212.1	1,362.5	1,541.7	1,760.9
2	Rail	941.0	986.9	1,016.5	1,061.3	1,129.3	1,221.3	1,326.9	1,448.8	1,591.0
3	Water	494.1	456.9	403.0	486.5	513.3	548.1	588.8	636.1	691.4
4	Air	3.0	4.5	5.7	5.0	5.7	6.9	8.4	10.4	13.1
5	Pipeline	583.0	658.4	678.5	688.2	716.9	750.7	792.3	842.4	902.0
Total		**2,876.9**	**3,012.5**	**3,092.1**	**3,237.3**	**3,448.4**	**3,739.0**	**4,078.9**	**4,479.4**	**4,958.4**
Source: Author. Historical Data from 1993 and 1997 CFS. Projections Performed by Author. * The (H) denotes Historical Data.										

Modal Shares in Ton-Miles Transported		**Historical**		**Projected**						
		1993	1997	1993	1997	2000	2005	2010	2015	2020
1	Truck	29.72%	31.97%	30.07%	30.78%	31.41%	32.42%	33.40%	34.42%	35.51%
2	Rail	32.72%	32.87%	32.76%	32.78%	32.75%	32.66%	32.53%	32.34%	32.09%
3	Water	17.18%	13.03%	15.17%	15.03%	14.89%	14.66%	14.43%	14.20%	13.94%
4	Air	0.11%	0.18%	0.15%	0.15%	0.16%	0.18%	0.21%	0.23%	0.26%
5	Pipeline	20.27%	21.94%	21.85%	21.26%	20.79%	20.08%	19.42%	18.81%	18.19%
Total		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Source: Author. Historical Data from 1993 and 1997 CFS. Projections Performed by Author.										

Table D.2 Transportation Demand in Ton-Miles by Transport Mode

E Environmental Impact Figures

This appendix is a supplementation to Chapter 8.

E.I Energy Consumption by Freight Mode

Table E.1 shows historical values (1997) and projected figures for the energy consumption of U.S. freight transport modes.

Freight Transport Energy Consumption		CFS	Projected Energy Consumption				
Figures in trillion Btu		1997 (H)*	2000	2005	2010	2015	2020
1	Truck	4,217	4,568	4,984	5,472	6,062	6,802
2	Rail	371	385	367	353	343	336
3	Water	176	213	216	221	229	240
4	Air	118	117	139	167	205	259
5	Pipeline **	174	175	180	188	199	214
Total		**5,055**	**5,457**	**5,886**	**6,401**	**7,038**	**7,851**

Source: Author. Data in 1997 from CFS. Projections performed by author.
* The (H) denotes historical data.
** Includes data on crude petroleum shipments from ENO 2000.

Table E.1 Energy Consumption by Freight Mode

E.II Carbon Dioxide Emissions by Mode

Table E.2 shows historical numbers of carbon dioxide emissions in 1997, calculated from CFS ton-mile data, and model projections of CO_2 emissions by transport sector.

Freight Transport CO2 Emissions		CFS	Projected Energy Consumption				
Figures in Tg (million tons)		1997 (H)*	2000	2005	2010	2015	2020
1	Truck	326.2	353.4	385.6	423.3	469.0	526.3
2	Rail	28.7	29.8	28.4	27.3	26.5	26.0
3	Water	13.6	16.5	16.7	17.1	17.7	18.6
4	Air	9.1	9.0	10.7	12.9	15.9	20.0
5	Pipeline **	13.4	13.5	13.9	14.5	15.4	16.6
Total		**391.1**	**422.2**	**455.4**	**495.3**	**544.5**	**607.4**

Source: Author. Calculation in 1997 based upon CFS ton-mile figures. Projections performed by author.
* The (H) denotes historical data.
** Includes data on crude petroleum shipments from ENO 2000.

Table E.2 Carbon Dioxide Emissions by Mode

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