ENVIRONMENTAL IMPACTS OF THE DIGITAL ECONOMY:

THE CASE OF AUSTIN, TEXAS, 1990 - 2008

A Dissertation

by

WEI TU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2004

Major Subject: Geography

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Approved as to style and content by:

Daniel Z. Sui (Chair of Committee)	Andrew G. Klein (Member)
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ABSTRACT

Environmental Impacts of the Digital Economy:

The Case of Austin, Texas, 1990 - 2008. (May 2004)

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Chair of Advisory Committee: Dr. Daniel Z. Sui

This dissertation investigates the dynamic economic structure transformation and its corresponding environmental consequences at the Austin-San Marcos Metropolitan Statistical Area (Austin MSA) from 1990 to 2008. Input-output (IO) analysis is the major methodology and environmental problems are defined as emissions of industrial point air pollutants. Both three- and seven- segment IO models of Austin MSA for the years of 1990, 1994, and 1999 are constructed. Direct and total pollution coefficients of six major pollutants are calculated, hypothetical extraction measurement and structural decomposition analysis are implemented, and the quantity and pattern of pollutant emissions are simulated based on four major assumed development scenarios from 2000 to 2008.

This study finds: 1) the digital economy has emerged in the Austin MSA during the 1990s, 2) the manufacturing process of Austin MSA tended to be more environmentally friendly, which supports the hypothesis of dematerialization and decarbonization, 3) consumption-driven and non-production segments related environmental problems becomes more significant in the emerging digital economy.

This study predicts that industrial point air pollutant emissions will grow moderately from 2000 to 2008, assuming that the direct pollutant coefficients will change at the average rates of the 1990s and the final demand will grow at the half rates of the 1990s' average. Pollution contribution from production segment will generally decrease and contribution from other segments such as ICT and Information will increase, however, emission contributions of the segments will vary in terms of pollutants as well as development scenarios.

This study argues that the shift of the source and nature of environmental threats of in the digital economy mandates parallel reform of the current environmental policy. A new generation of policy should be cooperative rather than confrontational, integrated rather than fragmented, flexible rather than rigid. It should also facilitate innovative management initiatives to achieve sustainability. More fundamentally, it is expected to deal with environmental impacts of intangible information flows (bits) which are possibly more essential than flows of tangible goods and services (atoms) in the context of the digital economy and the information age.

DEDICATION

To my son, Qing Chuan (Jesse), the new generation.

ACKNOWLEDGEMENTS

I am deeply indebted to my major advisor, Dr. Daniel Z. Sui. This dissertation would have been a mission impossible without his extraordinary vision and inexhaustible imagination to the research topic, his superb guidance and ceaseless encouragement, his endless patience and trust, and his generous spiritual and financial support. More importantly, Dr. Sui inspires me with his words and deeds of the true meaning of scholarship, teaching, and service which will always motivate me to practice academic excellence in the boundless intellectual wonderland.

I would also like to thank Dr. Lonnie L. Jones, Dr. Robert S. Bednards, Dr. Andrew G. Klein, and Dr. Richard T. Woodward for all of their kind direction, assistance, and encouragement as my committee members. Special thanks are due to Dr. Jones, who not only generously provided me part of the data for my dissertation and shared with me his knowledge and experience in the field of input-output study, but also taught me the true spirit of the Texas cowboy.

Dr. Douglas J. Sherman, the head of the Geography Department at Texas A&M University, was very helpful in mentoring, guiding, and providing all types of resources during my doctoral study. Special thanks are also extended to all the faculty and staff members of the Department of Geography for their support and assistance, especially Dr. Jonathan Smith, Ms. Kathy Lamarque, Ms. Kathy Bruton, Mr. Barry Hunter, and Ms. Toya Meriweather.

Zhuolin Gu, my wife, was willing to sacrifice her own prosperous career in Shanghai to support my educational endeavor in College Station. She also patiently endured numerous lonely hours and assumed most of the housework during my study. Without her love and sacrifice, my academic mission would never be achieved. Qingchuan, my son, has given me immeasurable joy since he has come to the world. This dissertation is especially dedicated to him. I would also like to express my appreciation to all my Aggie fellows, other family members, friends, and teachers. Their love and friendship helped me go through many tough moments. Finally, a deep bow is extended to my deceased mother, Peihua Fei, and father-in-law, Yunmou Gu. Their love will be forever cherished from the bottom of my heart.

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CHAPTER I

INTRODUCTION

There are no passengers on spaceship Earth. We are all crew.

- M. McLuhan

1.1 Research background

The U.S. economy witnessed significant transformation in the 1990s. The so-called digital economy emerged quickly from the traditional industrial economy that has dominated the country for over a century. Although its future evolution trajectory remains uncertain, the past decade has demonstrated that the core of the digital economy, information and communication technology (ICT), has surpassed all previous technological revolutions – the printing press, the telephone, the television, the computer – in its impact on the economic and social life of common people (Tapscott 1996; Standage 1998; Cohen, Delong, and Zysman 2000).

Historically, fundamental changes in the economic system are always closely associated with far-reaching environmental consequences (Landes 1969; Headrick 1990; Rees 1992; Grübler 1994, 1998), and human beings tend to be late to recognize and identify, much later to respond, to the unintended negative environmental impact of technological innovations. The continuous worldwide economic growth after World War II has improved the welfare of the inhabitants of the Earth in general, but rising

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This dissertation follows the style of *Annals of American Association of Geographers*.

tides have not lifted all boats. In addition to the growing gap between the rich and the poor, the North and the South, the foundation of all economic activities – the natural environment – has been deteriorating at an alarming accelerating rate despite many local improvements of environment (Meyer 1996; Goudie and Viles 1997).

The linkage between contemporary environmental problems and the sudden acceleration in the rate and power of technological innovations has posed a series of questions about the environmental impacts of the digital economy, such as: is the digital economy a truly clean, completely environmentally benign economy, which will serve as the holy grail of the environment? Or alternatively, will it bring more burdens to the fragile environment by encouraging more demands on material and energy (Sui and Rejeski 2002)?

It is a daunting task to answer these challenging questions. Few available studies have not been able to provide definitive statements. Mixed evidence about both positive and negative environmental impacts of the digital economy has been reported in the literature (Marvin 1997; Mills 1999; Romm 1999; Hurst 2001; Reichling and Otto 2001; Gay 2002). On the one hand, the declining energy intensity and the decoupling of many kinds of raw materials at per capita level from manufacturing processes indicates the positive gains to the environment. On the other hand, the continuing growth of material consumption on absolute volume, the possible rebound effect, and the newly-created demands and consumptions on energy and materials, all point to the potential negative impact on the environment. The perplexing net environmental effect of the digital economy remains unknown for the time being.

The first generation of environmental policy, kicked off by the enactment of National Environment Protection Act (NEPA) in 1970, aims to mitigate severe water and air pollution through tough, nationally uniform "command-and-control" approach. To a large extent, it was successful in alleviating pollution from big factory smokestacks and dirty effluent pipes in the past three decades, bringing about cleaner air and clearer water in general[1]. However, whether or not the same policy path will be efficient and effective in dealing with the environmental problems of the digital economy is largely uncertain.

First, the sources and nature of environmental problems are shifting in the digital economy. Environmental threats today are quite different from those tackled over the past few decades. While pollution from manufacturing sectors turns to be less significant, global environmental threats, such as deforestation, climate change, stratospheric ozone layer depletion, and loss of biodiversity becomes more of great concerns. These new emerging problems are usually less apparent and acute, but are more subtle and difficult to identify, are potentially more harmful to human beings, and possibly impact larger geographical regions and last much longer (Esty and Chertow 1997; Sui and Rejeski 2002).

Scholars, governmental officials, and business leaders have recognized the importance of addressing environmental problems in the context of the dynamic digital economy (Beck 1992; Esty and Chertow 1997; Richards, Allenby, and Compton 2001; Sui and Rejeski 2002). In academia, the problem has been explored from both theoretical and empirical perspectives (Beck 1992; Fichter 2001; Miller and Wilsdon 2001; Gay 2002; Matthews et al. 2002). At the governmental level, new environmental policy has been experimented and evaluated, in industries and businesses, funds have been allocated to support the research on the relationship between economic systems and environment in the context of the new kind of economy (e.g., AT&T's fellowship on industrial ecology). These innovative initiatives offer many interesting arguments, valuable evidence, and inspiring thoughts; however, they generally suffer from the problems of inadequate quantification and the lack of regional dimensions in addition to the insufficient quantity.

Economists are traditionally among the vanguards in the academia to tackle the relationship between economic growth and environmental problems. Under the umbrella of neoclassical economics, pollution is generally viewed as an important form of externalities, which often generate harmful impacts to welfare (James, Jansen, and Opschoor 1978). An impressive literature on environmental problems has been devoted to environmental externalities and the tradeoffs between economic welfare and environmental qualities. Most of these studies adopt partial-equilibrium techniques that consider only variables regarding environmental impacts. The major limitation of the approach is that it does not capture some of the individually negligible but collectively very significant environmental impacts, such as carbon dioxide emissions from automobiles.

Input-output (IO) models are able to overcome these limitations and help better understand the relationship or linkage among major sectors of an economy with a large number of economic-environmental variables. The IO model was originally proposed for recording the transactions (demands) between economic sectors by Professor

Leontief (1941) in his study on the structure of the U.S. economy of the 1930s based on the earlier work of Mirabeau (1968) and Walras (1874). Environmental problems may also be tackled in physical terms as well as in monetary values in IO models. One noticeable advantage of the IO model is its flexibility to investigate problems in different spatial and temporal scales. The linear nature of the IO model does limit the scope of its application, but never excludes it from popular applications in solving social, economic, and environmental problems.

Geography as an academic discipline has a long and proud tradition in studying the human-environment relationship (Marsh 1864; Thomas 1956; Pattison 1964; Wilbanks 1994; Turner 2002), and geographers, especially regional geographers, have contributed much to the regional economic development issues using IO analysis (Isard 1951; Hirsch 1959; Isard et al. 1960; Miernyk 1970, 1982; Polenske 1980; Harte and Lonergan 1989; Bolton, Jackson, and West 1990; Siegel, Alwang, and Johnson 1995; Jackson and Dzikowski 2002; Hu and McAleer 2004). But it is also surprising that few geographers have been involved in intellectual expedition to investigate the environmental consequences of the digital economy with IO modeling, although such needs have already been recognized (Duchin 1992, 1998; Moffatt and Hanley 2001; Dewick, Green, and Miozzo 2003).

1.2 Research objectives

This study is dedicated to bridging, if not completely, at least partially, the gaps between the needs and available studies on the environmental impacts of the digital economy. The spatial scale is set at regional level, and the environmental impact (consequence) is defined as industrial point pollutant emissions in this study. This study has four major research objectives:

1) Within the Austin-San Marcos Metropolitan Statistical Area, provide empirical evidence on the environmental consequences of the emerging digital economy in terms of the quantity, the pattern, and the sources of point industrial air pollutant discharges, and forecast the trends (both quantity and patterns) of pollutant emissions under four major evelopment scenarios in the first decade of the 21st century (2000 - 2008).

2) Review the nature of the first generation of environmental policy and explore the possible evolution paths for the next generation of environmental policy in the context of the digital economy.

3) Test and enrich the tools used by geographers to explore the complex environment-economy interactions through experimenting with IO analysis and several other analytic tools on the Austin-San Marcos Metropolitan Statistical Area.

4) Help the general public better understand the relationship between economic growth and environmental problems in the context of the digital economy. This is important because public participation has been widely recognized as an integral part of achieving the goal of sustainable development.

The Austin-San Marcos metropolitan statistical (Austin MSA) area of Texas is selected as the case study area. The temporal interval of the study is 19 years, from 1990 to 2008. The dynamic transformation of the economic structure of the Austin MSA and its environmental consequences are investigated at the first half of the study period

(1990 - 1999). Industrial point pollutant emissions is simulated at the second half of the period (2000 - 2008) based on four major development scenarios. Both three- and seven- segments[2] IO models for the years of 1990, 1994 and 1999 are constructed. Four analytic tools are chosen for the three major research objectives: general IO analysis and hypothetical extraction measurements (HEM) are used to detect the region's economic structure change; environmental extended input-output (EIO) analysis is implemented to analyze and forecast the relationship between regional economic structure change and the quantity and pattern of pollution discharges; and structural decomposition analysis (SDA) is performed to identify the major factors influencing changes of the sources of the pollution.

1.3 Dissertation structure

This dissertation is divided into eight chapters. Chapter I briefly introduces the research background, defines the research objectives, and discusses the significance of the study. Chapter II reviews literature relevant to the research topic, including the major features of the emerging digital economy, the relationship between the economic development and the environment, and the traditional economic analysis methods on the environmental problems. Chapter III describes the study area – the Austin-San Marcos Metropolitan Statistic Area (MSA) – including a brief history, the dramatic economic structure change, and rapid development since the 1980s, and the current environmental management practices. Chapter IV suggests possible evolution paths of the next generation of environmental policy in the digital economy on the basis of the review of the major features of the environmental policy in the industry economy (first generation). This chapter also raises the research questions of the study. Chapter V describes the methodology used in this study, including general IO analysis, EIO, HEM, and SDA. Chapter VI presents the results of the dynamics of the regional economic structure of the Austin MSA in the 1990s based on general IO analysis and HEM. Chapter VII reports the results of the changes on the quantity and pattern of pollution discharges as the consequence of the economic structure change, the major factors contributing to the change of the pollution discharge, and the forecasted pollution discharges on the basis of four development scenarios by 2008. Chapter VIII summarizes the theoretical, methodological, and policy implications of the study. This chapter also discusses the limitations of the study and the future research directions. There are also three appendixes. Appendix 1 lists detailed segment information for both three and seven segments IO models. Appendix 2 provides the transaction tables, Leontief inverse matrices, and total flow matrices for the years of 1990, 1994, and 1999. Appendix 3 presents all the results of SDA at a segmental level.

Notes

[1] In the U.S., from 1970 to 1995, population and GDP increased 31% and 111% respectively. But the emissions of four critical pollutants all declined. Carbon monoxide by 28%, volatile organic compounds by 25%, sulfur dioxide by 41%, and lead by 98% (USEPA 2003a).

[2] A segment is defined as a group of economic sectors in an economy. Chapter V gives a more detailed explanation about the term.

CHAPTER II

LITERATURE REVIEW

I have gathered a posie of other men's flowers, and nothing but only the thread that binds them is my own.

- M. Montaigne

2.1 Introduction

This chapter presents a comprehensive review of the literature regarding the three major themes of the dissertation – the economic structure change, the interaction between environment and economy, and economic analysis of environmental problems. The three sections of this chapter sequentially review the literature on the emerging digital economy, the evolution of the paradigms describing the relationship between economic development and environment, and major economic analysis methods of environmental problems.

2.2 The emerging digital economy

It is generally agreed among scholars as well as policy makers that the U.S. economy has been undergoing a fundamental transformation since the early 1990s (Tapscott 1996; Standage 1998; Cohen, Delong, and Zysman 2000). The core of the transformation is the development and diffusion of information and communication technology (ICT). The ICT has not only amplified productivity in one or several leading economic sectors as many previous technological revolutions did, but more importantly, has become the engine for almost all economic sectors (Tapscott 1996; Litan and Niskanen 1998; Tapscott, Lowy, and Ticoll 1998; Cohen, Delong, and Zysman 2000). A new kind of economy has risen quickly during this process.

Among various names suggested for the new economy, such as “innovation economy,” “network economy,” “weightless economy,” “knowledge economy,” “e-economy,” “digital economy,” or simply “new economy” (Cohen, Delong, and Zysman 2000), the term “digital economy” is adopted in this study because it is used by the U.S. Department of Commerce and is most familiar to the general public.[1] There is no consensus on the definition of the digital economy so far.[2] However, three significant features of the digital economy can be identified. First, the digital economy refers to the revolutionary development of the ICT sectors and their tremendous impacts on the other economic sectors. Second, the digital economy means the exponential growth of Internet users and Internet-based business (also widely known as electronic commerce or E-commerce) for the delivery of goods and services. Third, the digital economy entails the globalization of business and growing flexibility for both producers and consumers at every expanding spatial and temporal scale (USDOC 1998, 2002a; Pohjola 2002). The following section reviews the above three features and discusses the possible social and economic implications of the digital economy to the society as a whole.[3]

2.2.1 The ICT revolution

The core of the ICT revolution is the computer and its wide-ranging applications. But the legendary story about the ICT revolution should start with the evolution of the transistor, the heart of ICT hardware. The evolution of the transistor can be explained clearly by "Moore's Law," which was coined by Intel Corporation co-founder Gordon Moore in the 1960s. It predicted that the density of transistors on a silicon chip (and thus the power of the chip) would double every 18 months. Interestingly, this law still holds true today (Figure 2.1). Moore's law, together with a set of other technological trajectories,[4] underpins the revolution in the ICT and world-wide development of the Internet (Dosi 1984).

The performance of computers increases dramatically and the prices plummet as the density of semiconductor continues to increase. It is estimated that there was perhaps a billion-fold increase in the installed base of computing power in the world from 1950 to 1990 (Campbell-Kelly and Aspray 1996). Today's $1000 personal computers have the same computational capacity of a $20,000 scientific workstation five years ago. The average price per megabyte hard drive disk decreased from $11.54 in 1988 to $0.02 in 1999 (Toigo 2000), and what was once a supercomputer is now "run-of-the-mill" (Table 2.1).

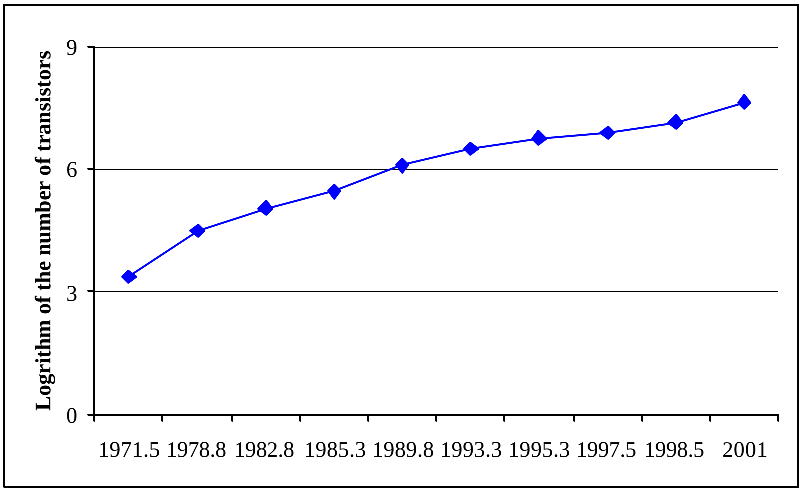

Figure 2.1. Moore's Law.
Sources: Waston (2000), Elliott (2003), and Intel (2003).

Table 2.1. Semiconductor parts price indexes by end use, North America, 1992 - 1999

Sectors	Compound annual change rate (%)		
	92-99	92 - 95	95 - 99
Auto	-12.46	-4.64	-17.91
Communication	-15.58	-3.41	-23.69
Computer	-34.74	-13.29	-47.26
Consumer	-15.22	-2.17	-23.85
Government	-14.74	-3.37	-22.39
Industrial	-16.11	-4.27	-24.02

Source: Aizcobe, Flamm, and Khurshid (2002).

The enormous increase in processing capacities generated by the hardware revolution has expanded, is expanding, and will continue to expand the applications of computers. Initially the computer was seen and used as a powerful calculation machine good at performing a complicated and lengthy set of algorithms. The world's first computer, ENIAC, born in 1946 at University of Pennsylvania, was the product of a military project named Project PX. At the beginning, most computers were limited to military applications such as the famous Whirlwind and SAGE projects. The large-scale civilian applications of computers started in the 1960s when society's demands for more efficient handling of a large volume of repetitive tasks (e.g., intensive calculation, report-generating, and record-analyzing) increased quickly. The capacities of the computer were soon expanded beyond performing repetitive calculations into the area of automating established processes (e.g., automated reservation system in air industry, sorting and classifying in insurance industry).

With the continuous growth in computing power and declining hardware prices, computer applications continued to diffuse into more areas. Computer-aided design (CAD) and automated office software turned out to be two hot spots in the early 1980s, which later led to the fundamental revolution in all kinds of design and office routine jobs. As the popularity of the computers in almost all fields of society grew, computer experts soon found that the computer's major function should not be confined as a calculator, nor as a database manager, but should be expanded to a machine which can be used to test many kinds of "what-if" questions. Theoretically, computers allow unlimited experiments in the virtual world, which may be prohibitively expensive in resources and time in the real world. With this insight, the application of computers soon penetrated into two other important domains: the spreadsheet and the real time controller. The former is used extensively in various office environments; the latter later evolved into indispensable parts in both the industrial production process (e.g., industrial robots) and the retail business (e.g., retail price-tag scanners).

The evolution of computer never ceased, and the application of computer consequently grew out of the limits of the traditional domains and penetrated into more social and economic areas such as agriculture, education, and entertainment. Two quite different paths generally dominate the evolution process: one is that computers have penetrated inside conventional products as they start to embed into systems and merchandise; the other is that computers have connected with each other to create the so-called World Wide Web (WWW) – a distributional global database of information accessible through the single global network – the Internet. The evolution along the first path is usually invisible, with the computers (or microprocessors) embedded in traditional products that alter the way such products perform. One of the eminent examples is the microprocessor in the various systems of an automobile. A typical car has about 30 microprocessors, making it safer, more efficient, and more reliable (Mowery and Rosenberg 1998). Along the second path, the connected computers lead to the formation of the global web of the Internet. The ICT revolution also caused the rapid rising of the ICT sectors and their enormous impact on the economy.

2.2.2 The rise of the ICT sectors and its impacts on the economy

In the U.S., ICT industries' share in total economic output grew from around 5.8 percent in 1990 to 8.3 percent in 2000, an approximately 40 percent increase. Although ICT industries accounted for less than 10 percent of total U.S. output, they contributed about 30 percent of the total U.S. economic growth in the second half of the 1990s (Tables 2.2 and 2.3). In 1998, the ICT workforce totaled roughly 7.4 million, accounting for 6.1 percent of all employment. ICT industry employment grew almost 28 percent from 1994 to 1998, compared to an average 11 percent in non-farm employment during the same period of time.

Table 2.2. Contribution of the ICT to the real GDP growth, 1996 - 2000

Items	Year				
	1996	1997	1998	1999	2000
(1) Changes in real gross domestic income (GDI)* (%)	3.5	4.5	5	4.5	4.7
(2) ICT contribution (%)	1.1	1.1	1.5	1.2	1.2
(3) All other industries	2.4	3.4	3.5	3.3	3.5
(4) ICT share in GDI change (2) / (1) (%)	32	25	29	28	26

*: GDI: the income that originates from the production of the goods and services.
Source: USDOC (2002a).

Table 2.3. The ICT sectors' share in the U.S. economy, 1996 - 2000

Items (Billion USD)	Year				
	1996	1997	1998	1999	2000
(1) GPO* of	522.0	588.4	646.9	718.2	796.6
(2) GDP	7715.9	8225.0	8750.2	9279.7	9941.6
(1)/(2)	6.77%	7.15%	7.39%	7.74%	8.01%

*: GDP is usually higher than GPO, so the actual ICT shares may be slightly higher than the figures in the table.
Source: Calculated by the author with the data from the USDOC (2002a) and the U.S. Census Bureau (2003a).

One of the main reasons for the growing importance of the ICT sectors is the continuous investment in ICT hardware and software in all the other economic sectors. U.S. business invested $407 billion in 1999, an over 100 percent increase compared to amount of 1992. At the same period of time, investment in "other capital equipment," including industrial equipment, fell six percent, from 38 percent to 32 percent, in total investment. The annual output growth rate of the ICT sectors jumped from about 12 percent in the early 1990s to roughly 40 percent in the six consecutive years following 1993. Prepackaged software and computer services had a remarkable expansion from 1995 to 2000, with a 17 percent average annual output (GPO)[5] growth rate.

Jalava and Pohjola (2002) synopsized three primary impacts of the ICT sectors[6] on economy: (1) the producing of ICT goods and services contributes directly to total value added generated in an economy, (2) the use of ICT capital as an input in the production of other goods and services indirectly contributes to economic growth, and (3) the growth of the ICT sectors contributes to the productivity of the economy. According to the annual report of the digital economy released by the U.S. Department of Commerce (USDOC 1998, 1999, 2000, 2002a), the ICT sectors have significantly influenced the U.S. economy, and the dynamism of the ICT sectors has led the society into a new economic era.

The contribution of ICT productivity growth is generally positive and significant, most clearly in service industries that purchase ICT (Baily and Lawrence 2001; USDOC 2000). The real net stock capital per labor hour is a direct measurement of the productivity growth. The ratio of the capital stock of computer hardware to hours worked (capital deepening[7]) increased by an average of 16.3 percent annually over the period 1991 to 1995, and 33.7 percent yearly between 1996 and 1999; but the average capital deepening in most other sectors (not including computer hardware and software, and communication equipment) averaged only about 0.5 percent over the 1990s.

At firm level, Brynjolfsson and Hitt (1998) find that average productivity is the highest among firms with both high ICT investment and decentralized organization. Brynjolfsson and Yang (1999) report that a one-dollar increase in computer capital is associated with a $10 dollar increase in the valuation of the firm in the stock market. At the sectoral level, several independent studies show that the ICT contributed about two-thirds of the total acceleration in labor productivity growth in the second half of the 1990s[8] (USDOC 2002a; Table 2.4).

Table 2.4 Contribution of ICT capital to growth of the labor productivity

Studies	Period	Capital deepening		Technical advance		Total ICT contribution	Productivity acceleration	ICT share of acceleration
		IT	Other	IT	Other	a	b	a/b*100
1	1996 - 99 over 1991 - 95	0.45	0.03	0.26	0.41	0.71	1.04	68.3
2	1996 - 99 over 1974 - 99	0.40	NA	0.20	NA	0.60	1.10	54.5
3	1995 - 99 over 1973 - 95	0.47	NA	0.23	0.70	0.70	1.47	47.6
4	1995 - 98 over 1990 - 95	0.31	0.18	0.19	0.44	0.50	1.00	50.0
5	1996 - 98 over 1974 - 95	0.46	NA	0.27	NA	0.73	0.99	73.7

Source: USDOC (2000).

Though the full effects of the ICT on the economic productivity during the 1990s have not been completely unveiled due to difficulties in the measurement of output in many service industries, evidence from both sector and firm level analyses conclude that the ICT contributed substantially to overall productivity growth and thus to the entire economy, especially in the second half of the decade. The growth of the ICT sectors may not be the only indicator of the emerging digital economy, but it definitely is one of the most evident and important ones.

2.2.3 The coming of the Internet age

The IT revolution and the rise of the ICT sectors laid a solid foundation for the accelerated development of the Internet. Technically, the Internet is the result of two revolutionary factors: the availability of high-performance and low-price personal computers, and the network and the various media permitting these computers to intercommunicate with each other.

In the U.S., like the initial applications of computers, the origin of the Internet was closely associated with military applications. The well-known APRANET was fully funded and built by the Department of Defense. With the plummeting cost of computers and communication bandwidth, the spread of the Internet became not only technologically possible,[9] but also economically feasible. At the beginning, the majority of the Internet users were in institutions, especially universities, where desktop computers were connected through a local area network (LAN). Files were accessed through Gopher, and email was exchanged through network systems. The Internet was not truly open to millions of home users until the hype text transfer protocol (http) and the image-displaying browser were released in the early 1990s. After the releasing of the first WWW software in 1992, the Internet began to grow exponentially worldwide.

Figure 2.2 shows the growth of the number of Internet users both in the U.S. and worldwide between 1995 and 2002. Figure 2.3 shows the increase in Internet host between 1990 and 2002.

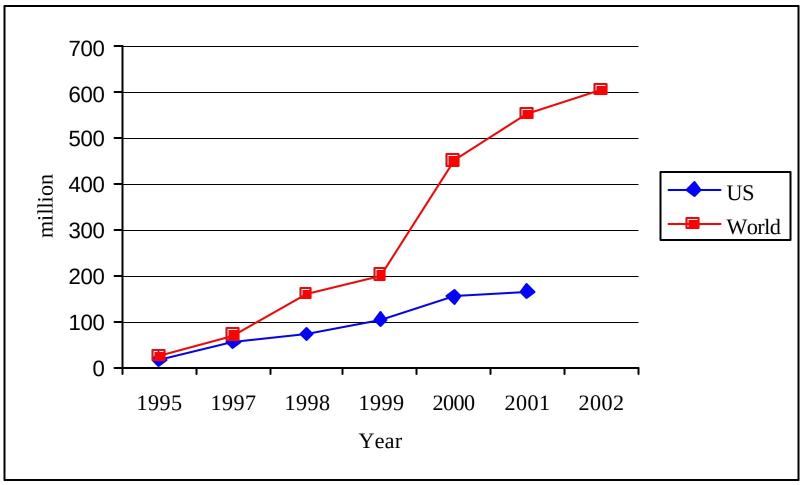

Figure 2.2. The U.S. and worldwide online population.
Source: Nua.com (2003).

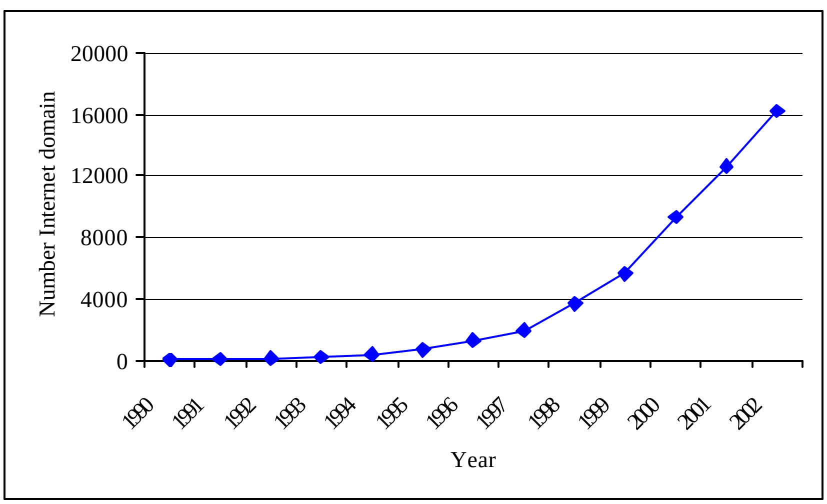

Figure 2.3. The growth in the Internet host, 1990 - 2002.
Source: ISC (2003).

By late 1999, more than 60 million computers had accessed the Internet, which is, in large part, based on the existing voice telecommunication systems. The emerging new generation of data connection technologies offers consumers more options such as cable modem, DSL, and wireless connections. The wide-band width, low-latency connections not only bring users more convenience and flexibility, but also generate more new Internet services and applications. But the Internet seems to be still in its early stage of evolution. Subsequent generations of still wider-bandwidth connections have are on the horizon. Maxwell (1999) predicts the video-on-demand (VOD) service will start in 2003 and fiber optic cables are to be connected to homes around 2015.

The bottleneck for both wire and wireless communication is the networking infrastructure. Although the communication companies are trying hard to upgrade the copper cable to fiber optic cable, fiber optic cable is generally not used in the "last mile" to home. The problem of the application of wireless communications lies in the narrow bandwidths. The fastest wireless data transfer rate today is around 14kb/sec, about four times slower than that of the average dial-up connection. Despite these difficulties, high-speed communication subscribers had reached 9.6 million by June 30, 2001, a 250-percent increase since December 1999 (FCC 2002). The acceleration in speed means that the Internet can accomplish more sophisticated tasks with much less latency and expense. On the side of wireless networks, the providers are setting off a new round of network deployment, bringing both new applications and challenges to equipment and software players. The backbone of the network, another important component of the Internet, is also evolving rapidly. It is predicted that a veritable tsunami wave of new capacity, technical advancement, and dropping costs is approaching (Cohen, Delong, and Zysman 2000).

By April 2002, total U.S. online population reached 165.75 million, compared to 18 million in 1995 (Nua.com 2003). The growth of online population is also evident across various demographic and economic dimensions such as race, ethnicity, income, and education (USDOC 2002a). The Internet is becoming an integral part of the daily life of more and more people. A variety of activities can be fulfilled with this new emerging media, such as e-mail, online shopping and entertainment, personal banking, driver's licenses renewal, conferencing, self-education, and more (Figure 2.4).

With the continuous growth of the computer processing power, widening communication bandwidth, and declining costs of computer hardware, software, and communication services, the Internet enters more domains of society, significantly impacting our daily lives and ways of doing business. The full story of E-commerce starts to unfold here.

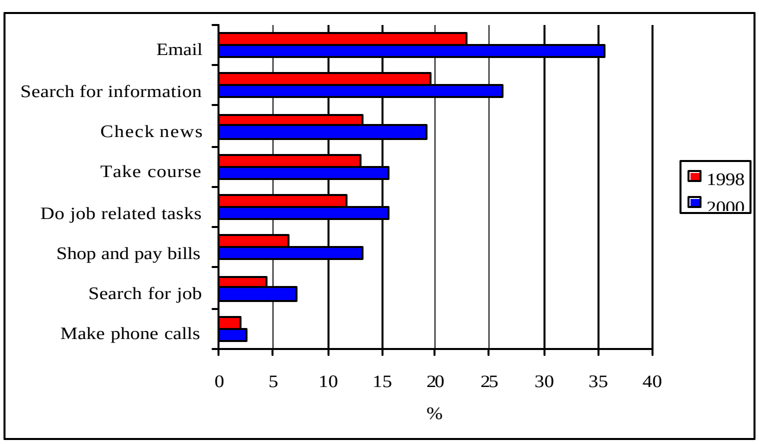

Figure 2.4. Percentage of online activities in the U.S. population 1998 and 2000.
Source: USDOC (2002b).

2.2.4 The emerging E-commerce[10]

By definition, E-commerce is Internet-based business for the delivery of goods and services on a global scale (Leebaert 1998). Several Silicon Valley firms first sensed the Internet's potential applications in business and started to get involved. Cisco was almost immediately aware of the commercial opportunities of the Internet; now it is the leading provider of the Internet traffic controllers, routers, and switches. Sun Microsystems is both the developer of Java, a cross- platform programming language especially suitable for the development of Internet applications , and an important supplier of servers for large web sites. Oracle's database software is almost the standard choice for most websites. These three firms are composed of key Internet infrastructure providers.

Big computer manufacturers like IBM, HP, and Dell also responded quickly to the business applications of the Internet. Dell rapidly shifted from the traditional production mode of build-to-order to the Internet mode of "just-in-time," which was quickly rewarded by decreasing cost, increasing sales, and fast growth. In contrast, Compaq's reluctance to replace its long-established traditional retail channels with the Internet-based ones turned out to be one of the major causes leading to its merger with HP in late 2001 (The Inquirer 2003).

Generally speaking, more technologically sophisticated and entrepreneurial firms are more likely to experiment with the computer and the Internet in commercial applications. However, rising competition among startups also became a significant stimulus to force more established firms to consider Internet applications for their businesses.

The startups initiated the Internet data communication business in the late 1980s with funds mainly from venture capital investors. The first major successful startup was Netscape. Founded by two university professors, Jim Clark of Stanford and Marc Andreessen of University of Illinois, Netscape was at the very beginning dedicated to the development of web browsers. Its value on the stock market skyrocketed to nearly one billion shortly after it went public in August 1995. Shocked by the legendary success of Netscape, venture capitals began to rush into those startups related to the Internet. By March 9, 2000, about 370 Internet firms had gone public and their total valuation reached $1.5 trillion, compared to an extremely low sale of $40 billion (Perkins 2000).

The Metcalf law also worked out very well. The rule is simple: more users, greater commercial opportunities, and less cost. The rapid growth in returns stimulated more startups to develop new software, create new web pages, and open new web-based services. From 1995 to early 2000, investments to the pioneer startups gained excellent returns as firms went public despite fluctuations. Facing unbelievably high profits, venture capital investing became frenzied. In 1999, the average return for early stage funds was 91.2 percent (NVCA 2000).

Although a large amount of investment in this massive investment bubble was later proven to be blind, rash, and even foolish, the feverish and panic investment wave has not only created some global leaders of the Internet, but also forced established firms to react to the change of business environment. During the process, cyberspace was gradually transformed into an economic space at various levels. This capital-driven commercialization process also exhibited the winner-take-all characteristic in the business game of the Internet. The earliest entrants growing to substantial size often acquire an insurmountable first-mover advantage.

It is not a simple task to define the boundaries and to categorize different types of E-commerce. Hunt and Aldrich (1998) uses an ecological metaphor to describe the organization of the Internet. Kenney (2001) categorizes five kinds of E-commerce by the business types of the websites: portals and other miscellaneous sites, consumer-to-consumer (C2C), consumer-to-business (C2B), business-to-consumer (B2C), and business-to-business (B2B) sites.

1. Portal E-commerce

Established in the early stages of internet commercialization, portals are important "gates" for web users. And nearly all the dominant global portals such as Yahoo, Excite, Altavista, and Infoseek are the U.S.-based.

2. C2C E-commerce

C2C sites create virtual marketplace to connect consumers together. The profits come not from direct sales, but from other revenue sources such as advertising, commissions, and referee fees. The premier example is eBay. Established in 1995, the company has grown into the biggest C2C site in the world. It planned to expand the business into 25 countries by 2006 (Kenney 2001), but by the end of 2002, the businesses had been operated in 20 countries (Ebay 2003).

3. B2C E-commerce

The idea behind B2C E-commerce is to replace physical stores (brick and mortar) with online sales (click and pay). When the virtual storefront substitutes for the physical one, the sellers save the cost of spaces, employees, and supply chains. In return, the consumers possibly get the same products with lower prices. Large retailers like Wal-Mart, Home Depot, and Office Depot have quickly added online services. One direct consequence of online retailing by these giants is the further marginalization, in some cases even the devastation, of both small independent and department stores. The shift is also changing the purchasing habits of the consumers.

Amazon.com started its online bookstore in July 1995, one year after the launching of Netscape and Yahoo. Today, it has expanded its business from books to thousands of items such as CDs, videos, toys, electronics, and computers. The successful listing of Amazon.com on the NASDAQ prompted another round of frenzy investment in online retail startups. Following the steps of Amazon.com, there appeared a plethora of specialized sites selling groceries, pet supplies, air travel services, CDs, PCs, and more. Nearly every commonly consumed item can be found in more than one online firm. Some of these firms have not only survived, but have even gone public. Others were bankrupted, consolidated, or delisted from the NASDAQ when the initial public offering (IPO) boom broke in early 2000. Although parts of Amazon's empire have gone bankrupt, the sales still reached $3.93 billion in 2002, a 26 percent increase from that of 2001. The pro forma[11] net profit was $223 million in 2002, compared to $167 million in 2001 (Amazon.com 2003).

Facing threats from those startups, traditional retailers also followed to establish online operations. Since selling online is totally different from selling in stores, even the retailer giant Wal-Mart had to establish a joint-venture agreement to reestablish its online selling after the first unsuccessful attempt (Waxer 2000).

B2C E-commerce is still undergoing rapid changes along an uncharted path. But it is almost certain that the U.S. retail system has been forced to operate more efficiently than ever due to the birth of E-commerce.

4. B2B E-commerce

B2B E-commerce aims at providing online marketplaces for businesses to buy and sell. Although B2B firms emerged later than B2C did, they quickly beat B2C in sales. By the middle of 1998, independent market space of B2B has been filled with nearly every imaginable business (Helper and MacDuffie 2001; Kinsey 2001). Most B2B firms were funded either by traditional venture capital or the new publicly-held venture capital firms such as ICG and CMGI.

Just like B2C E-commerce, the establishment of B2B sites was initially launched by startups and uncontested by existing large firms and industries. These startups aimed at attracting established firms to their sites. Larger firms soon decided to create their own websites in order not to give up market shares. In 2001, the largest B2B sites were those operated by focal firms such as Cisco, Dell, IBM, and Intel for their suppliers and/or consumers.

Kenney (2001) argues that U.S. firms have become the global leader in every aspect of the Internet business except wireless Internet and optical switching. He further attributes the situation to three major factors: (1) the early thoroughgoing deregulation of the U.S. telecommunication market and the flat-rate tariff structure for local phone service significantly reduced online costs, encouraging the use of telecommunication services and the Internet, (2) Americans seem to be comfortable with purchasing remotely. With the previous experiences of purchasing by catalog, by phone call, or by mail, and paying by credit card, it is not a difficult task for them to shop online, (3) the unique environment of the venture capital system strongly supported high-tech entrepreneurship. Venture capital entered almost all types of Internet investments. The large amount of funds not only financially nurtured the rapid growth of the Internet, but also attracted many of the best managers, technologists, and workers of the country to compete and make their fortunes in gold mines of newfound cyberspace.

2.2.5 The digital economy: Respect and prospect

The continuous productivity gains, economic growth, and E-commerce boom in the 1990s seem to support an optimistic view of the future for the digital economy. The third annual report on the digital economy released by the U.S. Department of Commerce claimed that E-commerce has become the engine for economic growth in the new millennium, and the U.S. economy has entered a new period of economic growth with higher, sustainable growth rate and productivity gains (USDOC 2000).

But changes sometimes come more quickly than what has been predicted. During the second half of 2000, when many economists were busy forecasting the growth rate for the new digital economy, the U.S. economy, for the first time in more than a decade, quickly sank into a recession after five years of unprecedented growth.

Following terrorists attack on September 11 of 2001, more uncertainty and doubt were added on the future of the digital economy. The answers to the nature and future of the digital economy suddenly became elusive and unclear.

Due to the strong growth inertia in the previous decade, economic indicators did not reflect the recession till the first half of 2001. ICT investment continued to grow through the end of 2000, but the nominal ICT investment in the following year was slashed by 16 percent and computers and peripherals were down 29 percent. Both production of equipment and the dollar value of ICT shipments plunged over 20 percent during the first two quarters of 2001, with a slight bounce-up during the second half of the year. Business spending on computers and peripheral equipment dropped 20 percent during the fourth quarter of 2001 compared to that of the same period in the previous year (USDOC 2002a).

Another important signal of the recession was the shakeout of Dotcoms. According to a survey, from the first quarter of 2000 to the first quarter of 2003, 962 large Internet firms were shut down[12] (Figure 2.5). Close to one million people lost their jobs in 2001, compared to three million jobs created in the last five years (Baker 2001). According to the study conducted by the Industry Standard, from the December 1999 to July 2001, over 134,727 employees in 902 dot-com related companies lost their job.[13]

The economic environment is cold and difficult under the severe recession. Dropping investments on ICT software and hardware, plunging stock values, retreating flows of venture capital, dotcom shutdowns, layoffs, all these bad signals have triggered deep worries about the future of the digital economy. Debates like "Dotcom or Notcom" have filled headlines of magazines and websites (Kalin 2000; Krin 2000).

Despite these difficulties, the economy is still benefited from the past investments; the ICT continues to fuel more applications; online expenditures are expanding; and more dotcoms are emerging despite the demise of the old ones. More importantly, as E-commerce turns into a standard medium in business, the digital economy is becoming a taken-for-granted (Kenney 2001). The recent skepticism is reasonable, but possibly greatly exaggerated, and the previous expectation to the digital economy might be too high to be realistic (especially the second half of the 1990s).

During the recession, many encouraging signs indicated that the digital economy was battered but enduring. Despite a 1.4 percent decline in total private sector employment during 2001, employment still grew by 0.5 percent in telecommunication services and 1.4 percent in computer software and services. On each of the last eight occasions since 1950 when growth in non-farm business output has turned negative for two consecutive quarters, productivity growth has also turned negative. On the contrary, productivity growth remained at a remarkably robust 1.9 percent during 2001. Continued strong productivity growth in a period of economic weakness suggests that U.S. industries are continuing to benefit from past and current investments in ICT equipment, software, services, and related human skills, which are building foundations for a stronger digital economy in the coming years (USDOC 2002a).

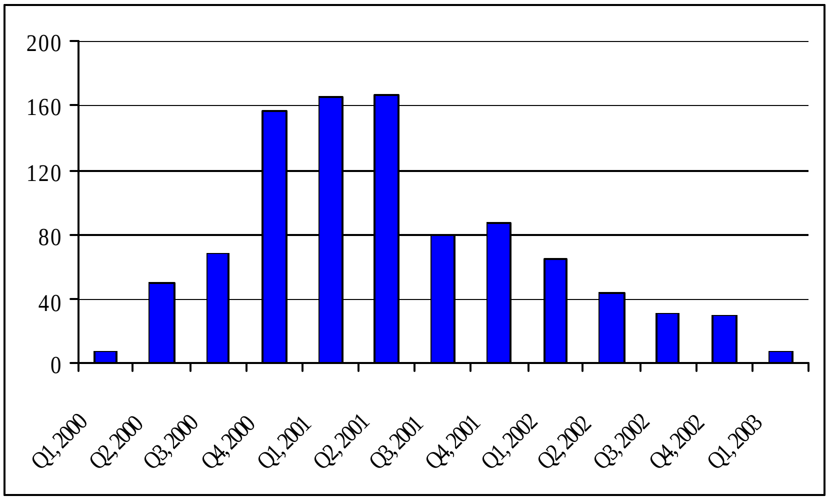

Figure 2.5. Quarterly dot.com shutdowns, Q1, 2000 – Q1, 2003.
Source: Webmergers.com (2003).

Then what is the future of the digital economy? What are the impacts of the digital economy on society and to our daily lives? It is always a tricky and hazardous business to predict the future[14], and it is more challenging to forecast the impacts of the rapid evolving digital economy under an uncertain economic environment. Despites these difficulties, scholars have attempted to explore these perplexing questions from various perspectives.

Pohjola (2002) believes that the digital economy will impact economic growth, geographic concentration of production, and equity issues related to income and wealth. Miller and Wilsdon (2001) argue that the digital economy is altering human being's relationship with the natural environment by changing the way of doing business. Thus it is possible to channel the dynamism and creativity of the digital economy for the good of economy, environment, and the society. Cohen et al. (2000) point out that the digital economy is impacting almost all the important domains of society. They further suggest reconstructing the policy agenda in order to consider many broad social questions raised by the digital economy. Some commonalities on the impacts of the digital economy to society in general can be identified from these diversified perspectives and arguments,[15]

1) The impacts of the digital economy are diffusing into almost all sectors of the economy, rather than influencing just one or a few major economic sectors. Thus the economy is experiencing a fundamental structural change, characterized by the increase of gross output of the ICT and service sectors and the decrease of output of traditional pillar sectors such as mining and manufacturing.

2) The digital economy is intruding into almost all important domains of the society, changing all aspects of our daily lives such as shopping, communication, transportation, entertainment, education, and doing business; and altering the level, the pattern, and the style of consumption.

3) The digital economy is changing the geographic location of production. On the one hand, several centripetal forces (e.g., technological leakage, spillover between companies, and access sharing of a common pool of skilled labor force) are attracting the geographical cluster of industries. On the other hand, some ICT industries (e.g., semiconductor manufacturers) are shifting the mode of production from a single firm to extended networked firms. Geographic locations of ICT industries are under radical changes during the process of closing, sharing, and relocating wafer fabrication units (Mazurek 1994). Thus any generalization about the trend of the location change of the ICT production will be premature.

4) Recent economic recession has brought down the rapid growth rate of the digital economy in the 1990s, and it may well be some time before growth returns to its 2000 peak. But the stronger foundation of the economy is still under construction, indicating an optimistic future for the digital economy.

In the several paragraphs above, I have attempted to synopsize the answers for those frequently-asked questions (FAQ) about the impacts of the digital economy on the economy and society in general. The answers may be far from complete, but those infrequently asked questions (IAQs) such as "what are the environmental consequences of the digital economy?' seem to require more immediate attention. The environmental dimension of the digital economy deserves equal, if not more consideration than the other two dimensions because it is one of the three major aspects of sustainable development (Munasinghe 1996). In addition, history has revealed that economic growth is always associated with some kind of environmental consequences. History may not always be used to interpret the future, but it at least provides some valuable insights and references. The following section focuses on the environmental impacts of the digital economy, starting from depicting the complex relationship between economic development and its environmental impacts since the Industrial Revolution.

2.3 Economic development and the environment

During the past 8,000 to 10,000 years, as human society evolved from hunting and gathering to an agrarian economy, especially since the beginning of the industrial age in the mid-18th century, human beings have increasingly transformed the Earth's surface, resulting in the deterioration of the fragile environment at an accelerating rate

(Sui and Rejeski 2002). The scope and scale of the environmental problems have expanded from local, to regional and global level,[16] coinciding with the increasing intensity and extent of human activities, and in many countries and regions, with the improvement of human welfare (Colby 1991). The major technologies associated with each stage of economic development actually played a dual role as both the source and remedy of environmental problems (Grübler 1994, 1998).

This section first reviews various perspectives of the relationship between economic development and the environment. It then introduces major economic development stages and their correspondent environmental problems. Following the discussion of human's knowledge and responses to these problems from the perspective of economics, the section ends with a summary of the latest studies on the environmental impacts of the digital economy.

2.3.1 Introduction

The economy is a collection of technological, legal, and social arrangements through which individuals in society seek to increase their material and spiritual well-being (Field and Field 2002). Environment, on the other hand, essentially refers to the conditions or surroundings where human beings or things exist, live, or develop. These conditions or surroundings could be roughly put into three categories: (1) the combination of physical conditions that affect and influence the growth and development of an individual or community; (2) the social and cultural conditions that affect the nature of an individual or community; and (3) the surrounding of an inanimate object of intrinsic social value (Gilpin 2000). Gilpin's approach, albeit with a strong anthropocentric flavor, recognizes that all the human activities (including economic activities) happen within the limits of the natural environment. However, till very recently, many scholars disagreed with Gilpin's view on the relationship between the economic system and the physical environment.

In the eyes of these scholars, the economic system is a close and cyclic system, in which producers and consumers interact through a market mechanism. The exchange of material and energy exists only between economic agents in the system, but not between the economic system and the natural environment. Cross-boundary energy and material exchange is totally ignored (Figure 2.6). Environmental parameters are relevant in circumstances related only to the problem of optimal extraction of non-renewable resources, or to the determination of the growth rates of renewable resources. Pollution is generally regarded as one important type of externalities,[17] created by the harmful residuals and the spill-over from not wholly efficient production and consumption processes.

This view on the environment-economy relationship is built on the framework of neoclassical economics, which was pioneered by Marshall (1890) and several other economists. Neoclassical economists believe that only two factors are relevant to an economic system: consumption households and production firms. It is assumed that households always try to maximize their satisfaction by allocating financial means over various consumption possibilities. Firms, on the other end, aim at maximizing profits under restrictions regarding to the availability of factors of productions (e.g., resources, capital, and labor). Households offer labor and other different things in exchange for certain products. Firms demand inputs such as labor and capital, and offer consumption goods in return. The behaviors of households and firms are determined by the prices of goods. Environmental goods and services are different from those conventional ones in five aspects: (1) lack of market, (2) difficulties in entering the market, (3) the effects of individuality; (4) the effects of externality, and (5) the uncertain and unknown effects (James, Jansen, and Opschoor 1978). The deficiencies of the market system in handling these problems are the major causes of the indifference to environmental problems in the traditional market system.

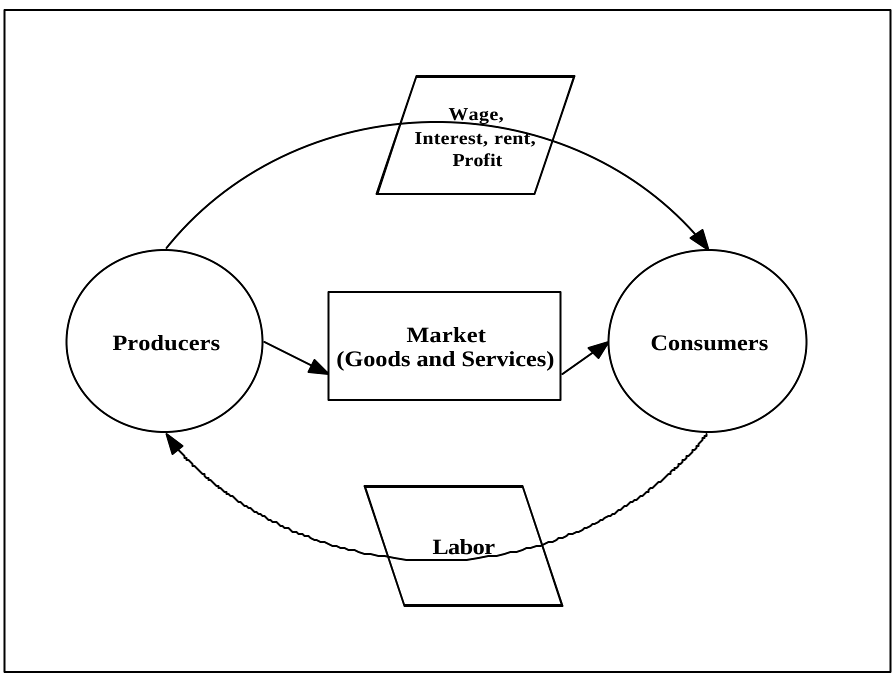

Figure 2.6. The components of a traditional economic system.
Sources: Asafu-Adjaye (2000).

The neoclassical view of the relationship between the economic system and the natural environment was challenged in the 1960s. Boulding (1966) applied two metaphors to criticize the ignorance of environmental factors in the traditional economic system: the spaceship earth and the cowboy economy. He argues that the physical environment has posed restriction on the economic development. In the framework of a cowboy economy, problems such as shortage of energy and natural resources should never be worried about because these problems are so insignificant and negligible compared to the vast size of the natural environment. By contrast, people in a spaceman economy realize that they have only a limited stock of inputs and the spaceship has only a limited capacity to carry wastes. The activities that can be undertaken on board the spaceship are therefore circumscribed absolutely by the ability of the on-board environment to cope with the consequences of those actions (Edwards-Jones, Davies, and Hussain 2000).

Boulding's insights were widely accepted and further explored in the following years. His followers and advocates generally agreed that: (1) the Earth is a nearly closed system with very limited material exchange with areas outside the system, and (2) economic activities must be kept within the limits of the natural capacity (although the boundaries of limits are hard to define). They also believe that the natural environment plays three important roles: (1) as a source of materials (in the form of stocks such as mineral deposits, or of flows, such as forest products and water resources); (2) as a sink to accept all the residuals from human economic activities; (3) as the amenity (such as nature's beauty, landscape etc.). Figure 2.7 shows the relationship between economy and environment as conceptualized by this group of scholars (Georgescu-Roegen 1971; Meadows, Meadows, and Behrens 1972; Costanza 1989; Meadows, Meadows, and Jorgen 1992; Daly 1968, 1992, 1996).

Both nature and society are seen not as simple linear systems, but as complex non-linear systems. The environmental consequences of the human impacts are believed to be far more complicated than had been understood before. Adams (1990, x) argues that the overlapping of the two complex systems ". . . Profoundly complicating our assessment of past human impacts on the environment, or estimates of future ones, is prevalence of indirect, or second order interactions . . ." The implication is that the environmental problems are far beyond an isolated single externality which could be easily corrected by a market scheme. James et al. (1978) argue that environmental impacts of human activities[18] manifest in three forms: (1) something is added into the natural environment,[19] (2) something is taken out of the environment as both renewable and nonrenewable resources, and (3) natural ecosystems are replaced by artificial ones.

If we consider the flows in Figure 2.8 in greater detail, there also exist three ways to solve the problem of pollution: (1) reduce the quantity of goods and services produced in the economy, (2) reduce the residuals intensity of production, and (3) increase recycling. If our ultimate goal is set to reduce the damage caused by the discharge of production and consumption residuals, Field and Field's (2002) framework is helpful to understand the relationship among residuals discharge, ambient quality, and environmental damage.

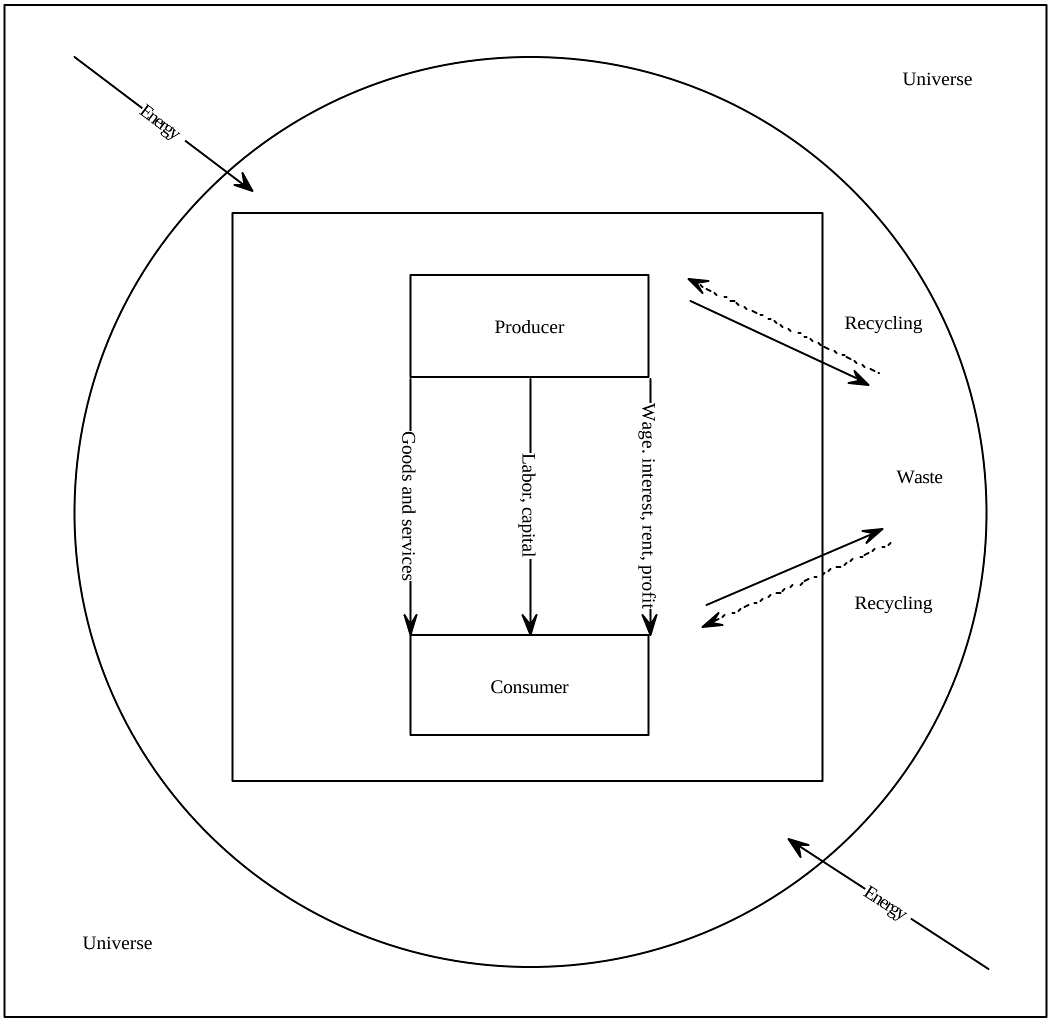

Figure 2.7. Economy as a subsystem of the natural environment.
Sources: After Asufa-adjaye (2000).

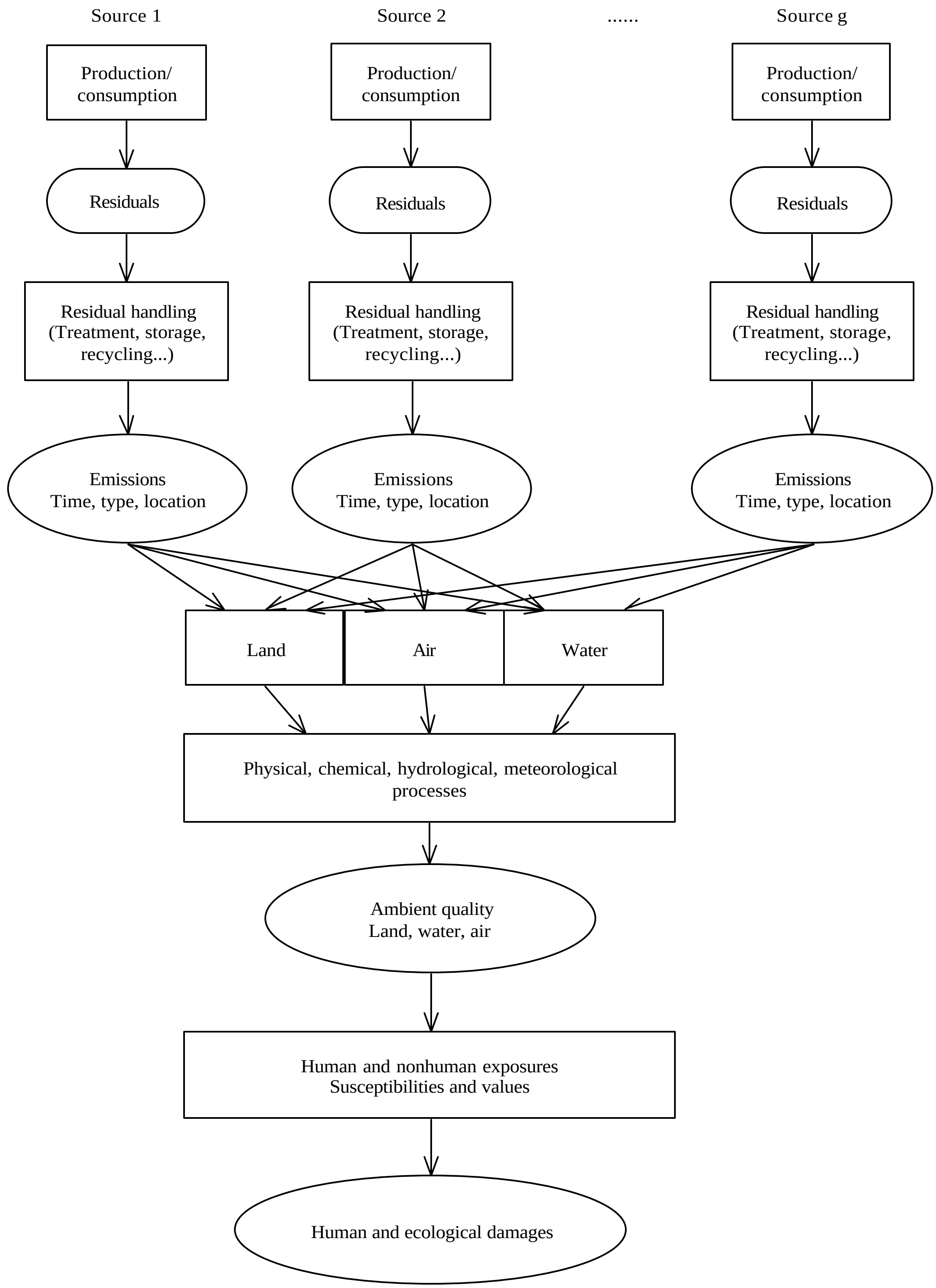

Figure 2.8. Emissions, ambient quality, and environmental damages.
Sources: After Field and Field (2002).

2.3.2 Major economic development stages and the correspondent environmental problems since the Industrial Revolution

Environmental change is a continual process that has been in operation since the Earth first came into existence. In most of the Earth's history, the agents of change have been the natural elements such as wind, ice, water, plants, and animals. The interactions among these elements have brought about gradual but sometimes catastrophic transformations to the atmosphere, hydrosphere, lithosphere, and biosphere. The mutual interactions between humans and nature started about two to three million years ago when *Homo sapiens* (modern humans) emerged as a new agent. Human beings then gradually evolved into not only the most powerful agents of environmental changes, but also a special sphere, noosphere.[20] However, significant human impact on the environment did not begin until about 8000 to 10,000 years ago after human beings colonized most of the Earth's warm and temperate zones and took hunting and gathering as their main food-procurement strategy. Simmons (1993) divides human history into five periods in terms of the unity of human cultures, economic activities, and human-environment interactions: (1) hunting-gathering and early agriculture (7500 BC to 4000 BC), (2) riverine civilization (4000 BC to 500 BC), (3) agricultural empires (500 BC to AD 1800), (4) the Atlantic-industrial era (AD 1800 to AD 1960), and (5) the Pacific-global era (AD 1960 -). Mannion (1991) suggests a more generalized while similar division. His trilogy of human history includes prehistoric (Hunter-gatherers, early agriculture, and metal-using sub-periods), historic, and post-1700 period. According to these two and other studies, human impact on the environment inevitably started in the periods before the Industrial Revolution.[21] However, the most significant environmental changes of the earth did not happen until the Industrial Revolution (Kates, Turner, II, and Clark 1990; Mannion 1991; Simmons 1993; Meyer 1996).

It is thus more important to take a closer look at the human activities and impact on the environment since the Industrial Revolution. Among those related studies (Mannion 1991; Simmons 1993; Grübler 1998), Grübler not only presents a comprehensive review of the relationship between the technology evolution and global change,[22] but also adopted a unique perspective. He argues that the disadvantage in unfolding the relationship of economic growth and environmental problems based on compartmentalized environmental media has potential danger in overlooking important interdependencies or joint causes of environment change, so he chooses to explain the relationship in terms of the technological clusters and the economic structural change. His major accounts are as follows:

1. Agriculture

There are three primary technology clusters from the early 19th century to the present. The first is from the early to mid-19th century. During this period, agricultural output and productivity growth were primarily achieved by biological innovations in the forms of inducing new crops and new agricultural practices. The second period is from the mid-19th century to the 1930s. The agricultural improvement in this period was driven mainly by new transportation modes and worldwide trade expansion. The third period covers the remaining years of the 20th century. The unprecedented output growth in this period was attributed largely to mechanization, chemical fertilizers, synthetic factor inputs, and new crops species.

Four major social and environmental consequences are related to the agricultural output and productivity growth: (1) the continuously rising labor productivity dramatically reduced the demands for farmers. Consequently, the migration from rural to urban areas led to the trend of urbanization,[23] (2) progress in agricultural technologies significantly decoupled the expansion of arable land from population and food consumption growth. International trade also effectively transferred the arable land expansion to less developed countries. Since the 1950s, the further expansion of agricultural land in industrialized countries is significantly limited, with some land even reconverted to other uses, and (3) the quality of the land is continuing to degrade. Humus losses over the last 300 years have averaged approximately 300 million tons annually. But the rate has increased to some 760 million per year over the last 50 years (Rozanov, Targulian, and Orlov 1990), (4) agriculture has significantly influenced both the global nitrogen (N) and the phosphorus (P) cycle. Overall, human activity has approximately doubled the rate of global nitrogen fixation since pre-industrial times (Ayres, Schlesinger, and Socolow 1994). The main mechanisms have been synthetic nitrogen fertilizers, leguminous crops, and biomass burning. The major environmental concerns about the N and P mobility include the surface and groundwater pollution, urban photochemical smog, the global greenhouse effect, and eutrophication of rivers and lakes.

2. Industry

Similar to agriculture, the global industrial expansion has been accomplished through successions of manufacturing technologies, materials, energy sources, and improvement of industrial organization. Industrialization has been divided into five stages: textiles (1750 - 1820), steam (1820 - 1870), heavy engineering (1870 - 1930), mass production/consumption (1920 - present), and total quality (1980 -). Each stage is associated with one or several major technologies, dominating energy type, and transportation method. The shift of stages can be observed from the four major groups of facts: (1) augmentation of resources usage, (2) diversification of products and production, (3) enlargement of markets (output), and (4) enhancing of productivity. The industrialization process brings both positive and negative environmental impacts. On the one hand, the sustained productivity gains generally reduced the demand for natural resources at a per capita base, and consequently mitigated the pollution to some degree. On the other hand, industrialization not only significantly intensified certain types of environmental impacts (e.g., deforestation, land disturbances, and air and water pollution), but also created new problems by introducing new materials (e.g., DDT and CFC) that may bring long-term negative impacts on the environment.[24] Environmental concerns are moving from local and regional to global levels; global warming and stratospheric ozone layer damage appear to be two prominent examples. Environmental productivity gains are still outpaced by output growth in general, resulting in continuous increase of resource depletion and pollutant emissions in terms of absolute volume.

3. Service

The service sector is playing an increasingly important role in the economy. The sector determines how individuals use their time and spend their money. The environmental impacts of the service sector are highly associated with the pattern and level of consumption. One example is the personal use of automobiles. Air pollution and urban sprawl are two direct results of the quick growth of private automobiles. It is possible that the environmental impacts from the service sector will be as significant as that from agriculture and industry in the future.

In October 1987, about 100 interdisciplinary scientists and scholars around the world gathered at Clark University in Worcester, Massachusetts for a week-long conference around the topic "The earth as transformed by human action." Meyer (1996) later synopsizes the major points of the conference as follows:

1) Human-induced change has penetrated into most of the significant spheres of the earth, including the atmosphere, biosphere, hydrosphere, and lithosphere. Human-induced change has not only become a significant fraction of natural change, but in some cases, has also overwhelmed natural impacts. In addition, the human-induced impacts have significantly changed the earth's principal material and energy cycle and landscape "faces" with an unprecedented acceleration rate since the Industrial Revolution.

2) Both inadvertent (e.g., CFC emission) and deliberate activities (e.g., deforestation and urbanization) are the causes of human-induced environmental changes

3) Modern environmental impacts are complexly interwoven together. Ameliorating one problem may create a new one or make another worse. And environmental problems are more likely to be nonlinear rather than linear in nature.

4) More environmental changes are expected in the future even though significant change has happened already. The increasing population and the improving living standard are two major causes of the expected environmental changes.

2.3.3 The evolution of the environmental management paradigms: From frontier economics to industrial ecology

The threats of environmental problems on human civilization have a long history, as do human's attempts to understand and deal with these problems (Kula 1998). The collapse of civilization in the Middle East is very likely related to large-scale deforestation, over-salinization, soil erosion, and the following desertification. The capital of the Roman Empire suffered from water pollution and human waste. In China, soil erosion caused by intensive logging and rice terrace was observed as early as in the Zhou Dynasty (1066 BC - 771 BC). In 1388, English Parliament has enacted the ordinance to penalize those who cast dung, the remains of animals and rubbish, into ditches and rivers (Clapp 1994).

Quesnay is among the earliest thinkers who were concerned about the relationship between economic growth and natural resource problems before modern economics was founded (Woog 1950). Malthus (1890) is probably the first economist who not only expressed grave concerns, but also proposed solutions to the population growth and resource (food) supply issues. Debates about the relationship among economic growth, environmental protection, and natural resource conservation have actually never ceased. Different questions have been raised, different assumptions made, different evidence and arguments provided, and various solutions and management strategies proposed and practiced. Various schools and paradigms appeared, being argued and challenged, prevailed, and evolved. More are yet to come. Most of these studies appearing after the nationwide environmental movement in the 1960s are rooted in two schools of thought: neo-classical economics and ecological economics.[25] The major themes of the two schools can be further represented in the following five major paradigms.[26]

1. Frontier economics

Colby (1991) employs "frontier economics" to describe the approach which prevailed in many of the countries until the late 1960s. The term first appeared in Boulding's (1966) short but inspiring article "The economics of the coming spaceship Earth." Frontier economics is built on the theory of neo-classical economics, in favor of free market economy, arguing that economy will correct itself in the long run if government and other obstacles are removed (Kula 1998).

Holding onto a strong anthropocentric stance, frontier economics suggests a total separation between man and nature. Nature is treated as an infinite supply of physical resources for human benefits, and also as an infinite sink for by-products of the consumption of these benefits. Nature is seen in this paradigm as existing to be explored, manipulated, exploited, and modified by humans. The biophysical environment is regarded as irrelevant to the economy. As Thurow (1980) argue, it is not rational to worry about natural resource exhaustion from the point of view of economics. Another important figure, Gifford Pinchot, the former head of the U.S. Forest Service, contends that there are only people and resources; animals and other species are merely resources for mankind to exploit and enjoy for recreational proposes and for their aesthetic values. They should be saved for future generations only for similar exploitation and enjoyment (Fox 1981; Sessions 1995a).

Frontier economics is deeply influenced by Bacon's thought of "technological progress" which once illuminated the way of modern Western science. The Baconian paradigm sees nature as existing for man's instrumental benefit: to be explored, manipulated, exploited, modified, and even cheated in any way possible that could improve the material quality of human life (White 1967; Berman 1981; Pepper 1984).

The growth rate of the gross national product (GDP) has been almost universally accepted as a standard measurement rod for the economic success of the nations. Likewise, at an individual level, income and wealth give a person great prestige in a modern consumer society. Consumption and production are regarded as good things, and little consideration is paid to resource depletion and environment deterioration. Frontier economics errs in ignoring economy's basic dependence on the natural environment for both material inputs and waste disposal (Westman 1977).

2. Deep ecology

Emerging at the peak of the environmental movement of the 1960s, deep ecology was promoted outside the U.S. by Naess (1989) and Synder (1977, 1994). Deep ecology is thought to be at the other end of the spectrum of the environment and economic development paradigms close to frontier economics. It emphasizes the ethical, social, and spiritual aspects of the dominant economic worldview that have long been ignored (Nash 1989). It promotes a shift of values, perceptions, and lifestyles from anthropocentrism to ecocentrism in the human-environment relationship. The roots of deep ecology can be traced in the teachings of Taoism and Zen Buddhism and to the thoughts of Huxley, Orwell, Jeffers, Muir, and many more (Sessions 1995b).

Deep ecologists advocate a harmonious view between man and nature. They sell the idea of "biospecies equality," which champions the reduction of human population, encourages bioregional autonomy, and biological and cultural diversity; and advances more dependence on indigenous management and technological systems. Technology is believed to be able to bring more troubles than solutions to the environment. The extreme form of the paradigm is of an anti-growth eco-topia, which expects the entire world to return to pre-industrial, rural lifestyles (Naess 1973; Devall and Sessions 1995b).

In practice, humans are required to be subservient to nature, a total reverse of frontier economics hierarchy. The traditional economic growth, measured by level of the GDP, is argued to have nothing to do with human welfare (Capra 1995). Radical changes of social, legal, and economic systems, and definitions of development and welfare are expected. The distinction between shallow and deep ecology is that the former focuses on the fight against pollution and resource depletion, while the latter targets on more normative goals, such as promoting the ecophilosophical movement (Naess 1973).

Its opponents criticize deep ecology as highly unrealistic and excessively simplistic. Hooker (1992) argued that deep ecology lacks a solid theoretical foundation, and it is so simplistic and idealistic that is not able to take into account many important societal circumstances, for example, tensions and conflicts between interest groups. Bookchin (1987) criticized Naess's "anti-human" bias and points out that social change, primarily through a local participatory democracy and decentralized economic system, is necessary to bring transition to a more ecologically sustainable lifestyle.

While parts of the arguments of deep ecology are valid and inspiring to re-examine the human-environment relationship, the extreme imperative of an anti-development stance is impractical and undesirable to most people. As Jantsch (1980) commented, the "organic" feature of deep ecology is not consistent with the "creative" nature of human beings, which may be one of the most fundamental driving factors of the development of the society.

3. Environmental protection

The paradigm of environmental protection emerged in the late 1960s when environmental problems attracted the public's attention and became a nationwide concern. This paradigm holds a more moderate stance compared to polarized views of both frontier economics and deep ecology in dealing with environmental problems.

Environmental protection recognizes the tradeoffs between the environment and economic growth. It is largely based on the externality theory of economics. The concept of externality was first introduced by Marshall (1890), and further developed by others (see Pigou 1929; Kapp 1950). It is argued that negative externalities are mainly caused by market failure, and the standard solution is to "internalize" these externalities; that is, externalities are priced and bearers are compensated by the producers of negative externalities (Scitovsky 1954; Bator 1958).

In practice, negative or defensive strategy in environmental management is widely adopted, with "command and control" being the major institutional regulatory tool. The governmental environment protection agencies are assigned the responsibility to set pollution limits, monitor environmentally harmful activities, enforce pollution controls, and clean up pollution. Optimal pollution levels are defined according to short-term economic acceptability rather than the need for long-term maintenance of ecosystem resilience. The goal of pollution control is to mitigate pollution levels rather than to restore ecological functions of the environment. The practical strategy of the paradigm has been labeled as "end-of-the-pipe" or "business-as-usual" as well as a treatment plant approach (Colby 1991).

4. Resource management

Forrester (1971) constructs a purely hypothetical, functional correlation model using a number of stock and flow variables to simulate the quality of life in the future. Based on the simulation results, he concludes that quality of life will decline progressively as the population and economy continue to grow. His primary prescription is to greatly reduce the birth rate in order to curb pollution and depletion of natural resources. Meadows et al. (1972) model the future world resource consumptions using Forrester's system dynamics model as a prototype. The conclusion is that economic growth might not benefit human beings, and was even potentially harmful and disastrous to human beings, with or without population growth. Despite serious deficiencies of these models and the failure of the "doom and gloom" predictions, the concepts behind these models still have valuable implications on many serious social and environmental problems such as globalization of pollution, non-renewable resource depletion, and population explosion. It also nourishes the successive paradigm: resource management.

Although theoretical foundation of resource management extends from neoclassical economics theory, substantial changes are made in terms of practical strategies. This paradigm requests that all types of capital and resources, from biophysical, to human, to infrastructural, to monetary, should be incorporated into the social and economic accounts. These capitals and resources are also considered in development and investment planning. The concept of natural capital is induced to emphasize the importance of ecological products and services to the quality of life (Hawken, Lovins, and Lovins 1999).

In practice, ecological services and products are regarded as fundamental, vital resources to be managed. The interdependence and multiple values of all types of resources are taken into greater account. New initiatives in many international issues, such as global climate change, stratospheric ozone layer depletion, biodiversity protection, and oceanic resources management have been launched to protect the "global commons."[27]

The paradigm is also composed of the primary theme of the reports from many important international institutions and organizations, such as the Brundtland's Report (WCED 1987), the Worldwatch Institute's Annual State of the World, and the World

Resources Institute's Biannual World Resource Report. Concerns over the environment are no longer regarded as anti-developmental. Although neoclassical imperative of economic growth still dominates the decision-making process, sustainable development has gradually been accepted as an important concept and has become an integral part of the development strategies. Much has been done to integrate the understanding of the economy of nature with the economy of markets. New national accounts systems and indicators are introduced to measure economic success of the nations more objectively (Serafy 1997; England 1998; Tjahjadi et al. 1999; Gerlagh et al. 2002).

Mandatory adoption of particular clean-up technologies is recognized as an inefficient instrument in environmental management. The "polluter pays principle" (PPP) of internalizing the social costs of pollution is gradually put into practice. Pollution taxation and tradable emission permits are introduced as new policy instruments for more efficient environmental management.

5. Eco-development

The eco-development paradigm emerged in the 1980s (Riddell 1981; Glaeser 1984; Sachs 1984a, 1984b) as another attempt to reconcile the tensions between the polarized "back-to-nature" view of deep ecology, and frontier economics' traditional ignoring of the limits of nature. The essence of eco-development is to restructure the relationship between economic development and environment to reach the goal of "positive sum game." Human activities are proposed to be reorganized to be synergetic with ecosystem processes and services. The use of "development" rather than "growth" indicates the emphasis on the integration of social, ecological, and economic concerns rather than inclining to any one aspect of the three.

The emerging ecological economics becomes theoretical foundation behind the paradigm. Ecological economics aims at connecting the neoclassical environmental economics and ecologic impacts studies together with a holistic view (Costanza 1989). Under the framework of ecological economics, the economic system is viewed as a thermodynamically open system embedded within the ecosystem, rather than a closed system separated from the natural ecosystem.

In practice, the principle of environmental management shifts from the "polluter pays principle" to the "pollution prevention pays". An important strategy to deal with environment problems is to reduce throughput to economic activities. The goal of environmental protection goes beyond pollution mitigation to maintain throughput at a sustainable level while achieving growth in economic welfare. New multidisciplinary fields such as agroecology, industrial ecology, and ecological engineering appeared in the 1980s, starting to consider environmental impacts of more nodes in the entire product life cycle chain to achieve synergic environmental gains (Sachs and Silk 1988; Costanza 1989; Mitsch and Jorgensen 1989). Industrial ecology has been gaining increasing attention from both academia and industries. Robert White (cited in Powers and Chertow 1997, 27) defined industrial ecology as "the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources." The lens of industrial ecology is focused on three driving factors influencing the material flows among economic processes: (1) industrial production of (raw) materials, (2) industrial manufacturing of products, and (3) the cycle of consumer products. The ultimate goal of industrial ecology is to optimize total industrial material use and disposal in every single stage of the product life cycle: raw material, finished material, components of the manufacturing product, finished product, waste, and ultimate disposal.

Eco-development suggests that society give up the business-as-usual notion because things that have been done in the past are possibly not appropriate today. Tradable pollution permit is accused of not able to adequately take ecological uncertainty and social equity considerations. A new tax scheme is proposed, in which taxes on resource extraction and polluting activities are increased, while taxes on other activities (e.g., labor, savings and investment) are simultaneously leveled down. The so-called eco-tax is considered to be more flexible in taking more social equitable issues into account (Colby 1991; Fredriksson and Gaston; 1999; Matschoss 2002). Eco-development also shares with deep ecology many ideas on social equity and cultural concerns. It suggests the shift from economizing ecology to ecologizing the economy, from the conflict between anthropocentric and ecocentric views, to place humanity neither above nor below nature.

6. Summary

Colby (1991) lists three sets of conditions that may combine together to drive the convergence of these paradigms toward the direction of eco-development: (1) the unprecedented degree of threat of global changes in the ozone layer depletion and global warming issues, (2) widespread problems of resource depletion/degradation, and (3) the easing of the military and ideological competition between the superpowers. He also contends that the defensive (remedial) strategy has gradually given way to more neutral (resource management, systems analysis) approaches. Colby succeeded admirably in summarizing the trends of the paradigm evolution of environmental management before 1990. But the unprecedented development of the digital economy in the 1990s raises new questions about possible environmental consequences in the information age, and corresponding environmental management strategies, which become the major themes of this study.

Figure 2.9 is a summary of the above paradigms and depicts the major research objectives of the study. From left to right, X axis represents three major themes: the environmental management strategies, the economic theories, and the environmental problems. Y axis is the evolution of these themes over time. The top row of the figure depicts the major objective of the dissertation: to examine the possible environmental consequences and propose an environmental management framework in the emerging digital economy.

The symptoms of environmental problems shift from resource scarcity and diminishing economic return in the late 19th century to today's global environmental challenges. The corresponding environmental management strategy evolves from pollution mitigation to ecosystem management. Three diversified branches of economic thoughts – neoclassical, neomarxist, and neomalthusian – are rooted in the theory of classical economics. They are all valid to some degree, but none is able to ultimately explain and solve the perplexing environmental problems. The climax of paradigm evolution is ecological economics. It is not a new discipline but rather a synthesis of many separate disciplines, and it examines the relationship among economic, ecological, and social systems to assist in a comprehensive understanding of complex environmental problems, and to search for ways to harmonize the co-evolution of three systems (Edwards-Jones, Davies, and Hussain 2000).

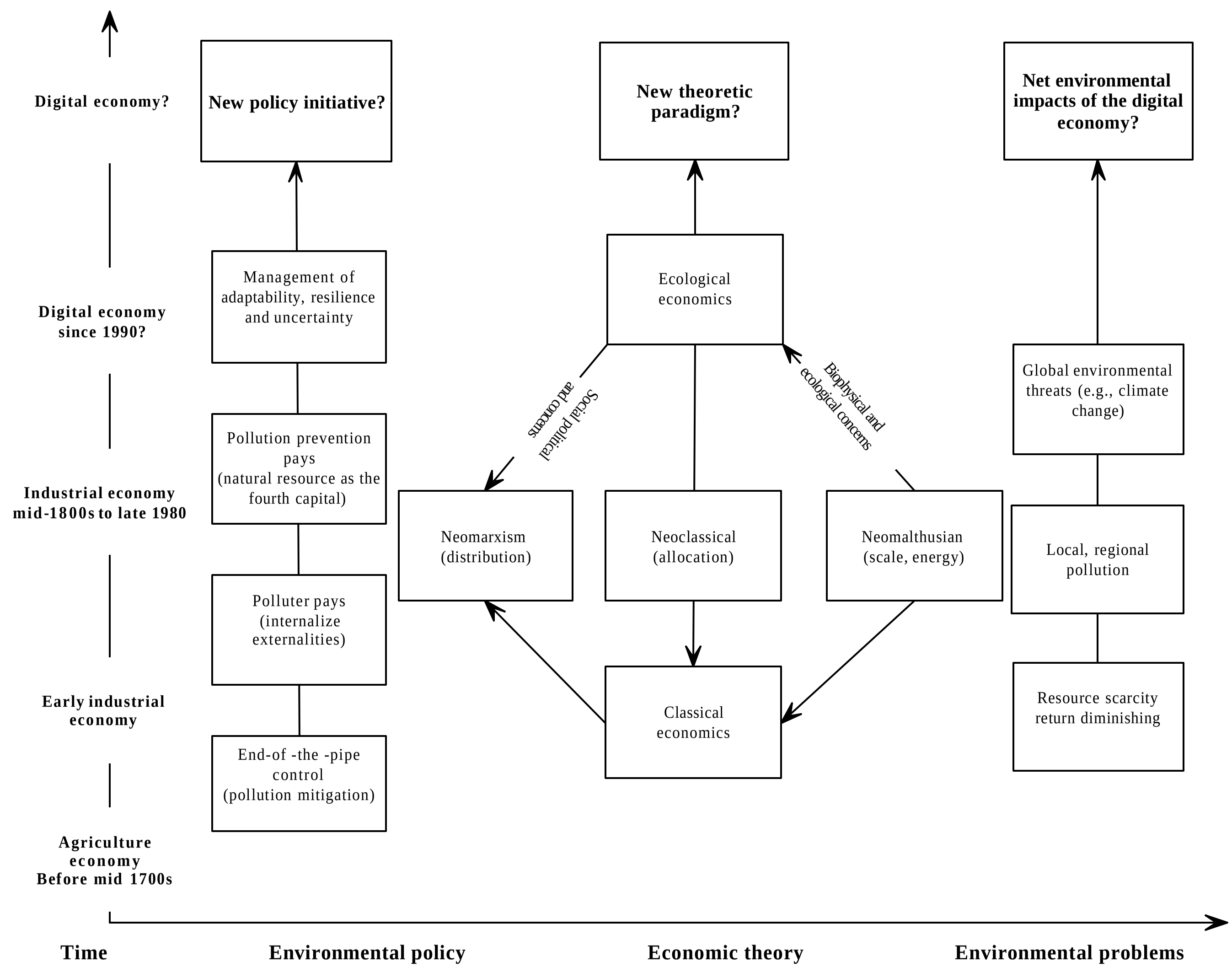

Figure 2.9 Evolutions of environmental problems, economic thoughts, and policy prescriptions since the Industrial Revolution. Source: After Colby (1991).

2.3.4 The environmental impacts of the digital economy: What do we know now?

Understanding the possible environmental impact of the digital economy will provide valuable insights for further exploration on environmental policy, strategy, and instruments in the new information age. Literature reports are growing as more scholars become aware of the significance of these problems, although the results of the existing studies remain anecdotal, speculative, and inconclusive (Jokinen 1998; Jokinen et al. 1998, Cohen 1999, Hurst 2001, Sui and Rejeski 2002). These studies can generally be put into five categories: theoretical-oriented exploration, examination of impacts of the ICT sectors, examination of impacts of ICT applications, examination of impacts of E-commerce, and examination of social and economic structure change.

1. Theoretical explorations

In the English translation of Beck's seminal book, "Risk Society," published in the early 1990s (Beck 1992), three trenchant issues threatening modern society were illuminated: the liabilities of economic growth, the pervasiveness of hazardous technology, and the inadequacies of reductionism in scientific research. Beck questions the conventional development paradigm, which argues that human social evolution is an inexorable forward march in which successive stages of economic progress bring increasing levels of mastery over the environment and security from adversity. He contends that risk society is caused by the escalating uncertainty bringing by technological hazards and by a system in which scientific knowledge has been stretched to its limits.[28] Contrasted to Beck's view of the future, Huber (1985), along with Janicke (1985) and Simonis (1988), propose the theory of ecological modernization, taking a more optimistic stance on the future development of human society. The theory suggests the refortification of industrial ingenuity to correct the environmental failures of contemporary production and consumption practices. The power of human ingenuity is believed to be able to harmonize economic advancement with environmental improvement. Although Beck's and Huber's studies are not conducted in the context of the digital economy, the possible environmental consequences of technological advancement and economic growth in the postindustrial society are discussed.

Miller and Wilsdon (2001) propose an "agenda for a sustainable digital economy" by introducing 10 "dot commandments." They argue that the digital economy offer an explosion of opportunities to tackle the challenge of sustainability. Cohen (1999) claims that E-commerce may cause both positive and negative impacts to the environment. He calls for manufacturers, consumers, and government to work shoulder to shoulder to win a green future by prescribing 10 solutions for the digital age.

Sui and Rejeski (2002) contend that the Internet, is not the Holy Grail for environmental salvation, but rather is full of potential environmental risk and uncertainty. They also suggest reexamine environmental policy in the context of the digital economy. Fichter (2001) points out three possible directions to investigate the environmental impacts of E-commerce and Internet use: (1) the direct environmental impacts of ICT infrastructure (e.g., energy consumption of ICT hardware), (2) the secondary effects caused by the Internet use, and (3) the subsequent and rebound effects brought by E-commerce and Internet application. Geels and Smit (2000) believe that failure in predicting the future is due largely to the overly simplistic conceptualization of technological development and its impacts on society, and the overlooking of the dynamic co-evolution of technology and society. Heinonen et al. (2001) discuss the necessity and possibility of developing scenarios and indicators to launch detailed life cycle analyses on ICT products, infrastructures, and applications. They suggest replacing the ICT with Information Society Technologies (IST) to assess the consequences of information society in broader economic, socio-cultural, technological, and ecological contexts.

2. Impacts of the ICT sectors

Plepys (2002) suggests understanding the environmental impacts of the ICT from two levels: the life cycle of ICT hardware (direct impact) and the ICT applications (indirect or higher order impact). He argues that additional studies should be dedicated to both the direct and indirect negative environmental impacts of the ICT, although he also believed that the ICT would help decouple economic growth from environmental degradation. Langrock et al. (2002, 108) argues that ICT products are "far from environmentally friendly". By implementing a four-stage life cycle analysis,[29] they conclude that neither the direct nor the indirect environmental impacts of ICT products are sufficiently understood. Both policy prescriptions and legal actions were required to retard the negative impacts of the ICT products. Mazurek (1994) examines three organizational and spatial manifestations of restructuring in the semiconductor industry to illustrate how economic and geographic changes complicate efforts to evaluate and manage industry's environmental performance. She finds that decrease in toxics release listed in the Toxic Release Inventory (TRI) of the U.S. EPA is caused not by the real reduction of toxic discharges from these semi-conduct companies, but more likely by organizational and geographic shifts of the semiconductor industry.

3. Impacts of the ICT applications

Lang (2002) argues that the applications of the ICT have brought new environmental challenges. On the production side, the outsourcing of manufacturing and relocation of manufacturing facilities helped diffusion of environmental harms throughout the world. The compression of product life-cycles and hastened product obsolescence translated into more stresses on the environment. On the consumption side, quick and effortless access to products information promoted and facilitated an increasingly ravenous consumption, which might bring more wastes and pollutants. Reichling and Otto (2001) contends that telecommunication services and new network infrastructure offers new opportunities for the increase of energy and resource efficiency under certain circumstances, but they are not necessarily more inherently environmentally. Romm (1999) predicts that 67 billion cubic feet of natural gas will be saved and 35 million metric tons of greenhouse gas will be reduced by the year 2007 in the new digital economy. He argues that fewer pollutants will be discharged in the age of digital economy due to the overall productivity growth and energy and materials savings in the manufacturing processes.

In contract, Mills (1999) argues that environmental problems will be very challenging in the Internet age because a large amount of energy (electricity) is required to power the movement of information over the network. His calculation shows that eight percent of the total electricity generated in the U.S. is used to support the running of the Internet. Marvin (1997) examines the environmental consequences of the development of telecommunication systems. His conclusion is that telecommunication will not only displace the need for travel in cities, but will also induce new demands for physical flow and movement. And the net environmental impacts are uncertain.

4. Impacts of the E-commerce

Gay (2002) studies the energy consumption of E-commerce and traditional retail commerce in five distinctive businesses: bookstore, grocery and perishable food, software compact disc, music industry, and personal computer. He finds that E-commerce is beneficial to the reduction of energy consumption and pollutants emissions in most cases. Galea and Walton (2000) challenge the assertion that the wider adoption of E-commerce will lead to greater environmental gains. After examining the business model of Webvan, an early American online grocery delivery service, which filed bankruptcy on July 2001, they conclude that Webvan's business practice is less energy-efficient, emits more air pollution, and provides no significant improvements in product and delivery packaging than conventional grocery business.

Hurst (2001) summarizes 13 direct and indirect environment impacts of E-commerce through case studies on seven companies and literature evaluation. She employs an iceberg metaphor to indicate that the unknown (the below-water part of the iceberg) portion of the environmental consequences of E-commerce was much more voluminous than the known part (the iceberg visible above the water) (Figure 2.10). Matthews et al. (2002) explore the energy consumptions of online book retailing both in the U.S. and Japan. Their research indicates that online book selling is not necessarily more energy-efficient than the traditional book retailing. They believe that energy consumption of book selling business is related to multiple factors, such as the mode of transportation and distance to bookstores. On the basis of two case studies using life cycle analysis (LCA) on traditional and "digital" way of providing communication services, Zurkirch and Reichart (2001) argue that the relative environmental burdens of telecommunication service are more dependent on real context, than on how to provide service (i.e., transitional or digital).

5. Social and economic impacts

Debates on and predictions of the social and economic impacts of the economic structure change have lasted for decades. Even though most of these studies were not carried out in the context of the emerging digital economy, they still provided valuable insights to this study. It is argued that the post-Fordism age was approaching, and the environmental problems in this incoming new age (and with indeterminate form) could not be solved using market-led solutions because the "implacable logic" of capitalism would lead the efforts to solve environmental problems only into an impasse[30] (Lipietz 1992 a, 1992b; Altvater 1993; Drummond and Marsden 1995). One inevitable outcome of the post-Fordism era was the emergence of dispersed and self-contained local economies in which small firms and smaller units of larger firms were more likely to grow. The restructured economy might reduce negative environmental impacts because the localized economy was assumed to be more self-reliant and less environmentally harmful (Welford and Gouldson 1993). Through analyzing the economic structure changes in the U.S. economy, Machlup (1962, 1984) and Porat (1977) claim that the U.S. is evolving into an information society.

The implications of the information society, however, were not discussed explicitly in these studies. By studying the U.S. national input-output tables between 1963 and 1987, Machado (1994) demonstrates that production sectors are more dependent on information sectors but less dependent on energy sectors. He concludes that there exists substitution effect between energy and information (see also Machado and Miller 1997). Bell (1976) brings the theory of post-industrialism in his book The Coming of Post-Industrial Society". He asserts that modern industrial countries are experiencing the transition into the last of a three-stage sequence of economic evolution. "Finally the third stage . . . This is the economy of the knowledge worker. Whereas the pre-industrial economy is a game with nature, or the industrial a game with the fabrication of nature, the post-industrial economy is a game among people where intellectual technology replaces machine technology" (cited in Williams 1988, 16). Bell explicitly expresses his optimistic view about the future of the environment in the post-industrial economy.

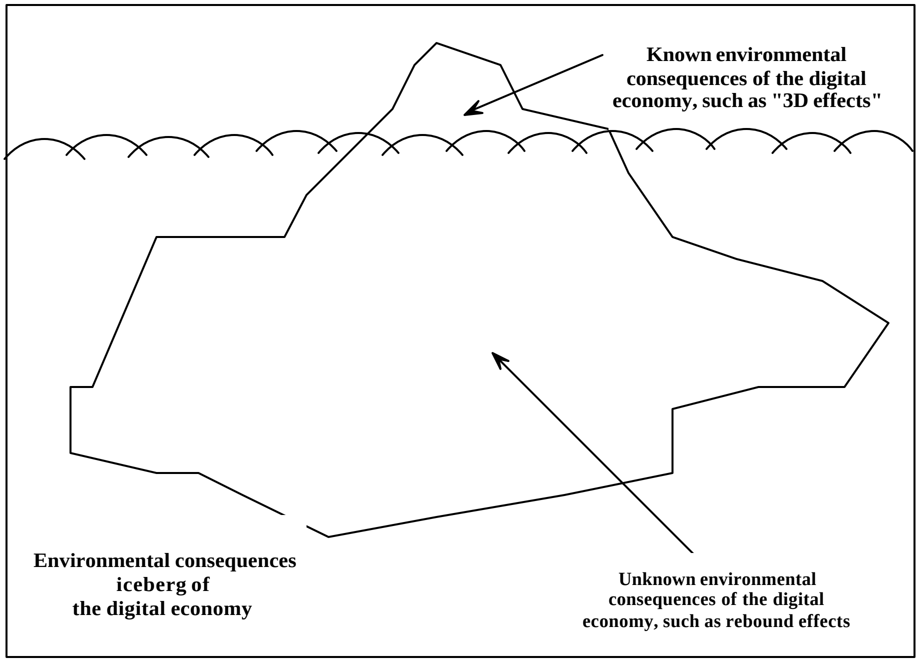

Figure 2.10. Iceberg metaphor of the environmental consequences of the digital economy.
Source: Adapted from Hurst (2001).

6. Summary

So what do all these studies tell us? It is indeed a daunting task to answer the question "What are the environmental consequences of the digital economy." However it is still possible to weave these small pieces of evidence together to make a larger and clearer picture. In general, the environmental impacts of the digital economy are like a double-edged sword, presenting both positive and negative impacts.

Optimists summarize the potential positive impacts of the digital economy using "3D effects": de-materialization, de-carbonization, and de-mobilization. Their beliefs are based on the following arguments. First, the relative importance of production, transformation, and exchange of information is rising quickly in all types of economic activities. In the meanwhile, the relative significance of production of tangible goods is declining. The replacement of "atom" with "bit" indicates energy and materials savings. Economic structure change also lead to the decrease of heavily polluting industries such as mining and manufacturing and the increase of "cleaner" industries such as information and service sector. Pollution will be possibly decoupled from economic growth due to the reduction of material and energy throughput in the production processes. Second, continuous technological progress is assumed to be able to promote considerable pollution abatement and more efficient use of natural resources. These arguments are backed up by several empirical studies (Ausubel and Sladovich 1989; Ausubel and Langford 1997; Billatos and Basaly 1997; Nilles 1998; Romm 1999; Gay 2002).

However, the opponents of those optimists argue that positive impacts may be simply the tip of the iceberg above the sea surface, with many substantial and mysterious parts submerged under the waves. First, a stable increase in the productivity of tangibles may be directed toward the growth of total production; thus the savings resulting from dematerialization are offset by the increasing total use of material resources. Some empirical studies demonstrate that the inputs of natural resources and emissions of pollutants are decreasing on a per capita basis, however, the absolute environmental stresses and natural resource consumption are still increasing (Wernick et al. 1996; Grübler 1998).

Second, the so-called "rebound effect"[31] may cause unintended consequences to cancel the environmental gains from the 3D effects. The digital economy may boost rather than reduce the consumptions of some types of commodities. One example is the continuous growth of paper consumption in the U.S. since the 1950s.[32] The implication is that the substitution effect of the digital economy may not be as high as expected. Bits may better seen as supplements rather than substitutions of atoms. In addition, expansion and differentiation of the ICT offer more chances to generate more linkages between economic sectors and more options to the consumers (Ellger and Scheiner 1997). The possible consequence is the induction of new material flows and movements, creating new demands on travel and physical spaces (Mokhtarian, Handy, and Salomon 1995; Marvin 1997; BOMA 2000).

Third, the supposedly negligible environmental impacts of these "clean" economic sectors such as the service sector are not completely self-evident. Instead, there are growing concerns about the possible negative environmental consequences of service sectors (Ellger and Scheiner 1997; Salzman 1999; Rosenblum, Horvath, and Hendrickson 2000; Lang 2002). Service sectors may have low direct environmental impacts, but the indirect and secondary impacts caused by inter-industry linkages are potentially high. Negligible individual threats may accumulate into non-negligible total effects (Rosenblum, Horvath, and Hendrickson 2000).

With all things considered, we are still not able to develop a picture of the net environmental impacts of the digital economy. Both optimists and pessimists only provide only partial and inconclusive answers, so any generalization will be premature. There are three major gaps in the available studies: the lack of empirical evidence, the lack of quantification method, and the lack of regional studies. This research makes an effort to bridge these gaps, if not completely, at least partially, and hopefully shedding more light on the mysterious iceberg submerged in the water.

2.4 Economic analysis methods of the environmental problems: A methodological perspective

2.4.1 Introduction

Specialized vocabulary, conceptual structure, and analytical tools must be prepared to give coherent explanations to the environmental consequences of various economic conditions and to elucidate connections and interactions between economic and environmental variables (Field and Field 2002). Economics is a mature discipline that is able to provide well-developed theories and rich analytical tools in studying environmental problems.

Munasinghe (1996) explains how economic analytical tools can help explore the impacts of economic activities on the environment in a socio-economic system at various geographic scales (Figure 2.11). The bottom part of the figure indicates the hierarchical nature of socio-economic activities that happen in various geographical scales. The global or multinational level refers to one (or more) sovereign nation(s); the national level refers to multisectoral economic activities of a country, or several sectors in a region; and the sub-sectoral level refers to specific projects. The top part of the figure shows the breakdown of environmental issues in terms of subjects of pollution: (1) global and transnational (e.g., climate change and stratospheric ozone layer destroy), (2) natural habitat (e.g., forest), (3) land (e.g., agricultural zones), (4) water resources (e.g., water basin, aquifer), and (5) urban-industry (e.g., metropolitan area). Complications arise when a natural system cuts across the structure of a socio-economic system (e.g., a large river basin), or when environmental subsystems interact each other (e.g., SO_2 in the air becomes acid rain). The middle part of the figure depicts the major analytical tools and methods used to trace environmental impacts associated with the socio-economic activities. The following sections review major conventional economic analytical tools for environmental problems to decide appropriate methodology for this study.

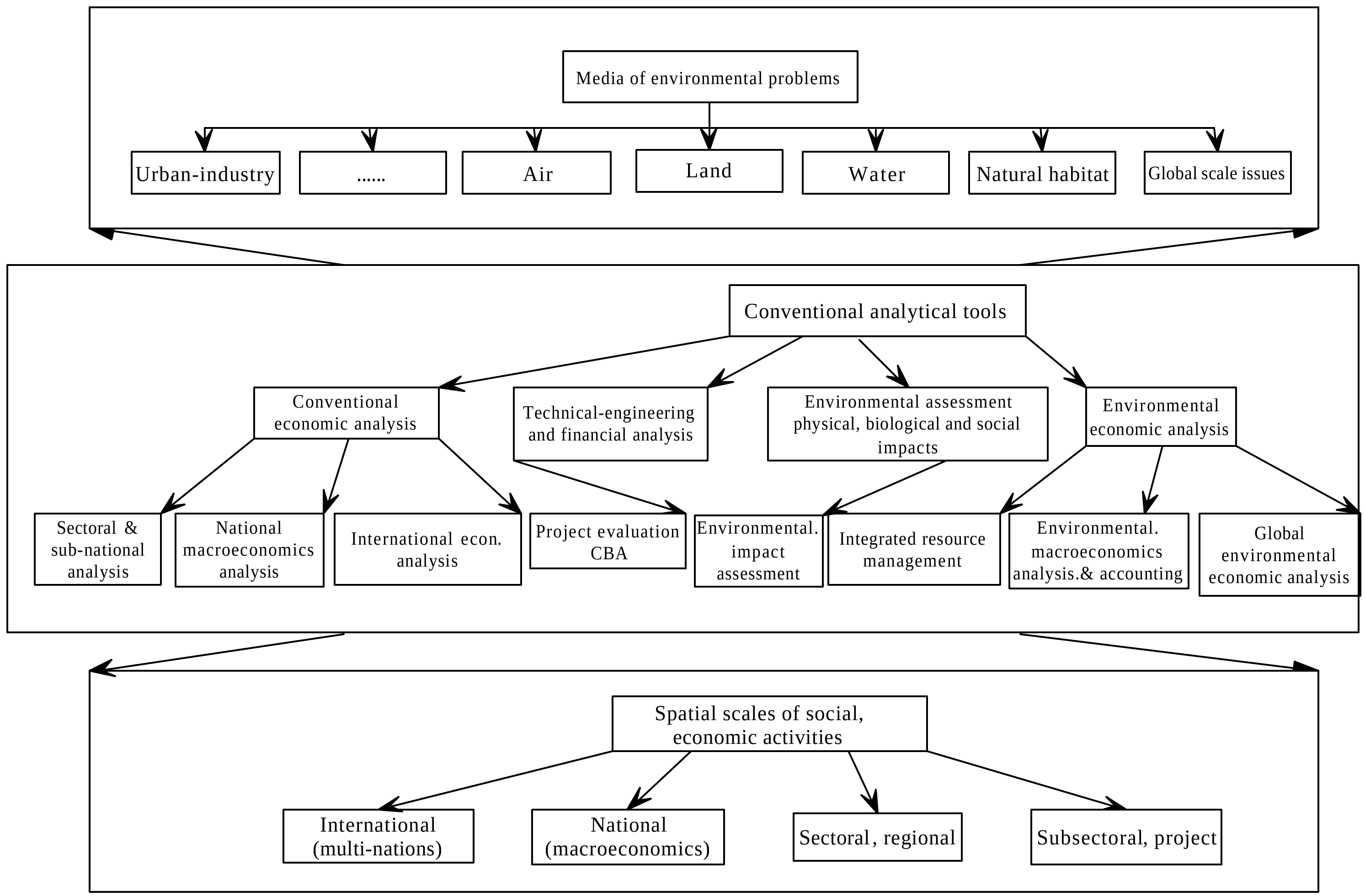

Figure 2.11. Major Environmental –economic analytic tools.
Source: After Munasinghe (1996)

2.4.2 Environmental valuation

Environmental valuation involves two important tasks: (1) measuring the benefits of environmental goods, services, and environmental protection activities, and (2) measuring the costs of environmental damage. The central question of environmental valuation is how to use monetary terms to quantify the benefits and damages. In terms of the utility theory of neoclassical economics, the underlining assumption of environmental valuation is that changes of natural environment somehow impact an individual's utility. Conventional economic analysis on the utility change is performed in assumed perfect market systems.[33] The market system, however, is not perfect due to the following reasons: (1) for many environmental commodities there is no market; (2) market entry is not transparent to all interested parties; (3) some environmental commodities are indivisible; and (4) relatively little is known about the consequences of environmental deterioration. In practice, it is common that environmental commodities are assigned very low or even zero values due to the imperfection of market.

Several assumptions must be made to valuate environmental commodities and services. Edwards-Jones (2000) makes four assumptions: (1) environmental changes must impact on the utility, or well-being, of individuals in some ways if the changes are assigned non-zero monetary values, (2) society is understood to be simply all individuals added together. So the total value of the environmental goods is the sum of the values of their effects on individuals, (3) different kinds of impacts must be commensurable: that is, they can be compared and a monetary sum can always act as a substitute for some quantity of environmental goods, and (4) similarly, environmental goods of equal value can be substituted for each other with no loss of welfare.[34]

1 Measuring the benefits of the environmental assets

The total economic value (TEV) of environmental goods and services is the total value of these goods and services in so far as they affect human welfare. TEV can be further divided into two broad categories: use values and non-use values.

Use values are associated with the benefits that come as a result of direct contact with the environmental goods in some way, including both direct consumptive (e.g., logging forests for timber) and non-consumptive uses (e.g., using forests as an important media of soil stabilization and water retention). Option value is sometimes regarded as the third component of TEV in addition to the other two.[35] It is defined as the value placed on environmental assets by those people who want to secure the use of the goods or services in the future.

Non-use values relate to the benefits not from the direct and indirect consumption of, but from the existence of environmental goods. Non-use values can be further subdivided into intrinsic values and bequest values. Intrinsic values come from the simple knowledge of the existence of an environmental good; for example, a particular habitat. Bequest values relate to altruism towards others as part of the value (e.g., preserve a piece of forest for the enjoyment of other people).

The total economic value of an environmental asset can then be obtained by summing up the three value components. Figure 2.12 illustrates the categorization of these values to the total economic value of environmental assets.

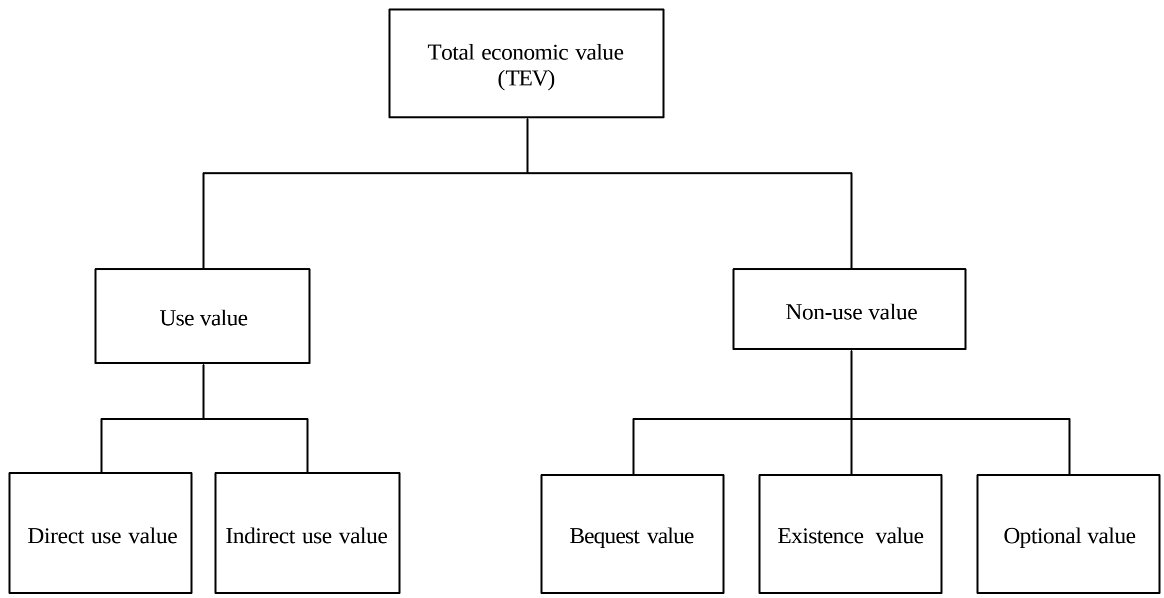

Figure 2.12. The components of total economic value of environmental assets.
Source: After Asafu-Adjaye (2000).

There are generally two methods to evaluate the benefit: the market value method and the non-market value method. The former method is more straightforward. In practice, real situations and conditions determine which method is preferable; for instance, the availability of the data.

1) Market value method

The market value method is usually based on the direct, indirect, and optional use of the environmental commodities. It is relatively simple and straightforward to estimate the actual market value of the environmental goods or services. There are, however, two shortcomings of the method: (1) it is not suitable for capturing non-market value, (2) physical flows of the goods may be difficult to define, and environmental goods and their market values may not have obvious linkage. The usual market value methods include productivity function method, opportunity cost method, dose-response method, defensive or preventive expenditures method, restoration cost method, and substitute cost method.

2) Non-market value method

The non-market value method is much more complicated than the market value method in that it deals with the intangible values. Revealed preferences (RV) and stated preference (SP) are the two most common approaches. RV obtains the value of environmental goods or services by investigating an individual's behavior in an actual or simulated market, and SP mainly uses survey techniques to obtain data on how much an individual is willing to pay for specific environmental goods and services. SP is relatively straightforward method based on fewer theoretical assumptions behind, obtaining the valuations based on the statistical analysis on the information collected from individual interviews. In the meanwhile, the validity and reliability of the method are questionable due to inherent biases of the method, such as hypothetical bias, part-whole bias, and starting point bias. Certain practice procedures in survey design are usually applied to minimize the negative impacts of the biases before putting these methods into use.

2 Measuring the costs of environmental damage and protection

In the framework of traditional neoclassical economics, pollution has been regarded as the addition of physical environmental factors so that the increased level of such factors in the environment is proven or assumed to negatively influence present or future human welfare (James, Jansen, and Opschoor 1978). Human activities also produce more of other types of outputs, except for the pollutants that positively impact the welfare. In the same neoclassical economic framework, the goal of environmental protection is reduced to seek the optimal level of human activities and pollutant discharges.

1) Homogeneous pollution approach

This approach aims to maximize the welfare by locating the point at which marginal control cost equals marginal damage cost. Pollution is usually treated as one single entity (Muraro 1974). The advantage of this approach is that environmental problems can be analyzed rigorously in an economic framework. The disadvantages, on the other hand, are twofold. First, it is a static model considering no spatial and temporal changes of environmental factors. Second, the one-entity assumption of pollution is not realistic because environmental problems are always associated with multiple pollutants.

2) The monetary damage function (MDF)

Theoretically, physical and monetary damage should be of the same importance. Practically, however, the economic valuation seems to be more popular to the general public as well as policymakers because monetary units are simple, and easy to convert and compare. MDF provides means not only to quantify the effects of environmental deteriorations, but also to convert multi-dimensional physical effects into monetary units.

The method generally follows Nath's principle of value judgment, including four assumptions: (1) the welfare of society is a function of individual levels of welfare, so calculation must consider the welfare of all individuals of the society, (2) individuals should be considered the best judge of their own welfare; (3) if a certain change increases the welfare of some individuals without reducing that of any other, then the change should be considered to have increased social welfare, and (4) greater social or individual welfare is preferred (Nath 1964).

The application of MCF has also been built on the assumptions of full employment of production factors and perfect competition. Considering the imperfection of the market for environmental goods and services, Mäler (1974) proposes four principles to better estimate monetary damage, (1) use an interview or survey techniques to derive individual estimates of willingness to pay, or compensation required, for a change in environmental quality, (2) estimate indirect effects using interdependencies between private marketable goods and elements of environmental quality, (3) estimate physical damages with the aid of market prices, and (4) vote behavior with respect to environmental quality.

The validity of MCF is always questionable due to the inadequacy of the knowledge of physical effects, dose-effect relationships, and reliability of measuring instruments. However, MCF not only provides partial answers to the questions about the environmental damage in monetary terms, but also forms the basis for other economic analysis such as cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA).

2.4.3 The cost-benefit analysis (CBA)

In many cases, it is important to decide whether or not to carry out a project or to choose which plan to implement from several candidates. The project here is defined as a set of activities that are inter-related to form a “whole” in order to reach certain social and economic goals. Examples are the construction of a wastewater treatment facility or an airport.

CBA is defined as a tool to transform all relevant effects of the projects into monetary values. Under the Pareto criterion (Goodstein 2002), a project (or one plan of the project) is regarded as desirable when the total valuation of the positive effects exceeds evaluation of the negative effects.

CBA plays an important (although not dominant) role in the decision-making process in the fields where different environmental consequences needed to be compared. CBA usually follows steps to those described by Asafu-Adjaye (2000) and Tietenberg (2000): (1) define the objectives and scope of the project, (2) identify and screen alternatives, (3) value the costs and benefits for the remaining alternatives, (4) calculate discounted cash flows and project performance criteria for each alternative, (5) rank the alternatives according to the preferences, (6) conduct a sensitivity analysis and /or risk analysis for the preferred alternative, and (7) make a final recommendation.

The French engineer A.J. E.J. Dupuit first proposed the procedure of CBA. In the U.S., CBA did not receive formal recognition from the government until the passing of the U.S. Flood Control Act in 1936 (Gilpin 2000). In 1950, a formal procedure was introduced by the U.S. Federal Inter-Agency River Basin Committee to compare costs and benefits of flood control projects (Pearce 1983). Theoretically, CBA is a powerful instrument since it is based on a set of widely accepted value judgment rules. Practically, CBA suffers from disadvantages like any other method, which reduce the satisfaction of the outcomes and limit its applications. Some major disadvantages are: ignorance of distribution issues, the difficulty in dealing with ethical or political concerns, the difficulty in dealing with temporal changes; the possibility of producing multiple, rather than single solutions, and difficulty in the conversion between money and welfare. Thus, it is preferable to use BCA together with other instruments to better accomplish its strength (James, Jansen, and Opschoor; 1978; Tietenberg 2000).

2.4.4 Other types of analyses

CBA is important, but is also only a subset of policy analysis. Many other types of analyses are also needed to obtain more complete information related to the project evaluation. Some major analyses include cost-effectiveness analysis (CEA), environmental impact analysis (EIA), stakeholder analysis (SA), damage assessment (DA), and risk analysis (RA).

CEA is preferred when the major benefits cannot be quantified in monetary terms. CEA does not provide absolute criteria to judge the economic viability of projects, so it is not suitable for the decisions that require level of the output. CEA generally follows the procedure of common CBA, and suffers from disadvantages similar to those found in CBA.

DA appeared after the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. It estimates the value of damages to an injured resource so that these amounts can be recovered from those held liable by the courts. The U.S. Department of Interior (DOI) decided the damages should be equal to the lesser of: (1) the lost value of the resources or, (2) the value of restoring the resource to its former state. In recent years, it is preferred to measure damages according to the restoration costs which may include restoration, rehabilitation, replacement, and /or the acquisition of equivalent resources. DA is actually a legal procedure to evaluate the cost of the damage of environmental goods and services.

RA was developed to analyze the uncertainties in environmental decisions. Standard RA involves three primary steps: risk assessment, risk valuation, and risk management. Risk assessment studies where risk comes from and how people respond to it. Risk valuation deals with the determination of prices tagged on certain risks, which are normally calculated based on the principle of willingness-to-pay (WTP). Risk management involves the study of the possibility and distribution of environmental risks under different policies.

2.4.5 General equilibrium assessment method

The analytical tools discussed so far are suitable for projects or one specific sector of the economy, but not for the evaluation of total environmental costs (or benefits) throughout the entire economy. General equilibrium assessment methods can satisfy the needs to study the economy-environment interactions in all the sectors of an economy through two dominating modeling approaches: Input-output (IO) models, and mathematical programming (MP). IO models are extremely useful in studying structural interrelationships of a large number of economic and environmental variables, providing (although limited) information about an economic system with n-dimensional economic activities, resource inputs, environmental services, and waste discharges. When decision-makers' value judgments are known, MP becomes a useful tool in that social preferences may be combined with an extended consumption possibilities set to determine a specific social optimum in a general equilibrium model using mathematical programming methods.

The IO model will be briefly introduced below; a more detailed discussion will follow in Chapter V. Developed as a tool of empirical economic research, the IO model is a special kind of linear system model initially designed to simulate the responses of production sectors within a given region or nation to a change in final economic demands. Its applications are later extended to model environmental problems, from simple representations of demands for environmental inputs and generation of waste flows to model ambient levels of pollution and the behavior of an ecosystem (Miller and Blair 1985).

An IO model divides the entire economic system into multiple sectors that are related to each other by a linear relationship. Each industry is both a supplier and a buyer. The change of final demands in one sector leads to chain reactions of input and gross output across all sectors due to the interindustry linkages. The distinct advantage of the IO model is that it provides the opportunity to study industries in fine detail and the performance of the economic system as a whole.

For optimization problems such as seeking the largest benefit or profit, or spending the smallest amount of money, mathematical programming techniques turn out to be an ideal choice. The common techniques include, linear programming, integer programming, and non-linear programming. The general linear programming involves construction objective functions and restriction functions. The optimal solution is situated on a corner of the feasible region.

If some restriction functions are added to the set of the general linear programming problem, then the optimum solution may not be situated at the corner of feasible area, an integer programming technique then has to be introduced to help solve this kind of problem.

For problems with non-linear relationships, which are more frequently encountered than those of linear types, new programming methods have to be induced to solve the optimization problem. However, non-linear problems are far more complex than those of linear programming. In fact, no standard method is available to solve the problems even though theorems are available to describe some properties of the optimum. That's why linear programming is often used, even when the functions are in fact not linear (James, Jansen, and Opschoor 1978).

2.5 Summary

The review of the history of human impacts on the natural environment, especially the most recent 300 to 400 hundred years, reveals how the Earth's surface has been significantly and quickly transformed with an accelerating rate and toward an uncertain future. From Amazonian tropical rainforest to Arctic tundra, human beings have left their footprint almost everywhere on this spaceship Earth, even if many of the transformations are invisible to the naked eye. Furthermore, many transformations, such as ozone layer depletion, are of humankind's doing, but not humankind's original intention (Meyer 1996).

The review also illustrates multiple consequences of industrialization. Industrialization has brought tremendous productivity gains and rising welfare (e.g., increased incomes and reduced work time). In the meanwhile, decreasing per capita resource input and waste discharge has been observed in most industrial sectors as the result of technology advancement. However, the absolute volume of material and energy consumption and certain types of pollutant emissions are still increasing due to many interactive factors such as population growth and improving living conditions.

The emerging digital economy is bringing both improvements and uncertainties to the environment. The mixed evidence presented in the existing studies is insufficient to depict a clear picture for the net environmental impacts. Thus it is meaningful to continue to explore, both theoretically and empirically, the question of "What are the environmental consequences of the digital economy?"

Environmental economics has provided a set of analytical tools for the study of environmental problems such as environmental valuation, CBA, and CEA. Most of these methodologies are partial-equilibrium tools, focusing primarily on the microeconomic aspect and partial equilibrium effects. This study aims at examining the environmental impacts of the digital economy from a macroeconomics perspective. Thus a general-equilibrium approach, IO analysis will be taken as the main methodology to investigate the problem at the regional level.

Notes

[1] Cohen et al.(2000) suggest using the term "E-conomy." They argue that other names were either too general, such as "new economy," or too narrow, such as "network economy."

[2] The U.S. department of Commerce began to publish the annual report on the digital economy in 1998. But the term "ICT" has not been formally defined in these annual reports.

[3] The environmental impacts of the digital economy will be discussed in a later section.

[4] The other three less known trajectories are Metcalfe's Law, postulating that the functionality of a network will increase exponentially with the addition of each user; Shugart's Law, basing upon the observation that the price per bit of magnetic storage halves every 18 months; and the Law of the Telecom, predicting that the price of transmitting a bit of information is halved every 12 months.

[5] GPO: Gross product originating. GPO excludes intermediate transactions between businesses, it equals GDP in private business equals gross domestic product in the economy, but less than GDP in government, private households, and nonprofit institutions (USBEA 2003).

[6] ICT sectors here follow the definition given by U.S. Department of Commerce (USDOC 2000), including four big groups of industry, 29 sub-sectors.

[7] Capital deepening occurs when the amount of capital rises relative to the amount of labor hours.

[8] Broadened ICT definition to include software, communications equipment in addition to computer hardware also helped ICT gain importance in the economy.

[9] As early as the reign of Queen Victoria, the bits could be transferred at light speed across 4000 miles by the means of telegraph, but the extremely high cost prevented its application at that time (Standage 1998).

[10] This section draws heavily on Kenney's (2001) research on the growth and development of the Internet in the United States.

[11] Pro forma: Description of financial statements that have one or more assumptions or hypothetical conditions built into the data. Often used with balance sheets and income statements, "pro forma" financial results that address only one component of a company's financial results – for example, earnings before interest, taxes, depreciation, and amortization, so it can sometimes be misleading.

[12] "Substantial" refers to all the Internet companies that have received some kind of outside funding from venture capitalists or other investors (Webmergers 2003).

[13] The industry standard layoff tracker, July 26, 2001, cited in the USDOC (2002a).

[14] History provides enough examples of unsuccessful prophecies. In 1899, Charles Duell, the former U.S. patent commissioner, proposed shutting down the Patent Office because he thought that "all that could be invented has been invented." Thomas Watson, the former CEO of IBM in the late 1940s predicted that "there is a world market for maybe five computers." Cited in Miller and Wilsdon (2001).

[15] There are growing concerns about the environmental consequences of the digital economy. As a major theme of the study, literature review on this topic will be offered in the following section.

[16] According to Grübler (1998), the "global change" started at the preparatory work for the 25th anniversary celebration of the first International geophysical year, which first took place in 1957-1958. But the perceptions of the Earth as a complex, self-regulating system has emerged from the earlier work of Boulding (1966), Georgescu-Roegen (1971), Meadows et al. (1972), Lovelock (1979), and many other scholars.

[17] "Externality" refers to a cost of a transaction not borne by the buyer or seller. Pollution is termed an externality because it imposes costs on people who are "external" (not related) to the production and consumption of the polluting product (Goodstein 2001).

[18] Another widely-used classification of the environmental problems is based on the media that is polluted: air, water, soil, etc. See Munasinghe (1996).

[19] The addition includes both qualitative and quantitative form. Qualitative form refers to the addition of new factors to ecosystems (e.g., CFC). Quantitative form means an increase in the level at which factors are present already (e.g., SO2).

[20] Noosphere: the sphere of human consciousness and mental activity, especially in regards to its influence on the biosphere and in relation to evolution. Merriam-Webster online dictionary, http://www.m-w.com/cgi-bin/dictionary?book=Dictionary&va=noosphere (last accessed 11 January 2003).
[21] "Industrial Revolution" was coined by Toynbee (1896). It refers to the accelerated rates of change of industry after the middle of the 18th century. It was also criticized as a misnomer since the concept implicitly ignored the important development in pre-industry societies that paved the way for the "revolution" (Cameron 1989).
[22] Global change here is defined as transformation processes that operate at a truly planetary scale plus processes that operate at smaller spatial scales (local, regional and continental) but that are so ubiquitous and pervasive as to assume global importance (Grübler 1998).
[23] Urban environmental problems due directly to high population concentration are most notable as air and water pollution, usually overstretching the assimilative capacity of the environment (Grübler 1998, 189-90).
[24] The U.S. National Research Council estimates that there are approximately five million known chemical substances that theoretically need to have safety examination. Only about 7,000 have been tested for carcinogenicity so far.
[25] These thoughts are of course connected to the different world view or environmental philosophy; the emphasis here is on the economic perspective. More detailed discussions on the human-environment relationship from a philosophical perspective can be found in Armstrong and Botzler (1993).
[26] Colby (1991) summarizes five fundamental paradigms of environmental management in development and human-nature relationship. They are frontier economics, deep ecology, environmental protection, resource management, and eco-development. His taxonomy is generally followed but reorganized and further elaborated here.
[27] Some international efforts include: The Antarctica Treaty, the Convention on the International Trade of Endangered Species, Montreal Protocol on Ozone, Framework Convention on Climate Change, the Convention on Biological Diversity, and Tokyo protocol on greenhouse gas emission.
[28] Beck demonstrates two examples of the threat of catastrophic accidents associated with industrial production and technology, nuclear power, and toxic chemicals.
[29] The four stages include material acquisition, manufacturing and sale, use, and waste disposal.
[30] Fordism refers to the system of mass production and consumption characteristic of highly-developed economies during the 1940s-1960s. Under Fordism, mass consumption combined with mass production to produce sustained economic growth and widespread material advancement. The logic of a capitalist regime of accumulation founded on intensive growth and mass production for mass consumption has been to both produce and stimulate consumption to the maximum (Lipietz 1992b).
[31] Rebound effect is mostly studied in energy economics. It refers to the fact that the decrease of energy price may result in an increase in demand as the response to the price decreases. The increased demand for the energy without an offsetting increase in fuel price can erode technological efficiency (Greening et al. 2000).
[32] U.S. paper consumption is currently over six times the 1950 level, and has more than doubled since the 1970s (Resource conservation alliance, 2003).
[33] The following conditions are usually hold simultaneously for perfect market system: (1) there must be a market for all goods and services, (2) there is no concentration of power in markets, (3) there is free entry to all markets for all who are interested, (4) all goods and services can be broken down into individually consumable quantities, (5) utility functions and production functions are mutually independent, (6) there is full information so that all markets are transparent, (7) the individual is the best judge of his own welfare, (8) societal welfare is a function only of the welfare of individuals forming a society (James, Jansen, and Opschoor 1978).
[34] These assumptions are not without objections, especially at a philosophical level. See Edwards-Jones et al. (2000).
[35] For example, Tietenberg (2000) considers option value as part of the non-use value.

CHAPTER III

AUSTIN: FROM COLLEGE TOWN TO THE SILICON HILLS

Here in Austin our faith is not altogether in material things. We believe that intelligence is better than industry.

-A Macallum

3.1 Introduction

The Austin-San Marcos Metropolitan Statistical Area (Austin MSA)[1] has been chosen to be the study area for this dissertation due to several reasons. First, Austin's rapid ascent as the IT hub of the U.S. South in the past two decades makes it an ideal case to examine environmental consequences of economic structure change. Second, the environmental management strategy of the local government has been evolving in the past decade to deal with the increasing environmental pressures, with two most latest and significant efforts – the smart growth initiative (SGI) and the Central Texas Sustainable Indicator Project (CTSIP). So the study will shed new light on the future environmental management practice of Austin in the emerging digital economy. Third, the proximity to Austin makes data collection and field survey convenient and inexpensive. This chapter introduces the Austin MSA's historical development, its economic structure changes since the early 1980s, and the latest environmental and sustainable development strategies.

3.2 Geographic location, population, and a brief history of economic development

The city of Austin is located in Travis County, Texas, with the scenic hills and pleasant lakes in the west and the Colorado River running through it. The Austin MSA is composed of five counties in central Texas: Bastrop, Caldwell, Hays, Travis, and Williamson (Figure 3.1). The region was sparsely populated until the first half of the 20th century. A post-World War II economic boom stimulated fast population growth in the area. Since the beginning of the 1960s Austin's population has doubled every 20 years on average. The U.S. Census data indicated that the Austin MSA had 1,249,763 residents in 2000, with over half of them, 656,562, living in the city of Austin (Table 3.1, Figure 3.2).

The population growth rate of the Austin MSA is much higher than that of Texas and the nation as a whole. Inside the Austin MSA, Williamson and Hays are the two counties with the fastest growth rate, which can be partially explained as the result of Austin's urban sprawl (Yang 2001). The population of the Austin MSA is projected to have an accelerated growth rate in the years to come, increasing at a faster pace than that of Texas in general (Table 3.2, Figure 3.3).

The high population growth rate is one of the direct consequences of the rapid growth of the high-tech industries. About 59 percent of the Austin MSA's population growth is attributed to the move-in of out-of-state population during the 1990s (CAPCO 2003; GAACC 2003; and GACC 2003). The urbanized area of the city has doubled about every 20 years since the 1960s to accommodate the increasing population. In

2000 the City of Austin occupied a land area of 263.8 square miles and the Austin MSA covers an area of 2,705 square miles (Figure 3.4).

Table 3.1. Population growth in the Austin MSA, 1960 - 2000

	1960	1990	2000	1960 - 1990	1990 - 2000	1960 - 2000
BASTROP	16,925	38,263	57,733	126.1%	50.9%	241.1%
Caldwell	17,222	26,392	32,194	53.2%	22.0%	86.9%
Hays	19,934	65,614	97,589	229.2%	48.7%	389.6%
Travis	212,136	576,407	812,280	171.7%	40.9%	282.9%
Williamson	35,044	139,551	249,967	298.2%	79.1%	613.3%
Austin MSA	301,261	846,227	1,249,763	180.9%	47.7%	314.8%
Texas	9,579,677	16,986,510	20,851,820	77.3%	22.8%	117.7%
The U.S.	179,323,175	248,709,873	281,421,906	38.7%	13.2%	56.9%

Source: U.S. Census Bureau (2003a).

Table 3.2. Population projection of the Austin MSA, 2000 - 2040, Scenario 0.5[2]

	2000	2010	2020	2030	2040	2000 - 2040
Bastrop	57,733	75,386	97,601	123,734	153,392	165.69%
Caldwell	32,194	39,971	49,445	59,163	68,923	114.09%
Hays	97,589	118,606	178,784	223,665	268,766	175.41%
Travis	812,280	963,120	1,105,551	1,245,654	1,371,840	68.89%
Williamson	249,967	341,322	449,652	581,210	724,667	189.91%
Austin MSA	1,249,763	1,538,405	1,881,033	2,233,426	2,587,588	107.05%
Texas	20,851,820	24,178,507	27,738,378	31,389,565	35,012,330	67.91%

Source: Texas State Data Center and Office of the State Demographer (2004).

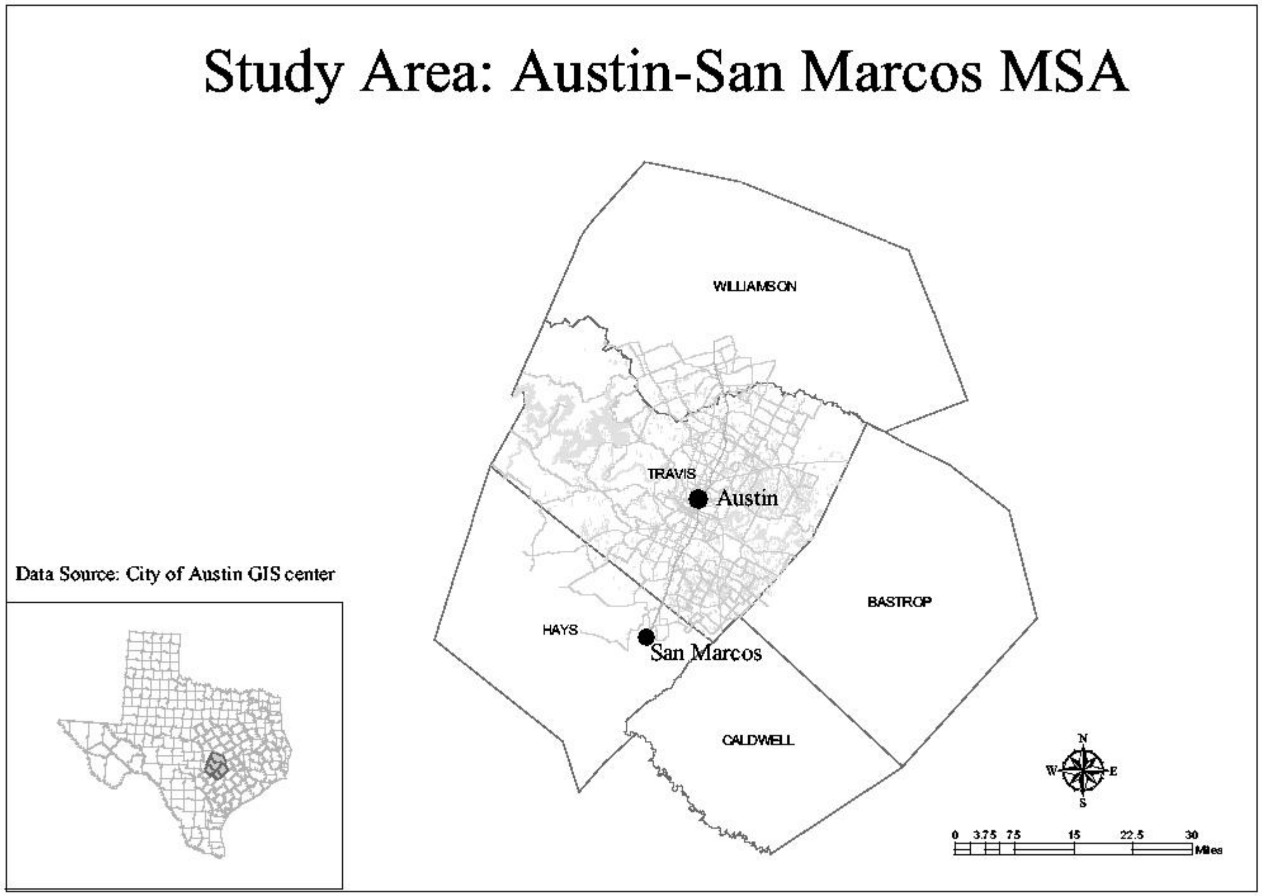

Figure 3.1. Austin-San Marcos metropolitan statistical area.
Source: City of Austin, 2003a.

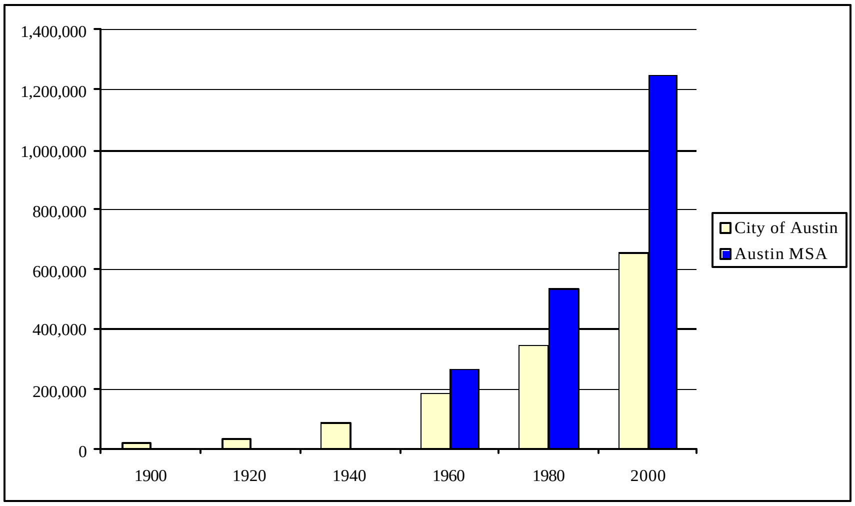

Figure 3.2. Population growth in Austin area.
Sources: City of Austin 2003b.

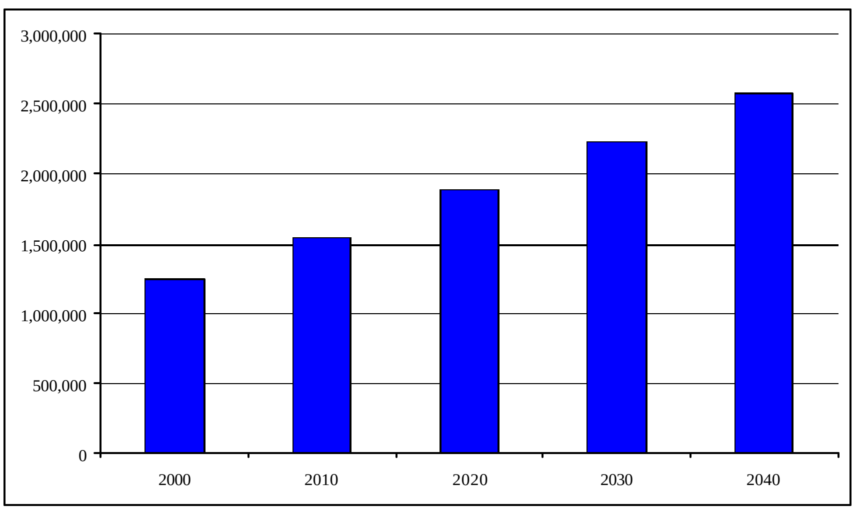

Figure 3.3. Population projection of the Austin MSA, 2000 - 2040, Scenario 0.5.
Sources: Texas State Data Center and Office of the State Demographer (2004).

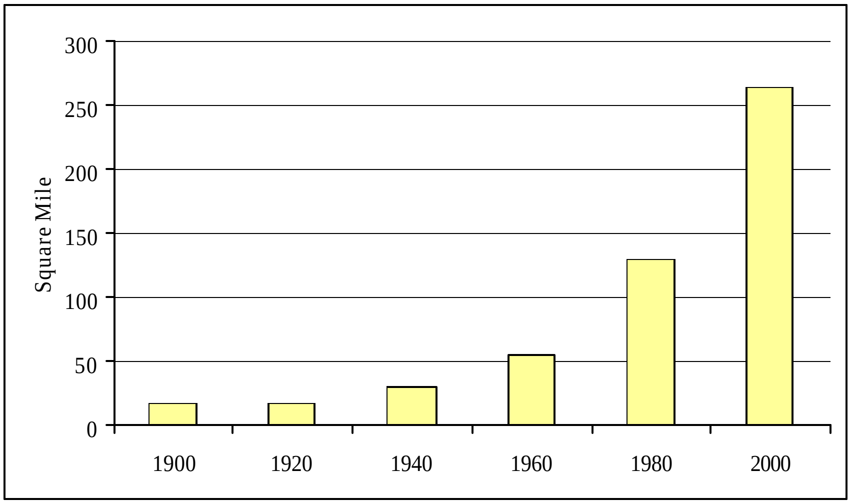

Figure 3.4. Land area growth of Austin, 19990 - 2000.
Source: City of Austin, 2003a.

Although Anglo-Americans' first settlement along the Colorado River could be dated back to the early 1800s, Austin did not become the capital of the Texas until 1872 after decades' of wrestling against political opponents, fighting armed enemies on the frontier, and competing with other Texas towns.[3] In the beginning, Austin was not envisioned as a simply political city but also an "emporium," a hub connecting the trading routes west to Santa Fe and along the upstream Colorado River. However, being the state capital did not help Austin gain many commercial and trade opportunities. On the contrary, the newly-built railroad diverted and sparked the trade and commerce to many other competing Texas cities, weakening Austin's bright future to achieve commercial prospects by being Texas' capital city.

Several years later, the victory of being the host city of the University of Texas (UT Austin) lighted Austin's hope to instantly boost their economy again. With the opening of UT Austin in 1883, the city started its new role as a seat of higher education.

But Austinities soon painfully found UT Austin did not boost the economy of the city as significantly as they had expected. Their dream to make their city a manufacturing and commercial success was still a long way off. Wooldridge, the mayor of the city from 1909 to 1919, suggested building a dam across the Colorado to provide waterpower for manufacturing and water for irrigation. His proposal successfully attracted support from both private investors and the general public, who believed that the regional economy would benefit from the supply of electricity, and that economic boom would "rushing the city like Johnstown flood." The rosy picture of a booming Austin was painted as factories lining the Colorado River resounding with the din of machines. The dam-generated electricity did power industry and city utilities, but Austin failed to sell itself as a manufactory center in the South. In fact, no one ever seriously considered Austin as a large factory site. The collapse of the dam in 1900 broke the last bubble of Austin's 19th century dream to become a manufacturing center.

In the first half of the 20th Century, Austinities seemed to have changed their minds about the identity of the city. As McCallum, the superintendent of schools at that time stated, "We do not claim the capital of Texas to be a great commercial center, here in Austin our faith is not altogether in material things. We believe that intelligence is better than industry" (Cited in Humphrey 1997, 47). Austin's 1928 plan made it clear that industrial development would not determine Austin's future; instead, a cultural and educational center would be the city's new development goal. In the following two decades, the city grew basically along the direction of the 1928 plan. At the same time, largely fueled by petroleum-dollars, UT Austin developed and swelled rapidly. A massive bond collected funds to make Austin a more appealing place to live. Mushroomed public facilities such as streets, sewage systems, parks, playgrounds, schools, and public libraries enriched the city' cultural landscape. Even at the period of the Depression, improvement in public facilities of Austin was much more auspicious than in most other American cities. By the middle of the 20th Century, Austin had established its special identity as a political and University community, with a modest-sized urban environment, small-town atmosphere, congenial neighborhoods, a leisurely pace, affordable cost of living, and a rustic landscape with green wooded hills and clear lakes.

3.3 The rise of Austin: From college town to the Silicon Hills

For about a century after it was chosen as the capital of Texas, the city of Austin was almost untouched by the "three waves" of economic development in Texas[4]. But the city successfully grasped the "fourth wave," transforming itself from a college town into a "Silicon Hills" in the second half of the 20th century, with the most dramatic changes occurring in the last quarter of the century. The starting point of the rising trajectory could be dated back to the period of World War II. Yang (2001) identified four stages of the economic development in Austin from the middle 1940s to the late 1990s.

3.3.1 Era of federal infrastructure investment (mid-1940s to early 1960s)

During this stage, the political leadership of Austin as a state capital outweighed its economic strength as a city. Like many other cities in the nation, Austin benefited from the expansion of military bases and facilities during and after World War II. The construction and permanent installation of Bergstrom Air Force Base in the early 1940s provided development opportunities for the city. In the following decades, the federal government continued to invest in such infrastructure projects in the city as highways and dams. Lyndon B. Johnson's election as U.S. president also helped promote Central Texas across the world as well as across the nation.[5] Federal investments in infrastructure not only compensated (at least partially if not totally) for the slow growth of private sectors during the war period, but also laid a solid foundation for the further development of Austin.

3.3.2 Era of advanced manufacturing (1960s to mid-1970s)

Traditional governmental and educational services still dominated the local economy in this period. By the end of the 1960s, about 45 percent of non-manufacturing positions, approximately four times the number of employees of manufacturing sectors in the region, were occupied by governmental employees (City of Austin 1976). However, the "fourth wave" finally started to rush into the quiet "college town" at the end of the 1960s.

The wave was triggered by the founding in 1955 of an engineering consulting firm by McBee and three physicists at UT Austin (The firm adopted its current name, Tractor, in 1962). Specializing in providing services for the Department of Defense, Tractor soon turned out to be very successful in its business. It was listed in Fortune 500 and spawned 22 spin-offs in a short period of time. At the end of 1993, the fast-growing

Tractor also created over 6,000 jobs for Austin. Tractor actually pioneered the transformation process of Austin toward a high-tech hub (Herbig and Golden 1993)

Following the success of Tractor, other three top-tier high-tech corporations – IBM, Motorola, and Texas Instrument (TI) – marched in. IBM and TI broke ground for their branch assembly plants at the end of the 1960s. Motorola opened up the Ed Bluestein branch for large-scale transistor and semiconductor fabrication manufacturing in 1974. These firms played not only instrumental roles in leading the development of manufacturing and ICT sectors, but also attracted more firms and "camp followers," small satellite firms that subcontract to larger companies.

There are several reasons to explain the charm of Austin to these IT giants. First is the locational advantage, such as low land price, availability of a high-tech labor force at relatively low cost, and accessibility to the potential market in the Southwest U.S. Second is the availability of public goods, such as well-developed government and university systems and good infrastructure facilities. Third is the quiet and pleasant environment, such as mild climate, amenities of the landscape, and recreational opportunities.

3.3.3 Era of incubation of research and development (late 1970s to late 1980s)

This stage can be seen as an important transitional period to add advanced research and development (R&D) into the simple assembly manufacturing of the region. In 1979, AMD, a microprocessor producer headquartered in the Silicon Valley, opened up a major chip fabrication facility in Austin. In the meanwhile, big companies like

IBM and Motorola also expanded the R&D facilities in the Austin branches to implement more researches in both hardware and software field.

In 1983, Austin defeated 56 other cities in 27 states to become the headquarter of the Microelectronics and Computer technology Corporation (MCC), a large private high-tech consortium aimed at the development of new generation of computers. The successful recruitment of MCC became the turning point for Austin's engagement in high-tech sectors, especially IT. On the one hand, MCC played an important role in attracting private parties to involvement in the advanced R&D activities. On the other hand, "Silicon Hills (Prairie)"[6] frequently appeared in the headlines of major newspapers such as the New York Times and the Wall Street Journal, which provided the city an opportunity to re-identify and promote itself. Austin's traditional educational advantages also contributed significantly to the development of R&D activities. In 1977, UT Austin received $55 million in grants and contracts, and the fund sharply reached $166 million in 1989, which helped to attract more top researchers who in turn brought even more research funding to the University. The flagship status of UT also stimulated a further agglomeration of other private and public research institutions in Austin.

Another milestone on Austin's road toward Silicon Hills was its excelling in the competition of the recruitment of SEmiconductor Manufacturing TECHnology (SEMATECH) in 1987. SEMITECH is a national research consortium, targeting at maintaining the leading position of the U.S. in the semiconductor industry against the rising competition from Japan (Boesche and Boesche 1999) by providing research and development in semiconductor manufacturing techniques and advanced semiconductor manufacturing processes.

Other noteworthy events during this period included the relocation of 3M and the birth of Dell. 3M is a multibillion-dollar firm with branches all over the world, focusing on display and graphics; electronics and telecommunications; health care; industry; safety, security and protection services; transportation, and other businesses. in 1984, it relocated one of its three divisions from St. Paul, MN to Austin. Founded in 1984, Dell has become one of the most successful legends in the circle of computer manufacturing in the 1990s. It is now the largest private employer in the Austin region.

With the continuous strengthening of research abilities in both public and private sectors, more spin-offs and start-ups have been generated and more companies have migrated to Austin to set up their home bases. High-tech companies have increased from 125 in 1979 to 457 in 1989 (Lee 2002). By the late 1980s, Austin had established its new identity as a new rising technopolis in the Southwest.

3.3.4 Era of fast-growing technopolis (late 1980s to late 1990s)

The last decade of the 20th Century witnessed the blooming flowers of the high-tech seeds sown in the past decades in Austin, which is nurtured by two factors. First, big firms like IBM, Motorola, and AMD not only became the major employers of the high-tech labor force of the city, but also functioned as important R&D bases. IBM created a major R&D center for of product designing and software development. Motorola set up the headquarters of communication and advanced consumer technologies. AMD built a research center for the development of the next generation of microprocessors. A recent survey showed that about three-quarters of the companies interviewed had increased R&D spending in the first half of the 1990s (Cunningham et al. 1997). Second, IT sectors have established theirs positions in the economy of Austin, and the software industry has grown more rapidly than the hardware counterpart.[7] By the end of 2000, high-tech employment accounted for approximately 21 percent of the Austin region's total employment. About three-quarters of the total number of high-tech employees were working in three major sectors: semiconductor and electronics, computer and peripherals, and software and telecommunication, indicating the rising IT industry in the region (Tables 3.3 and 3.4). By the end of the 1980s, hardware and software firms almost equaled in numbers. However, among 849 new-established high-tech firms in the 1990s, 587 turned out to be software companies (Table 3.5).

Entering the 1990s, the combined effects of corporate relocation and expansion, rapid population growth, extensive investment in technology and Internet-related start-ups, and the meteoric rise of Dell promoted Austin to be the fastest growing metropolitan area in Texas as well as in the country. From 1990 to 2000, per capita personal income rose from $18,092 to $32,039, the average price of a house sold grew from $87,600 to $199,500, and newly-created non-agricultural jobs increased from 164,000 to 272,000.

These achievements have not gone unnoticed outside the state. The Austin MSA remained in the top position in the latest POLICOM economic strength rankings released on July 15, 2002 (POLICOM 2003). This is the fourth consecutive year the Austin MSA has ranked the top among the 318 metropolitan statistical areas in the county. According to another survey, the Forbes/Milken Institute's best places for business and career, the Austin MSA was ranked number one among 200 metropolitan areas from 1999 to 2001 based on measured job and earned income growth, and the activity in critical technologies that foster growth (Forbes 2003). In addition, the unemployment rate dropped for 10 consecutive years in the 1990s, and it remained lower than the state and national average after the nationwide economic depression starting in the second half of 2000 (Tables 3.6 and 3.7, Figure 3.5).

Austin's short-term economic outlook has obviously been influenced by the overall national trends. The symptoms of the nationwide economic recession, such as slowdown in output and income, a soft labor market, sluggish investment, a continuous interest rate cut, and slowing consumer spending has also been experienced by Austin since the first quarter of 2001. The stagnant venture capital investment has had significantly negative impacts on the Austin economy, especially on the high-tech sectors, the most important contributor to the local economy in the past decade.

However, although the digital economy is battered, it has endured. Most people are still optimistic about the future of the Austin economy. According to an economic forecast report, growth in the Austin region will begin to accelerate from 2002 to 2006 if the U.S. economy continues its modest recovery rate, although it may well be some time before local manufacturing returns to its 2000 peak. Austin-area job growth is predicted to turn positive by 2003, expanding at a rate of 2.4 percent from 2002 through 2006, about half of the rate experienced between 1997 and 2001. Personal income is forecasted to grow 6.3 percent annually from 2002 through 2006, about half of the rate as the period of 1997 - 2001(City of Austin 2003c).

Table 3.3. Major IT employers in the Austin MSA, 2000

Company	Product or Service	Number of Local Employees
Dell Computer Corp.	Computers and Peripherals	20,800
Motorola Inc.	Semiconductors and Electronics	10,000
IBM Corp.	Computers and Peripherals	6,000
Sulzer Orthopedics, Inc.	Biosciences	5,479
Advanced Micro Devices (AMD), Inc.	Semiconductors and Electronics	4,600
Applied Materials, Inc.	Semiconductors and Electronics	4,500
Solectron Texas	Semiconductors and Electronics	4,400
Kent Electronics	Telecommunications	2,000
National Instrument, Inc.	Computers and Peripherals	1,800
3M Austin center	Semiconductors and Electronics	1,800

Source: GACC (2003).

Table 3.4. High-tech Employment by category in Austin, 2000

Industry	Total number	percent
Semiconductor and electronics	43217	30.5
Computer and peripherals	36383	25.6
Software	23948	16.9
Telecommunication	15955	11.3
Others	22361	15.7
Total	141864	100

Sources: GACC (2003).

Table 3.5. Growth of high-tech firms in Austin

Industry category	Exited before 1979	Established in 1980 - 1989	Established in 1990 - 2000	Total by 2000
Software*	54	184	587	825
Hardware*	71	148	262	481
Total	125	332	849	1306

Source: After Lee (2002).

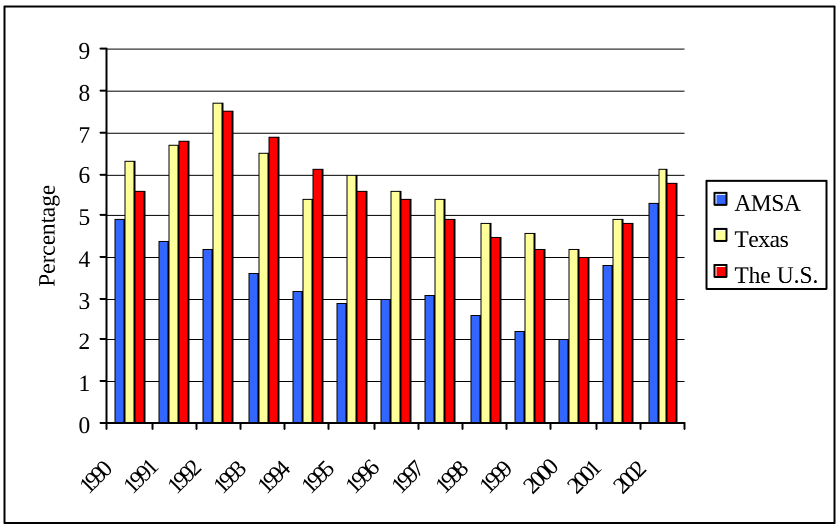

Figure 3.5. Unemployment rate in the Austin MSA, Texas, and the U.S., 1990 - 2002.
Source: USBLS (2003a).

Table 3.6. Top 10 MSA with the highest economic strength in the U.S., 1995 - 2001

Metropolitan Area	2002	2001	2000	1999	1998	1997	1996	1995
Austin-San Marcos, TX	1	1	1	1	4	24	27	28
Denver, CO	2	2	5	11	19	29	34	32
Atlanta, GA	3	3	9	12	7	2	2	3
Seattle-Bellevue-Everett, WA	9	4	2	4	6	5	4	6
Salt Lake City-Ogden, UT	7	5	3	2	2	3	7	14
Raleigh-Durham-Chapel Hill, NC	6	6	7	3	1	1	1	1
Dallas, TX	5	7	8	9	12	27	35	30
Fort Collins-Loveland, CO	8	8	4	5	3	8	5	13
San Antonio, TX	12	9	13	19	27	39	29	39
Madison, WI	11	10	6	15	9	10	10	24

Source: POLICOM (2003).

Table 3.7. Forbes/Milken best places rank, 1999 - 2002.

	1999	2000	2001	2002
Seattle, WA	1	13	15	92
Austin, TX	2	1	2	19
Dallas, TX	3	24	5	14
Ventura, CA	4	32	18	4
Oakland, CA	5	12	10	8

Source: Forbes (2003).

3.4 Environmental management practices

Far away from the dirty smokestacks, Austinities are always proud of the pleasant environment of their city, clear lakes and rivers, green wooded hills, and clear blue sky. The only natural environmental threat – flood – has been totally relieved with the construction of a network of dams and lakes northwest of the city in the early 1960s[8]. But the boom-bust wave featured by fast economic growth and urban expansion in the 1990s brought not only more jobs, wealth, and opportunity to the city, but also more visible and invisible environmental challenges.

In the middle of the 1980s, some environmental problems related to the rapid urban development emerged. The collapse of overloaded wastewater systems led to millions of gallons of inadequately treated sewage being discharged into Barton Creek and the Colorado River. Homebuilders had to ferry the sewage from the area served by an overloaded treatment plant to another area with surplus treatment ability, a process called "sewage on wheels" (Northcott 1987).

Traffic conditions have deteriorated as the region has become more populous, accompanied by rising congestion-related costs. Watchwords like "Pray for me – I drive

183" on a bumper sticker indicated Austinities' worry about the worsening traffic (Renfro 1990). One survey conducted in the early 1990s revealed that a high percentage of the general public felt that the general quality of the environment was worsening, rather than improving (Beatly and Brower 1994). At the city level, the responses to the new rising environmental problems were carried out through several approaches including conventional governmental regulations and enforcement, city ordinances, urban planning, and various environmental initiatives and programs.

3.4.1 Urban planning

Due to Texas's liberal annexation law,[9] the pace of suburbanization of Austin was very fast in the 1960s and 1970s (Figure 3.3). At the same time, public concerns over the negative impacts of urban sprawl (as manifested in Houston, and many other cities across the country) started to rise. In 1980, the city proposed Austin Tomorrow, an urban planning program aimed at protecting the natural environment and minimizing the negative impacts of growth in Austin. Thousands of citizens were involved in the compilation of the plan. In 1985, Austin voters approved an amendment to make the Austin Tomorrow (with the new name "Austinplan") a mandatory guideline because it was charged as being too broad to guide the course of urban development. However, the preferred growth corridors outlined in Austinplan were unable to regulate the major urban development afterwards due to strong resistance from the development communities, the lack of fiscal support, and the deficiency of administrative incentives. Despite the failure, thought, Austinplan left rich legacies. It was a successful social learning process which not only provided excellent opportunities for the citizens to comprehend the complicated planning process, but also offered a starting point for future planning programs and initiatives, such as the smart growth initiative launched in the late 1990s.

In the early 1980s, land prices in the environmentally sensitive northwest part of Austin suddenly rocketed due to 3M's decision to build a new facility there. The high land prices inevitably caused the high density development that was perceived to jeopardize the water quality and scenic beauty of the area. In December 1984, the planning department of the city of Austin released Northwest Area Land Use Guidance Plan (NALUG) to direct the development at about 77 square miles of land in northwest Austin. The plan was the result of the negotiation between the city and interest groups, without legal binding power like other city ordinances and plans, but NALUG nevertheless played an important role in balancing the development and environmental protection in the area.

The unprecedented economic growth in the 1990s pushed the land development to the uncontrollable edge. In 1999, 75 percent of new houses were built outside the city limits (Briseno 1999). The danger of losing its tax base, degradation of the environment, and deterioration of the central city made a new urban plan not only necessary but urgent. In early 1998, the Austin city council kicked off the Smart Growth Initiative (SGI), a long-range urban development plan to guide and shape future growth both to minimize the negative environmental, economic, and social impacts and to preserve the best aspects of life in the region. There are three major goals of the initiative: first, to determine where and how to grow; second, to improve the quality of life; and third, to enhance the tax base (City of Austin 2003d). Because it is a newly-launched program, the effectiveness of the plan is yet to known. According to a preliminary study, the plan seems not to work very well in the first few years after it has been officially launched. The expected outcome of the SGI, growing construction in encouraged development zones and decreasing construction in protected development zones, has not been observed (Sui, Tu, and Gavinha 2003). On the other hand, some negative social consequences of the program, such as deepening east-non-white and west-white social and racial segregation (Briseno 1999, Lee 2002). SGI is nevertheless the latest addition to the existing growth plans of the city with the goal of promoting the balance of fiscal equity, environment sustainability, and a better sense of community.

3.4.2 Environmental management

The mode of environmental management in Austin resembles the bureaucratic system of the U.S. municipal government; that is, separate governmental divisions are responsible for different problems. The City of Austin organizes environmental management divisions in terms of the various media, such as air, water, and wastewater. The primary functions of these divisions are to develop and implement programs to reduce the negative environmental impacts of the business and activities in the region, and to promote environmental-related education in local businesses and communities. The city of Austin also actively cooperates with environmental and natural resource management agencies and non-government organizations (NGOs) at regional, state, and federal levels, such as the Capital Area Planning Council (CAPCO), the Greater Austin-

San Antonio Corridor Council (GAACC), Texas Commission on Environmental Quality (TCEQ), EPA Region 6, and the Clean Air Force of Central Texas.

Ordinances are also taken by the City Council as important strategies to regulate the development and reduce the negative environmental impacts. The city council passed the first environment-related ordinance, Comprehensive Watersheds Ordinance (CWO), in May 1986 after intensive debates between pro-development and pro-environment groups. CWO aimed to control non-point source pollution by providing development standards within the watersheds in the region. Not surprisingly, the final product of the ordinance was a compromise among the interests groups, satisfying all parties involved in general. Land developers won a bit more time to adjust their development plan, and environmentalists were happy about the items related to the requirement of density and buffer zones control in all the land development plans.

With the rising environmental consciousness and the popularity of the concept of sustainability, the community gradually felt the traditional "piecemeal" way of environmental management was insufficient to meet the goal of sustainable development. Instead, a more holistic approach integrating the economic, environment, and social concern is needed. The City of Austin's sustainable communities initiative, UT Austin, and some community leaders began to create a sustainable indicators system to help the community better understanding the challenges of the sustainable development. The project was kicked off in 1999 by a regional survey called "Thumbs Up! For the Economy, the Environment, and the Community." The first annual report of the project was released in March 2000, covering three of the five counties of the Austin MSA, Travis, Hayes, and Williamson. The latest SIP report was published in May 2002, with several revisions on the indicators and inclusion of the other two counties of the Austin MSA – Bastrop and Caldwell – into the project (CTSIP 2003). These reports comprehensively examined the facts and trends of development in social, economic, and environmental aspects of the region using over 40. CTSIP provides both decision makers and the general public with a relatively complete picture about the three perspectives of sustainable development: economy development, environmental protection, and the social equity. The disadvantage of CTSIP is that it focuses more on the status than on the causes of the three concerns by threading a large amount of anecdotal information together.

3.5 Summary

The past two decades saw the Austin MSA grow quickly from a quiet college and state capital town into a prosperous high-tech hub. Historically, Austinities have never suffered seriously from the industry-related environmental problems. However, the rapid economic structural changes and urban expansion are bringing new environmental challenges to the region. According to the CTSIP 2002 report, fewer than half of the monitored water bodies in the Austin MSA have met water quality standards, the overall hazardous materials are increasing, and fewer than a third of the central Texan believe their surroundings are becoming more appealing.

Thus it is a meaningful and valuable task to explore the environmental consequences of the economic structure change of the Austin MSA. The results will provide us a clearer view about the trend of the status of the environmental quality, the possible change of pollutant sources, and the implications to the practices of environmental management of the city in the emerging digital economy.

Notes

[1] Most of the discussions of the chapter focus on the city of Austin, the core area of Austin MSA. Considering the geographical as well as economical connections of the five counties, the input-output analysis in chapters VI and VII is applied on the Austin MSA.

[2] This scenario has been prepared as an approximate average of Scenario zero (0.0) and Scenario (1.0) between years 1990 and 2000. It assumes that the rates of net migration are one-half those of the 1990s. It suggests a slower than the 1990s' average but steadily growing rate.

[3] The majority of the section is synopsized from Humphrey (1997).

[4] Agriculture, ranching, and oil industries are the first three economic development waves in Texas. The fourth wave is high-tech industry (O'Reilly 1985; Yemma 1987).

[5] It was Johnson who coaxed the most money out of New Deal officials into a set of civic projects in the Austin area.

[6] "Silicon Hills" was coined by a MCC recruitment team to identify and promote the city as a nice place for investment, living, and working (Kim 1998).

[7] Based on the high-tech industry definition given by the Greater Austin Chamber of Commerce (GACC 2003), Lee (2002) divides high-tech firms into two big categories: hardware and software. Hardware refers to Biosciences, computers and peripherals, semiconductors and electronics, and others. Software includes e-commerce, multi-media/film/music, software, and telecommunications.

[8] The dams not only controlled the annoying flooding, but also provided steady and cheap electricity for Austin.

[9] The 1963 Texas Municipal Annexation Act allows cities to annex with simply a majority vote of the City Council. It was later amended to include a few addition laws (Briseno 1999).

CHAPTER IV

ECONOMIC STRUCTURE CHANGE AND ITS IMPLICATIONS ON ENVIRONMENTAL POLICY IN THE DIGITAL ECONOMY

Every generation needs a new revolution.
-T. Jefferson

4.1 Introduction

As discussed in chapter II, contemporary environmental problems are closely associated with human's overexploitation of nature as both a source of raw materials and as a sink for waste discharges. Although the earliest concerns to natural resources and environmental protection in the U.S. can be dated back to the first half of the 19th century, they did not develop into a national movement before the 1960s. The first generation of environmental policy[1] emerging in the late 1960s and the early 1970s was the direct response of the government to the rising environmentalism. Symbolized by the enactment of the National Environmental Policy Act (NEPA) in 1970, the first generation of environmental policy was largely pollution control-based and law-driven, with smokestack sources sitting squarely in laws' regulatory crosshairs (Esty and Chertow 1997; Salzman 1999). The laws and regulations were effective and successful to some degree. The classic pollution images, like dirt-streaked factories shrouded in smoke, and leaking effluent pipes churning out drums of waste have gradually become history. However, these laws and regulations may not be effective and efficient enough to deal with the new environmental challenges of information age.

The structure of the economy has changed in many fundamental ways in the emerging digital economy. The nature of environmental problems is evolving quickly with the shrinking of some sectors (e.g., manufacturing, mining, and energy) and the expansion of other sectors (e.g., ICT, information, and service) in the economy. The major pollution sources are also shifting from a relatively few big dirty smokestacks to hundreds of thousands of small-scale, widely-distributed, and individually insignificant sources. In addition, consumption is turning out to be environmentally problematic because the new rising E-commerce is indirectly affecting the levels and patterns of consumers' options by fundamentally changing the ways of both selling and purchasing.

All these changes are challenging the first generation of environmental policy, which are characterized by their fragmented, industry-specified nature. As Allenby (1997) sharply perceived, "The simplicity of the underlying assumption – regulate manufacturing emissions and you will create an environmentally acceptable world – is touching but, unfortunately, wrong."

Surprisingly little existing research systematically has addressed the environmental policy issues in the context of the emerging digital economy. Salzman (1999) reported that among five major reviews[2] of the U.S. environmental policies involving major leading figures in the field, only one (the next generation project sponsored by Yale University) took economic structure change as an important factor influencing future policymaking. However, this review, together with a few other studies, addressed only the environmental policy implications of economic structure change from the perspective of the growing importance of the service sectors, rather than emerging digital economy (Ellger and Scheiner 1997; Guile and Cohon 1997; Salzman 1997, 1999; Davies 2000; Rosenblum et al. 2000). These studies, albeit offering many valid arguments and illuminating ideas, have not been able to give more insights on many critical environmental policy issues in the context of digital economy and information age.

This chapter reviews the evolution of the U.S. environmental policy over the last three decades (first generation) and discusses the possible directions of evolution of environmental policy in digital economy (new generation).[3] The purpose of the chapter is to set the context of the research questions and shed light on the interpretation of the results of empirical studies for the dissertation.

4.2 The first generation of environmental policy: 1970 - 2000

4.2.1 Policy prior to 1970: A brief retrospect

American environmentalism grew out of the movement to preserve forests, grazing lands, and wildlife (Nash 1989; Shabecoff 1993). As early as 1827, a forest preservation program was launched under the administration of President Adams (Englebert 1961). But political leaders and their advisors did not fully recognize the need to conserve natural resources till the end of the 19th Century. Two critical events heavily influenced their opinions on environmental issues. First was the successful establishment of Yellowstone, the first national park in the U.S. in 1872. Second, at the end of the 1800s, a group of influential federal employees including Gifford Pinchot, John Powell, Fredrick Newell, and George Maxwell promoted the idea of conservation, which suggested not a lockup, but wise use of natural resources. Their doctrines were gradually accepted by the federal government, and the concepts of “multiple use” and “sustained yield” later became the core creed of the conservation movement (Lester 1998).

However, the federal government played only a very limited role in environmental policymaking before 1970 except in the area of public land management. The Interior and Agricultural Departments were the two leading governmental agencies which managed the lands in public interest to protect them from inappropriate development (Culhane 1981; Kraft and Vig 2000). In the following decades, Congress enacted several important Acts to protect natural resources and landscape with remarkable biological, scenic, and cultural value, including the Wilderness Act (1964), the Land and Water Conservation Fund Act (1964), and the Wild and Scenic Rivers Act (1968).

Compared to the federal government’s long-term concerns and efforts in resource conservation and land management, air and water pollution were long considered as local issues and had never been in the center of the national agenda concerning environmental and natural resources issues. Environmental policies of the federal government extended very slowly in controlling industrial pollution and human waste before World War II, despite the fact that the Refuse Act for the control of pollution in navigable waters had been enacted as early as 1899. After World War II, the federal government began to work with its state and local counterparts to deal with air and water pollution through passing Acts, constructing sewage treatment plants, and setting pollution abatement standards. Some important Acts include the Water Pollution Control Act (1948), the Air Pollution Control Act (1955), and the Clean Air Act (1963) (Vig and Kraft 2000). However, through the post-war boom years, the threats from water and air pollution have still been regarded as regional, rather than nationwide problems. The situation was quickly reversed by the bottom-up, nationwide environmental movement in the 1960s, which not only fundamentally changed views of the general public toward the environmental issues, but also set the context for the emergence of the so-called first generation of environmental policies starting in the 1970s.

4.2.2 Policy in the 1970s: The command and control approach

Nationwide concerns over environment problems in the 1960s were triggered mainly by the interactions of several factors, including the accumulative damages of industrial pollution, increasing affluence, rising education levels of the general public, and the federal government's predicament in a series of internal and international affairs. The inspiring thoughts in several pioneering books and papers on environmental issues, including Carson's (1962) Silent Spring, Boulding's (1966) Spaceship Earth, and Hardin's (1968) Tragedy of the Commons, also deeply influenced public opinions on the seriousness of the issues related to resource depletion and environmental degradation. In addition, the newly-emerging environmentalism was politically attractive to policymakers who were deeply troubled by both domestic and foreign affairs. President Nixon proclaimed the 1970s as the "environmental decade", and the National Environmental Policy Act (NEPA) was the first act he officially signed in 1970, which raised the curtain on the first generation of environmental policy. During the 1970s, sets of legislation on environmental protection and natural resource policy was enacted, covering a wide range of issues such as pesticides regulation, endangered species protection, control of hazardous and toxic chemicals, ocean and coastline protection, restoration of strip-mined lands, and the creation of "Superfund" to clean up toxic waste sites. However, the full impact and cost of these laws and legislations were far from completely understood before they had been passed and enforced (Kraft and Vig 2000).

Despite the government's enthusiasm about the development of environmental policies, population and energy policy were largely ignored. In the early 1970s, two organizations – the Commission on Population Growth, and the American Future – suggested that the country should have a plan to stabilize population, but their advice went unnoticed. The population issue remained more or less dormant over the next two decades. The energy issue was more politically and economically complicated. The Nixon, Ford, and Carter administrations all focused on the policies to increase energy supplies to achieve energy independence. But their attempts were unsuccessful and no consensus was reached on a national energy policy due to many political constraints, and only President Carter connected energy policy with the issue of environmental safeguards and conservation.

Aside from the enactment of landmark environmental policies, rapid institutional development also surfaced as an integral part of the commitment of the government to the environmental issues. The Environmental Protection Bureau (EPA) was established in 1970 as an independent agency that reported directly to the President. The EPA one was a comprehensive institution dealing with various environmental responsibilities that had previously been scattered among dozens of agencies, offices, and programs. With a budget of $1.3 billion, the EPA had employed 13,000 staffs by 1980, a substantial growth compared to 7,000 employees and a $500 million budget of 1971. Other agencies, such as the Forest Service in the Department of Agriculture and the Bureau of Land Management in the Department of Interior, were also established to serve the need for better planning and management of natural resources (Kraft and Vig 2000).

4.2.3 Policy in the 1980s: Environmental relief and reform

Entering the 1980s, many problems and difficulties related to the implementation of the environmental policy enacted in the previous decade emerged. Implementation often lagged years behind schedule due to legislation's underestimation of the time necessary to develop and apply new technologies. Lawmakers felt headaches over the complex mission of setting standards for hundreds of major industries and dozens of pollutants. Regulated industries complained about the rigidity and inefficiency of the regulations and sought to block their implementation. Environmental management officials found that compliance costs were often underestimated.

These difficulties and problems stimulated the reform of environmental policy and improvement of administrative capabilities of the Reagan administration. Reagan's "environmental deregulation" decade was kicked off to reevaluate nearly all environmental and resource policies enacted during the 1970s to narrow the scope of governmental regulations, to shift part of the responsibilities to the states and local governments, and to rely more on the private stakeholders. However, the Reagan administration focused more on providing short-term regulatory relief to the industries, rather than supplying long-term solutions to environmental problems. The early 1980s saw sharply shrinking budgets, weakening authority of experienced professionals in environmental agencies, and elimination or restructuring of many offices and programs, particularly inside the EPA. Environmentalists charged that the Reagan administration's approach "blew the chance to streamline regulations and use marketplace incentives in an honest way to speed up environmental progress, lower regulatory costs, and foster economic growth" (Davies 1984).

Congress played an important role in partially offsetting the negative impacts of government's environmental policy during the period. It soon turned around its initial stance on supporting the budget cut and frequently criticized the management of the EPA and the Interior Department under the leadership of Anne Burford and James Watt. The U.S. Congress also strengthened several important Acts, including the Resource Conservation and Recovery Act (1984), the Superfund Amendments and Reauthorization Act (1986), the Safe Drinking Water Act (1986), and the Clean Water Act (1987). Congress also discussed the environmental impact of energy policy (energy consumption and global climate change) and other global environmental issues in the second half of the decade.

The budget cuts, loosening enforcement, and weakening of the administrative capacities of environmental institutions in the early years of the Reagan administration not only negatively influenced the development and implementation of the environmental policy, but also paradoxically strengthened environmental forces in the nation by stimulating more dissatisfied parties to join pro-environment groups, which forged formidable political pressures at different levels of government.

In the first two years of his Presidency, George H. Bush adopted a more positive environmental policy agenda than his predecessor. At the same time, Congress was also enthusiastic in advancing environmental policy. These all indicated a more positive environment agenda in the coming decade.

4.2.4 Policy in the 1990s: Standing at the turning point of information age

The Clinton-Gore team showed a far more supportive stance on the environmental protection issues than did George H. Bush during the 1992 campaign, though environmental issues were actually not among the top concerns of most voters. Gore (1992) even argued in his best-seller book Earth in the Balance that the central organizing principle for civilization was to rescue the environment. Clinton during his campaign promised a long and impressive list of commitments to deal with many environmental problems. He articulated a vision that environment protection would not block economic development, but rather would not only create jobs but also help improve the future competitiveness of the U.S. economy by promoting environmentally clean, energy-efficient technologies.

Clinton's appointment to key environmental positions indicated his intention to deliver his environmental agenda at the beginning of his Presidency. Relying primarily on the "administrative presidency" to achieve his environmental goals, Clinton attempted to reform and to strengthen the management of environmental protection through his powers of appointment, budget, reorganization, and regulatory oversight. The most important environmental legacy Clinton left behind was a new, more corporative relationship between government and business, and a more flexible regulatory system, which was ready to better serve the improvement of environment quality.

On the other hand, Congress strengthened the enforcement of the existing regulations despite the outcries, threats, pressures, and oppositions from industries and businesses. Tighter ambient air quality standards for ozone and small particulate material were implemented; more hazardous waste sites were cleaned up supplemented by the proposal of economic redevelopment in the "brownfields" of the inner-city; the quantity of chemical substances required by Toxic Release Inventory (TRI) doubled; and more criminal and civil cases were referred to the Department of Justice for assessment and prosecution (Kraft and Vig 2000).

More efforts also went into the protection of natural resources such as the Florida Everglades and Yellowstone National Park. On the international issues, the U.S. finally signed the Kyoto Protocol at the end of 1998, demonstrating America's attempt to reestablish its leadership in international environmental issues.[4] The President's council on sustainable development was established, comprising twenty-nine leaders from business, government, and nonprofit organizations. Across the nation, a series of novel initiatives at various levels of communities were launched to provide principles and strategies to direct the sustainable development.

In academia, the argument that environmental problems are shifting from the stage of acute pollution and environmental catastrophes to a new stage dominated by chronic and harder-to-diagnose pollution symptom has gradually been recognized. Targeting these "creeping catastrophes" (Böhret 1990), the environmental policy in the 1990s kept evolving to broaden the scope they covered, to induce new management strategies and enforcement instruments, to deepen the level of thinking about environmental issues, and to win greater societal supports (Lester 1998).

The scope of environmental policy was extended from local issues such as air and water pollution to regional (such as watershed management) and global issues (e.g., global warming and biodiversity). The enactment of the Pollution Prevention Act of 1990 marked a new age in dealing with environmental problems, focusing more on prevention beforehand rather than clean-up afterwards. The regulatory toolkit began to be supplemented by a range of new environmental policy instruments (NEPIs) and new environmental management systems (NEMSs) (Gunningham and Sinclair 1998; Jordan, Wurzel, and Zito 2003). Virtually all sectors of American society, from working-, middle-, to upper-class, paid more attention to environmental problems and policies. Scholars have extended their earlier emphasis from empirical studies to more normative and philosophical thinking on environmental problems (Lamb 1996; Lester 1998; Oliveira de Paula and Cavalcanti 2000; Ehrlich 2002).

Almost every dimension of environmental policy is evolving rapidly: the targets, spatial and temporal scales, institutional organizations, and regulatory instruments (Liberatore 1997). However, little has been achieved to fundamentally reform the current policy to satisfy the changing reality except few weak calls from academia (Esty and Chertow 1997; Salzman 1997, 1999). Facing the rapidly evolving digital economy and information age, current generation of environmental policy is at a crucial turning point. Comprehensive understanding of the nature of the current generation of environmental policy and of digital economy will be essential to formulate a new generation of environmental policies to guide our society to a more sustainable future.

4.2.5 First generation environmental policy: An assessment

Compared to the situation in the 1970s, today acute pollution from decades of industrial pollution has generally been alleviated, and the environment has been significantly improved as the result of the implementation of the first generation of environmental policy (USEPA 2004). There is no doubt that environment would have been much worse today without these laws and regulations. However, these successes did not come without problems, difficulties, controversies, and costs.

The first generation of environmental policy was largely industry-focused and law-driven, with environment and economic growth as two conflicting parties; that is, pollution was the inescapable side effect of human activities. Consequently, regulatory attention was focused on those high smokestacks and dirty effluent pipes in manufacturing sectors, relying almost exclusively on the “command and control” enforcement approach. While most major pollution sources in manufacturing sectors have been successfully captured and regulated, the impacts of many other rising sectors (e.g., the service sector) and other aspects of the economic system (e.g., consumption) have not been seriously and systematically considered. A report from EPA’s Office of

Policy admitted that the U.S. pollution control system was focused primarily on production industries such as manufacturing, mining, and agriculture. Comparatively little analysis has been done on the environmental impact of the service sectors (Salzman, 1999). The causes of negligence are complex and multidimensional. The buffering effect of environment to pollution; the inadequate knowledge of chemical substances, the deficiency of bureaucratic system, the high enforcement costs, and the partisan interests and bias are all possible influencing factors. In addition, these factors also tend to multiply and interplay each other, further preventing the effective catching the environmental problems outside the manufacturing sectors.

The first generation of environmental policy compartmentalized environmental problems according to major environmental media such as air, water, and land. Detailed regulatory rules were then designed, written, and rigidly implemented. The fragmentation approach has apparent advantage in expediting the enforcement process in face of the immediate environmental risks in the beginning. The environmental problems today, however, are much different from those of 1960s and 1970s as an industrial-based economy is gradually evolving toward an information-based economy. These problems tend to be less plainly harmful, more subtle and unpredictable, harder to identify and quantify, and impacting in longer temporal and on larger geographical scales. The setbacks of the fragmentation approach, such as the contradiction among separate laws and regulations, the lack of flexibility, and the missing of potential regulation targets significantly impact the effectiveness and efficiency of the first generation of environmental policy.

In short, the first generation of environmental policy succeeded in picking up those "low-hanging fruits" of environmental problems in the past three decades, but are not sophisticated enough to address the new rising problems in the emerging digital economy. However, the rich legacies left by the first generation of environmental policy has formed foundations for the development of a new generation of policy initiatives, which must go beyond the inefficient "one-size-fits-all" approach, to focus on the new rising environmental targets, to take a more holistic view, and to include new regulatory instruments.

4.3 Beyond smokestack: Toward the new generation of environmental policy

In the emerging digital economy, many primary elements of the economic system, such as methods of production, patterns of distribution, forms of business, and styles of consumption are evolving quickly; so is the nature of environmental problems, which is directly connected to the type and structure of the economy. Liberatore (1997) proposed a framework with multiple dimensions for the analysis of the environmental policy, including a sectoral dimension, an issue dimension, a spatial and temporal dimension, an organizational dimension, a toolkit dimension, and a distributive and ethical dimension. These dimensions not only suggest various angles to examine the environmental policies problems, but more importantly, provide a practical handle to develop new policy strategies and initiatives. The following sections synopsize some possible directions for the new generation of environmental polices in terms of these dimensions on further analysis of the weakness of the current generation of policy.

4.3.1 Overcoming policy fragmentation

The essence of the fragmentation is the divide/conquer dichotomy. Fragmentation makes the problems more tractable and accessible to deal with at the possible cost of losing the vision of the whole, missing potential targets, and generating unwanted overlap, gaps, and conflicts among pieces of laws and legislations. Powers and Chertow (1997) defines three types of fragmentation problems: 1) by type of pollutants, 2) by life-cycle stages, and 3) by organizational characteristics.

Many empirical studies have demonstrated that pollutants hardly follow any types of boundaries, whether political or ecological. Tall smokestacks can help release, dilute, and displace sulfur dioxide more quickly and efficiently, but they do not permanently eliminate it. Sulfur dioxide may easily land (in rare cases at the same geographical location as it was discharged) as acid rains that damage vegetation, buildings, and water supplies. Scrubs can be used to catch the pollutants before they are discharged, but the resulting sludge turns out to be more troublesome to dispose of The fragmentation approach also fails to identify pollution when pollutants shift between political and administrative regions (Powers and Chertow 1997).

Fragmentation by product life-cycle chain errs in that it focuses only on the emissions from factories, but neglects almost all the other stages of the entire product life cycle chain, from raw material extraction, to manufacturing, distribution, final use of product, and waste disposal. The fragmentation not only severely reduces the possibility of permanently getting rid of the wastes, but also increases the chance to displace the problems between different stages of the entire product lifecycle chain and geographical locations.

Fragmentation by organization means that each ecological medium is regulated by a separate set of laws and regulations, which are designed to have specific definitions, standards, penalty rules and liability, and different enforcement agencies (or different subdivisions inside the same agency). Polluters would try their best to satisfy specific regulatory requirements, and regulators would focus on whether those requirements are met. Unfortunately, the real goal of the environmental policy, seeking optimum solutions to improve the environmental quality and protect the ecosystems, has been largely been marginalized on both sides of the game.

The new generation of environmental policies have to adopt a more holistic and long-term view that goes beyond the fragmentation featured by single-medium, single-species, single-substance, single life-cycle-stage, and single organization approaches (Powers and Chertow 1997). Our growing knowledge and experiences concerning the nature of environmental problems, the connections between environmental problems and economic systems, and most efficient way of enforcement of environmental laws and regulations will help overcome the barrier of the fragmentation to achieve a more inclusive and holistic environmental policy framework.

4.3.2 Beyond the manufacturing sectors: Policies for the economic sectors outside the domain of manufacturing

The first generation of environmental policy emphasized on the treatment of tall and dirty smokestacks in manufacturing sectors. Policy prescriptions to other economic sectors, especially to the service and ICT sectors, remained marginal. The general lack of attention to sectors outside the manufacturing domain tends to be more problematic in the emerging digital economy.

1. The service sectors

The service sector contains a remarkably heterogeneous group of economic activities such as transportation, utilities, wholesale and retail trade, finance, insurance, real estate, health services, legal services, and government services. All vary significantly in the levels and patterns of environmental impact. The service sector is not necessarily more environmentally problematic than the manufacturing sector, but their incomparable importance on the economy and unusual environmental impact deserve special policy prescription, rather than the general treatment designed for the manufacturing sector. In addition, the service sector is more dynamic than the manufacturing sector. Table 4.1 shows that service sector experienced the most changes among all economic sectors of the years 1987, 1997, and 2002.

Table 4.1. Comparison of 1987 SIC, 1997 and 2002 NAICS

1987 SIC		1997 NAICS		2002 NAICS	
Code	Definition	Code	Definition	Code	Definition
01-09	Agriculture, Forestry, and Fisheries	11	Agriculture, Forestry, Fishing, and Hunting	11	Agriculture, Forestry, Fishing and Hunting
10-14	Mineral Industries	21	Mining	23	Construction
15-17	Construction Industries	22	Utilities	31-33	Manufacturing
20-39	Manufacturing	23	Construction	42	Wholesale Trade
41-49	Transportation, Communications, and Utilities	31-33	Manufacturing	44-45	Retail Trade
50-51	Wholesale Trade	42	Wholesale Trade	51	Information
52-59	Retail Trade	44-45	Retail Trade	52	Finance and Insurance
60-67	Finance, Insurance, and Real Estate	48-49	Transportation and Warehousing	53	Real Estate and Rental and Leasing
70-89	Service Industries	51	Information	54	Professional, Scientific, and Technical Services
91-97	Public Administration	52	Finance and Insurance	55	Management of Companies and Enterprises
		53	Real Estate and Rental and Leasing	56	Administrative and Support and Waste Management and Remediation Services
		54	Professional, Sc ientific and Technical Services	61	Educational Services
		55	Management of Companies and Enterprises	62	Health Care and Social Assistance
		56	Administrative and Support and Waste Management and Remediation Services	71	Arts, Entertainment, and Recreation
		61	Educational Services	72	Accommodation and Food Services
		62	Health Care and Social Assistance	81	Other Services (except Public Administration)
		71	Arts, Entertainment and Recreation	92	Public Administration
		72	Accommodation and Food Services		
		81	Other Services (except Public Administration)		
		92	Public Administration		

Sources: Summarized by the author from the U.S. Census Bureau (2003b).

Salzman (1999) categorized the service sector into three groups in terms of their environmental impacts: 1) smokestack services, 2) cumulative services, and 3) leverage services.[5] Smokestack services include utility companies, transportation industries, telecommunication firms, and healthcare providers, all of which usually emit significant quantities of pollutants. Cumulative services refer to all other services that do not cause significant environmental harm when they are operated individually, but may generate potentially large collective impacts. Leverage services contain large retailers and utilities providers, who act as funnels in product life cycles, influencing the behaviors of both upstream (producers) and downstream (consumers) players. The environmental impact of smokestack services falls mostly into “low-hanging fruit,” which has been picked by the first generation of environmental policy. Cumulative services, similar to other non-point pollution sources, are generally beyond the reach of the current laws and regulations, remaining to be “high-hanging fruit”. Salzman’s classification scheme, albeit coarse and subjective, is nevertheless helpful in identifying new pollution sources and in preparing and evaluating the effectiveness of new regulatory instruments.

1) Smokestack services

Among the three service types, smokestack services apparently contributes the most to the direct pollutant emission. During the past three decades, they were also directly squared in the center of regulator’s crosshair. For example, Title IV of the 1990 Clean Air Act amendment heavily regulates sulfur dioxide emissions from power plants, the mobile sources provision of the Clean Air Act regulates air pollution from transportation vehicles, and the Resource Conversation and Recovery Act regulates the biomedical waste from hospitals.

However, these laws and regulations are not tailored specifically for service sectors, but for those dirty smokestacks in the manufacturing sectors. The service sector in general is not considered as generic polluters, but is often regulated according to the standards proposed for manufacturing sector, which causes either under-regulation or over-regulation. The Toxic Release Inventory (TRI), one of EPA's major measures used to gather information on toxic chemical discharge from both industry groups and federal facilities, is an example of under-regulation. The TRI was established under the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and later expanded in the Pollution Prevention Act of 1990. However, the TRI database is limited to the facilities falling in the sectors with the two-digit 1987 SIC from 20 to 39, all of which belong to the manufacturing sector. The story about BellAtlantic, a telecommunication service provider in the Northeast U.S., provides an example of over-regulation. BellAtlantic has to deal with the hazardous waste from 113,000 manholes. BellAtlantic was not allowed to handle these waste sites using mobile treatment units which are permitted to use only by manufacturing companies (BellAtlantic's SIC identified it as a service company) according to the current law. Unfortunately, BellAtlantic has to bear the extra regulatory burdens caused by the mismatch of regulation and feature of the company (Salzman 1999).

The policy implications for smokestack services, according to Salzman (1999), are twofold. First, the operations, impacts, and interactions of service sectors should be fully understood before any governmental interventions may be applied. Second, smokestack services warrant special attention because over-regulation and under-regulation may cost both polluters and the regulators.

2) Cumulative services

Caldwell (1990) described two generations of environmental problems. The first generation comprises traditional point source emissions on local and regional scales, the new generation involves trans-boundary and global threats such as ozone depletion and climate change. Salzman (1999) coined the term "atomized sources" to identify the third generation of environmental problems following Caldwell's conception. Atomized sources are those small-scale, large-quantity, and widely-distributed pollution sources, falling in mostly the service sector. The story of the silver contamination in the San Francisco Bay area vividly illustrates the nature of the environmental impacts of atomized sources. In the early 1990s, both regulators and scientists were surprised to find concentration of silver in San Francisco Bay was much higher than the normal standard. After a long investigation, the dental offices in the area were accused of the major suppliers of the silver. Each individual office might discharge only a negligible amount of sliver, but the collective burden turned out to be significant enough.[6]

These atomized sources usually fall out of the crosshair of traditional regulatory system due mainly to the high compliance and regulation costs. These sources accounts for a large portion of the total number of firms in the U.S. economy. In 1999, among the total of approximately 5.6 million firms in the U.S, about 5 million firms had 19 or fewer employees (U.S. Census Bureau 2003c). In the emerging digital economy, the atomized sources are expected to grow continuously due to two reasons: the outsourcing of manufacturing giants to small and medium-sized companies, and the growing service sector. Thus it will be a new focus for the next generation of environmental polices to understand and regulate these rising sources.

Collection of the relevant information is the key to properly regulating the environmental impacts of cumulative services. The Environmental monitoring and accounting systems have to be reconfigured to be able to supply necessary data for further policy prescriptions. Two novel approaches emerged to overcome the practical barriers to deal with the environmental impacts of cumulative services: new environmental policy instruments (NEPIs) and new environmental management systems (EMSs). They will be further discussed below.

2 The ICT sectors

Policy implications of the ICT sectors merit a separate exegesis because of these sectors' significance to digital economy and information age. The environmental impacts of the ICT sectors can be generally categorized into two levels: direct impacts related to the life cycle of ICT hardware, and indirect or high-order impacts from the applications of ICT. Part of the direct impacts, especially the part related to the manufacturing process, has been covered by the first generation of environmental policy. However, many aspects of both direct and indirect impacts remained unregulated. First, the direct impacts outside the manufacturing process are largely ignored. The TRI records only the chemical emissions from the manufacturing processes, leaving behind the impacts of other stages of the product life cycle, although the number of the chemicals covered by TRI has doubled from 1987 to 2003. Second, the knowledge of the long-term toxicity and environmental impacts of these chemicals is far from complete. Third, many indirect impacts, such as the possible growth in energy consumption and rebound effects, have not been seriously and systematically considered. There is a long way to go before the entire picture related to the environmental impacts of ICT can be clearly delineated.

Langrock et al. (2002) offered a set of solutions to reduce the negative environmental impacts of ICT sectors, mainly through carefully analyzing the environmental problems associated with various phases of the ICT lifecycle (Table 4.2). This is a good starting point for the further exploration of the policy initiatives for ICT sectors in the emerging digital economy.

Table 4.2. Strategies toward more sustainable ICT products

Phase in Life cycle	Possible solution
Material acquisition	• Use more material with smaller “ecological rucksacks”
Manufacturing	• Reduce emissions and energy consumption by product environmental design
Final use	• Adopting end of life management • Encouraging product upgrading • Promoting new business models (such as leasing)
End product disposal	• Stop untreated disposal • Increase recycling quota • Treat parts that contain highly toxic substances separately • Stop illegal export of electrical and electronic waste • Collect electric and electronic waste separately from municipal waste

Sources: After Langrock et al. (2002).

4.3.3 E for environment: Policy prescriptions for E-commerce

Another important feature of digital economy is the rapid growth of E-commerce, whose policy implications requires further discussion. A common E-commerce chain consists of several interconnected nodes: suppliers, logistics (for the delivery of raw materials), company, logistics (for the delivery of final products), and the final users. These nodes, at first glance, seem not to be too different from those of traditional business chains; but some nodes of E-commerce chain may bear very distinct features. For example, logistics and distribution play an extremely important role in E-commerce because these two nodes are essential for maintaining new business modes such as "just-in-time," "just-enough," and "just-for-you." The tough competition forces the businesses to deliver the goods in the shortest possible time while keeping the leanest inventory. Air cargo transportation is more likely than in traditional businesses to be used; sometimes airplanes are even treated as the "flying warehouses" in E-commerce businesses. The changes in logistics and distribution systems have profound environmental implications. On the positive side, online shopping may save energy by reducing transportation to and from retail stores. On the negative side, online shopping may increase the energy consumption and pollutant emission by stimulating more energy-intensive delivery mode (e.g., overnight delivery).

The environmental impacts of E-commerce are actually far more complex than they first appear to be. Fichter (2001) distinguished three levels of environmental effects of E-commerce and Internet use: direct effects of information technology infrastructure (energy and material use of networks, servers, receiver systems, PCs, etc.), secondary effects caused by the transformation of business processes and markets, and tertiary effects due to subsequent and rebound effects (Table 4.3). Despite the possible overlaps and gaps, Fichter's approach still provided an useful analytical framework to examine the far-reaching the environmental impacts of E-commerce.

These new emerging problems have not been addressed in the first generation environmental policy. Although concrete policy prescription can be offered only after sufficient empirical studies, two points can be made to stimulate further thinking and discussions. First, it may be more appropriate for policymakers to play the goal-setting role, leaving the solutions of environmental problems to the profit-seeking industry. Second, a systematic approach should be adopted to cover every node in the entire E-commerce chain to avoid either displacement or omission of the possible environmental problems.

Table 4.3. Environmental effects of E-commerce and Internet use

Level of effects	First Order effects	Second Order effects	Third Order effects
Sources of change	• Networks, router, server, etc. • Receiving systems (Modems, etc.) • End appliances (PCs, mobile phones, etc.	• Product design and life-cycle management • Manufacturing and supply chain management • Logistics/distribution • Product use, take-back, recycling	• Changes in economic structure • Change in lifestyles and consumption pattern • Rebound effects
Potential environmental gains/losses	• Energy use • Hazardous substance • Electronic waste • Electromagnetic radiation	• Material and energy use • Transport volume Use of space	

Source: Fichter (2001).

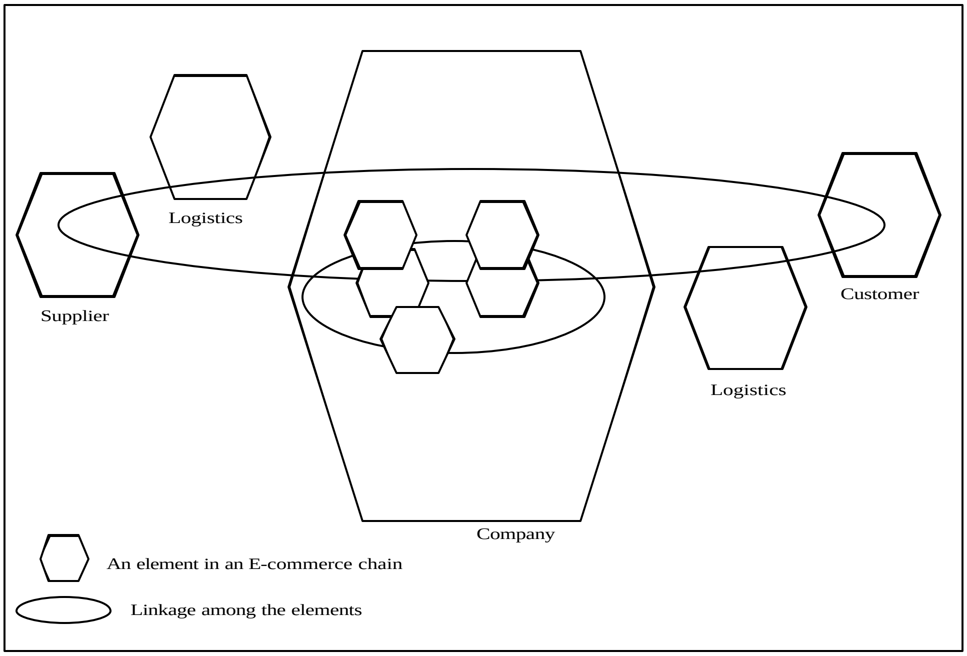

Figure 4.1. E-commerce components.
Sources: After Fitcher (2001).

4.3.4 Close the product life cycle: from sustainable production to sustainable consumption

So far the discussions on environmental policy has been narrowly confined into the manufacturing aspect of the economic system. Another equally important (if not more important) aspect, end users consumption, has been almost absent. It is surely very important to regulate the pollution from the producing processes in any type of economy. Pollution of manufacturing sources is in fact the major regulation target of the first generation of environmental policy. However, consumption-induced environmental impact has never been systematically considered, becoming a major setback of the current generation of environmental policy. How to bridge this gap should be a major theme of the new generation of environmental policy.

Consumption has long been taken as a self-evident concept and has rarely been precisely defined, but its meaning actually varies significantly in academia. Consumption has been conflated as all human material activity (Stern et al. 1997; Myers and Kent 2002); it has been equated with materialism (Scitovsky 1992; Wilk 1998); and it has also been treated as a population and technology issue (Wilkins 1997). In this study, the general production-consumption dichotomy is followed for the ease of analysis, and consumption is defined as consumers' decisions on purchase and use of all goods and services. It is beyond the scope of the study to clarify the definition of consumption; a thorough discussion on some conceptual issues surrounding consumption and the environment can be found in Princen (1999).

Durning (1992) reported that in the past 50 years, per capita consumption of some major raw materials has continued to increase in the U.S. Copper, steel, energy, timber, and meat consumption has doubled; plastic has expanded five-fold, and aluminum has had seven-fold increase. In fact, more goods and services have been consumed since 1950 than the consumption of all previous generations combined. In other developed countries, the situation of resource consumption is more or less the same. More noticeably, many intensely populated-developing countries are copying the lifestyles and consumption habits of the developed world as their economies continue to go up. The worldwide growth of consumption not only accelerates the use of natural resources, but also imposes additional burdens on the environment. Fortunately, the impact of consumption has been taken as one of the major themes of environmental protection in international community. In the 1992 Rio Earth Summit, the unsustainable pattern of consumption and production was recognized as one of the major causes of the continuous deterioration of the global environment, and industrialized countries were required o take the leading roles in adopting more sustainable lifestyle and consumption patterns (The UN 1992).

Princen (1999) identified three levels of consumption: background consumption, over-consumption, and mis-consumption, that aggregately impact the environment. While the background consumption is necessary to meet the basic physical and psychological needs of human being, its environmental impacts is considered to be inevitable. However, other two levels of consumptions negatively impact the environment in general.

According to Salzman (1997), consumption impacts the environment in two ways: by pattern (what to consume) and by level (how much to consume). The law is generally more effective in addressing pattern-related issues (e.g., mandate catalytic converters on cars) than levels-related problems (e.g., regulate how many cars each person is allowed to possess). Compared to the relatively straightforward goal of minimizing pollution in regulating the manufacturing sectors, the ultimate objective of consumption regulation is more subtle and uncertain because it is very challenging, if not at all impossible, to answer such normative questions as “How much is too much?” and “How much is enough?”

In the emerging digital economy, rapid evolving E-commerce is influencing both the pattern and level of consumption. The "click-and-pay" type of business mode makes the shopping process effortless, especially to those non-differentiated goods (e.g., electronics books, and CDs). The worldwide expansion of Internet and the number of online population not only make consuming goods more accessible, but also help consumption patterns and lifestyles more to easily penetrate physical, political, and cultural boundaries to spread throughout the countries. Thus the policies to regulate consumption are essential to the environmental protection and resource conservation in the emerging digital economy and information age.

In fact, the regulation of consumption pattern did exist in the first generation of environmental policies (e.g., the mandates for lead-free gas). However, they were not only inadequate in quantity, but also insufficient in the depth and broadness to fully cover the consumption issues and direct the way toward a more sustainable pattern and level of consumption.

Ehrlich and Holdren (1971) proposes the formula $I=PAT$ (I: environmental impacts, P: population, A: consumption, T: technology) to describe the relationship among environmental impacts, population, consumption, and technologic advancement. The model demonstrates that there exists three options to reduce the overall impacts on environment, 1) by increasing efficiency (doing more with less), 2) by reducing sufficiency (consuming less), and 3) by controlling population growth. Technological advancement seems to be the most ideal choice at a first glance. However technology is not always that reliable and predictable. John Von Neumann (1955) has warned half century ago, "New technologies affect the earth in its entirety. The more useful a technology is, the more unstablizing its effects can also be". Steam engines were able to produce the same amount of power with one-third the coal than the most efficient technology at the time it was invented. However, the coal consumption increased ten-fold because steam engine was soon put into many more applications (Jevons 1865). So the uncertainties of the inducing of new technologies have to be fully considered before the real environmental gains can be counted. Population control is difficult for many social, economic, religious, and political reasons. The remaining choice is to regulate the levels and patterns of consumption, which is also complicated by many factors, such as rebound effects, standardization effects, and cultural effects.

The environmental impacts of consumption are long-existing problems, rather than the direct outcome of digital economy. Although some unique features of digital economy do make these problems more significant and problematic in some degree, the long time evolution, accumulation, and inattention should be blamed as the major cause. The ultimate solutions remain distinct due to the complexities and difficulties in creating appropriate measurement methods, addressing equity concerns (intergenerational, intra-generational and geographical), and dealing with issues of societal norms, such as the freedom to choose lifestyles. Dowdeswell once noted, "Ultimately, sustainable consumption is not a scientific or a technical question. It really is first and foremost a question of values" (cited in Salzman 1997, 1256.).

Systematic policy solutions to the consumption issue have yet to develop. However, some promising approaches have been proposed. Caviglia-Harris et al. (2003)

suggests two “demand-side” policies to supplement the traditional supply-side policies to achieve both efficiency and sustainability, one is to promote substitutes in production, the other is to promote substitute in consumption. The former approach is expected to help sustainable production processes, the latter is assumed to indirectly contribute to sustainability by creating demands for products that generate less environmental burdens. The extended produce responsibility (EPR) introduced in Salzman’s paper (1997) also provides a promising model for the future policymaking to regulate consumption behavior. In general, market mechanisms and governmental interventions have to be combined to achieve the goal of sustainable consumption.

4.3.5 Atoms to bits: New foundations for the environmental policy in digital economy and information age

One of the fundamental changes in digital economy from the traditional industrial economy is the rapid growth of information related activities. The generation, retrieval, movement, transformation, and exchange of information are competing with the production of tangible goods as the primary economic activity in digital economy. The major targets of the environmental laws and regulations are shifting as the result of the declining significance of the industrial sources and rising environmental impacts from many other factors in the economy (e.g., the impacts of service and ICT sectors, the consumption issues), The next generation of environmental policies has to bring about new visions, new management approaches, and new analytical tools to deal with these new targets with high efficiency and effectiveness.

On the basis of the above discussion, five guidelines have been identified for the next generation of environmental polices. These guidelines are overlapping and cross-cutting in many subtle and complex ways. They also might not be detailed and solid enough to serve as the practical action plans, but they will nevertheless stimulate further thinking and discussions in many valuable aspects.

First, the new generation of environmental policy has to be adapted to the changing nature of the economy in digital economy, taking into account many new rising issues, such as the rising ICT, information, service sectors, the dynamic E-commerce, and the patterns and levels of consumption.

Second, the next generation of environmental policies should become more comprehensive in focus and attentive in the linkages across problems, covering the full range of the product lifecycle and both sides of the production/consumption dichotomy to minimize the omission and displacement effects of the old piece-meal approach.

Third, governmental interventions should play a more active role in correcting market failures, conveying correct price signals, and promoting the concept of sustainable consumption. For consumption policy, there are at least three roles the government can play, the gatekeeper to mandate product performance and content, the information source of environmental impact data of products to direct more rational purchasing decisions, and the price controller to capture externalities through fees and taxes (Salzman 1997).

Fourth, environmental protection should become the business of all stakeholders, inclusive of not only all levels of governmental officials, but also industrial organizations, environmental groups, businesses, civil associations, and common citizens. The ultimate solution to environmental problems may be how to influence the consumption decisions of billions of individuals, who are both passengers and crews of the spaceship Earth.

Last, but not the least, the toolbox of the new generation of environmental policies needs to be significantly expanded and upgraded to supply more powerful instruments. NEPIs and NEMSs are two promising directions in this regard and many practices in the Europe Union countries have been reported. These policy instruments and management strategies are different from the "command-and-control" approach in that they are in nature more flexible and cooperative incentive-based (Gunningham and Sinclair 1998; Jordan, Wurzel, and Zito 2003).

NEPIs can be divided into three major categories, market-based instruments (MBIs), voluntary agreements (VAs), and information devices (Jordan, Wurzel, and Zito 2003). MBIs associate the financial incentives with environmental goals through market mechanism, including pollution charge systems (e.g., eco-tax), tradable permits, and deposit-refund systems. VAs are basically commitments made by industries to pursue actions leading to the improvement of the environment (OECD 1998). Information devices (e.g., eco-labels) rely on moral persuasion by providing consumers with information about the environmental impact of particular products and services (Jordan, Wurzel, and Zito 2003).

The traditional environmental management systems (EMSs) focus on the enforcement of emission standards and promote advanced pollution control technologies for plants in the manufacturing sectors. The successful implementation of EMSs depends mainly on two factors: 1) the appropriate emission standards, 2) the suitable environmental technologies, but it is very difficult to achieve both efficiency and effectiveness at the same time. The NEMSs are more organic and mechanic in nature, that is to say, the entire ecosystem, rather than a single environmental medium or pollutant, becomes the central objective in the management system (Haeuber 1998); and management system focuses more on the strict following of pollution reduction procedures rather than on the setting of precise emission standards. New initiatives and strategies of these NEMSs include self-regulation, third-party oversight, and stakeholder involvement (Ring 1997; Gunningham and Sinclair 1998).

Hot disputes and debates are still going on both in academia and governmental agencies on both theoretical and practical issues of the NEPIs and NEMSs. It is important to understand that what really matters are “ideas.” That is to say, if these new instruments and initiatives are valuable in the basic principles, their effectiveness will be finally approved in the practice of the environmental management.

4.4 Summary: Research questions in the context of the Austin MSA

Explorations of the changing nature of environmental problems and correspondent policy prescriptions in the context of digital economy have become interesting to more and more scholars in a variety of disciplines. Existing studies have raised critical questions, presented interesting results, and reported valuable facts and evidence, but no general conclusions have yet been made, possibly indicating either the complexity of the problems or the insufficiency of the existing empirical studies. The present situation encouraged the author to study economic structure change and its environmental consequences at the regional level in the context of emerging digital economy. This study, equipped with environmental-extended input-output analysis, will provide answers, or at least throw more light on the three major research questions:

1) What kind of economic structure transformation is occurring in the emerging digital economy? Are there any observable trends from the perspective of macroeconomics?

2) How does the transformation in the economic structure contribute to the quantity, pattern, and source of the point industrial air pollutant emissions?

3) What will the environmental consequences be in the foreseeable future along various development trajectories?

Notes

[1] Esty and Chertow (1997) originated generational divisions for the U.S. environmental policies. The first generation started at the beginning of the 1970s and lasted about three decades till the late 1990s. Earlier efforts of resources conservation and pollution control have been recognized to set the stage for first generation of environmental policies, but not to be systematic enough to form a generational approach.

[2] Rejeski (1997) provides detailed descriptions about these reviews.

[3] Vig and Kraft (2000) have provided a more thorough and systematic review of the U.S. environmental policy from 1970 to 2000.

[4] The Bush administration retreated from the protocol on March, 2001 (ACS 2003).

[5] The author does not regard leverage service as a separate category of service; thus its policy implications are not included in the following discussions.

[6] More detailed description of the story can be found in Rejeski (1997).

CHAPTER V

RESEARCH METHODOLOGY

We have to remember that what we observe is not nature in itself but nature exposed to our method of questioning.

-W. Heisenberg

5.1 Introduction

Chapter II introduces the Input-output (IO) analysis as an appropriate analytical tool for studying the structural interrelationships in an economic system with n-dimensional variables of economic activities, environmental goods and services, and waste discharges. IO analysis, along with two other analytical tools, structural decomposition analysis (SDA), and hypothetical extraction measurement (HEM), are selected as the methodologies used to investigate the environmental impacts of the digital economy at a regional level. This chapter introduces the IO analysis, an environmental extension of IO analysis (EIO), HEM, and SDA techniques, and describes the data sources and the design of classification and aggregation schemes.

5.2 IO analysis

5.2.1 Origin and development

French economist Francois Quesnay published “the Tableau Economique” in 1758, in which he discussed the broad interrelationships within an economic system and the concept of general equilibrium (Spiegal 1952). But it is not Quesnay, but his French peer, Leon Walras, who is generally recognized as the founding father of modern general economic equilibrium theory. Walras developed a general equilibrium model based on a series of simultaneous equations representing goods or services produced in an economy (Spiegal 1952). However, Walras's focused on theoretical explorations, rather than on the practical applications of the model. About 60 years later, Wassily Leontief (1936) published the U.S. input-output table. His book, The Structure of the American Economy, 1919 - 1929 was published in 1941, which later became one of the classic textbooks on IO analysis (Leontief 1941). Leontief systematically extended Quesnay's and Walras' theories by providing an empirical tool for the general equilibrium model. He perceived that complicated interactions within an economy could be approximated by proportional relationships between industrial sectors. Further, the production level of each commodity can be determined by the final use of output and the assumed production structure.

IO models were later modified to satisfy interest in economic analysis at the regional level, which was developed to reflect the peculiarities of regional problems. Two basic features of a regional economy may influence the characteristics of a regional IO analysis. First, the structure of production in a particular region may be identical to, or may differ significantly from, that at the national level. Second, the smaller the economic region, the economy of the region is relied more on the trade with "outside" areas (Miller and Blair 1985). Starting from the 1950s, an enormous number of studies related to the regional and multiregional IO analysis appeared (Isard 1951; Moore and Petersen 1955; Hirsch 1959; Emerson 1969, 1971; Giarratani, Maddy, and Socher 1976; Polenske 1980; Miernyk 1970, 1982; McGregor, Swales, and Yin 1996; Li and Ikeda 2001; Lenzen et al. 2003).

The formal attempt to model the natural resource and environmental problems with IO analysis started in the early 1960s. Lofting and McGauhey (1963) calculated water-use coefficients using the IO table of California. Cumberland (1966) discussed the possibility of measuring the impact of economic growth on the environmental quality using IO models. Canion and Trock (1968) applied IO analysis to determine the resources required to sustain a given output level. In the following decades, more studies have extended the IO applications into many new fields, such as accounting pollution generation, estimating abatement costs, examining the impacts of taxation on the pollution generation, and investigating institutional aspects of environment impacts (Leontief 1970; Laurent and Hite 1971; Giarratani and Thompson 1974; Janicke et. al 1989; Hawdon and Pearson 1995; Lave, Cobas, Hendrikson, and Mcmichael 1995; Matthews 1999; Steenge 1999).

The latest expansion of IO analysis was made by Duchin (1998), who proposed the principles of structural economics on the basis of Leontief's IO model and Stone's (Stone 1970, 1971) social and demographic extension on input-output economics. According to Duchin (1998), structure economics is concerned with both quantitative and qualitative changes that take place in an economic system with the passage of time. Structural economics provides a new approach for situating economic activities (from both production and consumption side) in a broader environmental, technological, social, demographic, and cultural context compared to the stylized utilitarian approach in the theoretical framework of the traditional neoclassic economics.

5.2.2 Basics of input-output analysis

Table 5.1 presents a general IO model, in which an economy is divided into n purchasing (input) sectors (rows) and producing (output) sectors (columns). The rows of the table describe the distribution of a producer's output throughout the economy. The columns describe the composition of inputs required by a particular sector to produce its output (Miller and Blair 1985).

In Table 5.1, X_i is the total output of sector *i*, Y_i is the total final demand of sector *i*, x_{ij} is the flow from sector *i* to sector *j* (as one type of the input factor to produce *j*) in a given period of time. All the intersectoral flows are usually recorded with monetary values for the convenience of analysis, though the physical terms may be more appropriate for representing the exchange of materials between sectors. The total input of a sector (column sum) equals the row sum of the sector, including the intermediate demands of the other sectors and the final demand, which could be further disaggregated into four factors: household consumption, government consumption, investment, and export. Figure 5.1 shows that a standard IO table can be divided into four parts, intermediate industry exchange (upper left), final demand (upper right), value added (lower left), and gross national product (lower right).

The dimensions of an IO table may vary from a few to hundreds. The IO table produced by the U.S. Bureau of Economic Analysis (BEA) has its own coding systems different from standard industrial classification (SIC) and North America industry classification system (NAICS).[1] But items in IO tables can be easily bridged into SIC or NAICS or, vice versa. If there are more digits in the code for an item in an IO table, the greater detailed classification schemes are used for the record of that industry activity (or commodity produced), and the higher the dimension (n) of the input-output table may be. Encoding with four digits SIC, the most detailed input-output table usually has 528 economic sectors.

<table>
<tr><th rowspan="2"></th><th colspan="4">Producer</th><th colspan="4">Final demand</th></tr>
<tr><th>Sector 1</th><th>Sector 2</th><th>...</th><th>Sector n</th><th>Household consumption</th><th>Governmental consumption</th><th>Investment</th><th>Export</th></tr>
<tr><td>Sector 1</td><td colspan="4" rowspan="4">Intermediate Industry Exchange</td><td colspan="4" rowspan="4">Final Demand</td></tr>
<tr><td>Sector 2</td></tr>
<tr><td>...</td></tr>
<tr><td>Sector n</td></tr>
<tr><td>Employees</td><td colspan="4" rowspan="3">Value Added*</td><td colspan="4" rowspan="3">Gross National Product (GNP)</td></tr>
<tr><td>Owners of business and capital</td></tr>
<tr><td>Government</td></tr>
</table>

Figure 5.1. Four components of a general input-output model.
Source: After from Miller and Blair (1985).
*: Value added includes employee compensation, profit-type income and capital consumption allowances, and indirect government tax.

Table 5.1. A general input-output model

Producing Sectors	Purchasing Sectors (Intermediate Flows)						Final Demand	Total Output
	1	*2*	. .	*j*	. .	*n*		
1	x_{11}	x_{12}	. . .	x_{1j}	. . .	x_{1n}	Y_1	X_1
2	x_{21}	x_{22}	. . .	x_{2j}	. . .	x_{2n}	Y_2	X_2
.	.	.		.		.		
.	.	.		.		.		
.	.	.		.		.		
i	x_{i1}	. . .	. . .	x_{ij}	. . .	x_{in}	Y_I	X_i
.	.	.		.		.		
.	.	.		.		.		
n	x_{n1}	x_{n2}	. . .	x_{nj}	. . .	x_{nn}	Y_n	X_n
Households (h)	x_{h1}	x_{h2}	. . .	x_{hj}	. . .	x_{hn}	Y_h	X_h
Local Govt. (l)	x_{l1}	x_{l2}	. . .	x_{lj}	. . .	x_{ln}	Y_l	X_l
State Govt. (s)	x_{s1}	x_{s2}	. . .	x_{sj}	. . .	x_{sn}	Y_s	X_s
Federal Govt. (f)	x_{f1}	x_{f2}	. . .	x_{fj}	. . .	x_{fn}	Y_f	X_f
Gross Savings (g)	X_{g1}	x_{g2}	. . .	x_{gj}	. . .	x_{gn}	Y_g	X_g
Depreciation (d)	x_{d1}	x_{d2}	. . .	x_{dj}	. . .	x_{dn}	Y_d	X_d
Imports (I)	x_{I1}	x_{I2}	. . .	x_{Ij}	. . .	x_{In}	Y_I	X_I
Total Input	åx_1	åx_2		åx_i		åx_{ni}	å Y_I	åX_i

Source: After Gay (2002)

By examining Table 5.1, a series of linear equations can be generated:

$$
\begin{aligned}
X_1 &= x_{11} + x_{12} + \ldots + x_{1j} + \ldots + x_{1n} + Y_1 \\
X_2 &= x_{21} + x_{22} + \ldots + x_{2j} + \ldots + x_{2n} + Y_2 \\
X_i &= x_{i1} + x_{i2} + \ldots + i_n + \ldots + x_{in} + Y_i \\
X_n &= x_{n1} + x_{n2} + \ldots + x_{nj} + \ldots + x_{nn} + Y_n
\end{aligned}
\tag{5.1}
$$

Let A_x be the total output of sector j, the ratio of input from sector I to total input of sector j is:

$$a_{ij} = x_{ij} / X_j \tag{5.2}$$

Rewriting equation 5.1 by replacing i_n with $a_{ij}X_j$, yields equation 5.3:

$$
\begin{aligned}
X_1 &= a_{11}X_1 + a_{12}X_2 + \ldots + a_{1j}X_j + \ldots + a_{1n}X_1 + Y_1 \\
X_2 &= a_{21}X_1 + a_{22}X_2 + \ldots + a_{2j}X_j + \ldots + a_{2n}X_1 + Y_2 \\
&\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \\
X_i &= a_{i1}X_1 + a_{i2}X_2 + \ldots + a_{ij}X_j + \ldots + a_{in}X_1 + Y_i \\
&\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \\
X_n &= a_{n1}X_1 + a_{n2}X_2 + \ldots + a_{nj}X_j + \ldots + a_{nn}X_1 + Y_n
\end{aligned}
\tag{5.3}
$$

Bringing all X terms in equation 5.3 to the left and grouping X_1s together in the first equation, the X_2s in the second equation, and so on, then yields equation 5.4:

$$
\begin{aligned}
&(1 - a_{11})X_1 + a_{12}X_2 \ldots + a_{1j}X_j \ldots + a_{1n}X_1 = Y_1 \\
&- a_{21}X_1 + (1 - a_{22})X_2 + \ldots + a_{2j}X_j + \ldots + a_{2n}X_1 = Y_2 \\
&. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \\
&a_{i1}X_1 + a_{i2}X_2 + \ldots + (1 - a_{ij})X_j + \ldots + a_{in}X_1 = Y_i
\end{aligned}
\tag{5.4}
$$

. . . .

$$a_{n1}X_1 + a_{n2}X_2 + ... + a_{nj}X_j + ... + (1 - a_{nn})X_1 = Y_n$$

In matrix notion, define:

$$* A = \begin{bmatrix} 1-a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & 1-a_{22} & ... & a_{2n} \\ \\ a_{m1} & a_{m2} & ... & a_{mn} \end{bmatrix}, \quad Y = \begin{bmatrix} y_1 \\ y_2 \\ ... \\ y_n \end{bmatrix}, \quad X = \begin{bmatrix} x_1 \\ x_2 \\ ... \\ x_n \end{bmatrix}$$

Rewriting equation 5.4 in matrix notation

$$* AX = Y \tag{5.5}$$

or

$$X(I - A) = Y \tag{5.6}$$

Where

X : gross output vector

A: technical coefficients matrix

Y : final demands vector

I : $n \times n$ identity matrix

Solve equation[2] 5.6 for X :

$$X = (I - A)^{-1} Y \tag{5.7}$$

Rewriting equation 5.7 by denoting $(I - A)^{-1}$ with a_{ij}, yield:

$$X_1 = a_{11}Y_1 + a_{12}Y_2 + ... + a_{1j}Y_j + ... + a_{1n}Y_n \tag{5.8}$$

$$X_2 = a_{21}Y_1 + a_{22}Y_2 + ... + a_{2j}Y_j + ... + a_{2n}Y_n$$

. . . .

$$X_i = a_{i1}Y_1 + a_{i2}Y_2 + ... + a_{ij}Y_j + ... + a_{in}Y_n$$

. . . .

$$X_n = a_{n1}Y_1 + a_{n2}Y_2 + ... + a_{nj}Y_j + ... + a_{nn}Y_n$$

Equation 5.8 makes it clear that the output of each sector of the economy is dependent on the final demands of all the sectors. Matrix $(I - A)^{-1}$ is the key matrix in the IO model. The elements of this matrix measure both the direct and indirect output levels from each sector of the economy required to satisfy given levels of final demand. It is also called the matrix of interdependence coefficients, or the Leontief inverse matrix.

5.3 Environmentally extended input-output analysis

The environmental extension of the basic Leontief model requires the consideration of many additional conditions such as natural resource inputs, pollutant generation, and pollution abatement activities. Miller and Blair (1985) summarizes three types of environmental input-output (EIO) models: (1) generalized input-output models introducing the technical coefficients matrix with additional rows and columns to represent the pollution generation and abatement activities, (2) Incorporating “ecosystem” sectors into the general input-output models, recording ecological inputs and residuals flows between economic sectors and ecosystem, and (3) commodity-by-industry models describing environmental factors as commodities in a commodity-by-industry input-output table.

Laurent and Hite (1971) illustrates the first type of EIO using a figure in the studies on economic-ecologic interactions in the Charleston, South Carolina, metropolitan area. The figure (Figure 5.2) presents a clear conceptual framework for the EIO adopted in this study. The figure also helps one understand the linkage between the standard IO model and ecological (environmental) imports and exports. The upper left corner is a standard IO matrix. a_{11} is the amount of output sector 1 required to produce one unit of gross output of sector 1 , a_{21} is the amount of output sector 2 required to produce one unit of gross output of sector 2, and so on. This matrix is labeled as *A* matrix. Below the *A* matrix, in the lower left-hand corner, is the *G* matrix. It shows that m types of ecological imports are required to generate gross outputs by the economic sectors in the *A* matrix. If G_1 is water, the G_{11} is the amount of water required to generate one unit of gross output by *A*, and so on. The *E* matrix, in the upper right-hand corner, is analogous to the *G* matrix, except it shows exports of residuals (pollutants) back to the environment from the economic sectors in the *A* matrix. Thus, if E_1 is carbon dioxide,

e_{11} is the amount of carbon dioxide associated with one unit of gross output by sector 1, and so on.

	1	**2**	**...**	**...**	**n**
1	$\mathbf{a_{11}}$	$\mathbf{a_{12}}$	**...**	**...**	$\mathbf{a_{1n}}$
2	$\mathbf{a_{21}}$				
...	**...**				
...	**...**				
n	$\mathbf{a_{2n}}$				

Matrix A (Interindustry Matrix)

	1	**2**	**...**	**...**	**k**
	$\mathbf{e_{11}}$	$\mathbf{e_{12}}$	**...**	**...**	$\mathbf{e_{1k}}$
	$\mathbf{e_{21}}$				
	...				
	...				
	$\mathbf{e_{n1}}$				

Matrix E (Ecological exports)

	1	**2**			**n**
1	$\mathbf{g_{11}}$	$\mathbf{g_{12}}$	**...**	**...**	$\mathbf{g_{1n}}$
2	$\mathbf{g_{21}}$				
...	**...**				
...	**...**				
m	$\mathbf{g_{m1}}$				

Matrix G (Ecologic imports)

Figure 5.2. Simplified environmentally extended IO model.
Sources: After Laurent and Hite (1971).

When final demand requires output to increase (or decrease), the amount of pollutants generated also changes correspondently.[3] The direct pollution coefficient can be expressed as the ratio of total pollutants generated by a sector to total sector output. However, the total pollution coefficient is not enough to measure the total impact on pollution generation in the economy, since indirect pollution generation has not been taken into account. The Leontief inverse matrix can be used to estimate total pollution generated. The relationship between pollution generation and output can be stated as:

$$r_{kj} = b_{kj} X_j \tag{5.9}$$

Where

r_{kj} : the amount of pollutant k discharged from sector j

X_j : output of sector j

b_{kj} : the amount of pollutant k discharged per unit of output in sector j

$$b_{kj} = \frac{r_{kj}}{X_j} \tag{5.10}$$

Let R_k be equal to the total discharge of pollutant k. Then:

$$R_k = \sum_{j=1}^{n} r_{kj} = \sum_{j=1}^{n} b_{kj} X_j = b_{k1} X_1 + b_{k2} X_2 + \ldots + b_{kn} X_n \tag{5.11}$$

Expanding this equation, the discharges of pollutants $k = 1$ through m are:

$$R_1 = b_{11}X_1 + b_{12}X_2 + ... + b_{1n}X_n \quad (5.12)$$

$$R_2 = b_{21}X_1 + b_{22}X_2 + ... + b_{2n}X_n$$

$$R_m = b_{m1}X_1 + b_{m2}X_2 + ... + b_{mn}X_n$$

In matrix notation,

$$R = BX \quad (5.13)$$

Where

$$R = \begin{bmatrix} R_1 \\ R_2 \\ R_m \end{bmatrix}, \; B = \begin{bmatrix} b_{11} & b_{12} & ... & b_{1n} \\ b_{21} & b_{22} & ... & b_{2n} \\ b_{m1} & b_{m2} & ... & b_{mn} \end{bmatrix}, \quad X = \begin{bmatrix} X_1 \\ X_2 \\ X_n \end{bmatrix}$$

It has already been established in equation 5.7 that,

$$X = (I - A)^{-1}Y$$

Substituting X in equation 5.13 with equation 5.7, the discharges of the pollutants are,

$$R = B(I - A)^{-1}Y \quad (5.14)$$

or,

$$R = PY \tag{5.15}$$

where $P = B(I - A)^{-1}$

The matrix P shows the direct and indirect effect of the final demand change on the various pollutants' emissions/discharges. Let P_{kj} be an element in the matrix P. Then, for every unit worth of final demand for products of sector j, P_{kj} units of pollutant k are discharged directly from producing sector j and indirectly through discharges induced by output changes in other sectors of the economy.

5.4 The hypothetical extraction measurement

5.4.1 Introduction

One important theme of this research is to identify the change in relative importance of the sectors in an economy as economic structure evolves. Hypothetical extraction measurement (HEM) is one of the indices to quantify the relative importance of an individual sector in an economy (Schultz 1977; Cella 1984; Blair and Miller 1990). HEM is built on the assumption that sectors with higher linkages to other sectors are more important than those with lower linkage, and the key sector is the sector that has the highest linkage with other sectors. The general idea of the HEM is to compare the difference of the gross output generated in sector (j) in an economy with n sectors in two situations: (1) the gross output from *n-1* sectors, when sector *j* is still part of the *n* sectors economy to meet the requirement of a specified level of final demand, and (2) the gross output of the same *n-1* sectors, when sector *j* has been extracted from the economy through the removal of the row and column from the technical coefficients matrix to meet the same level of final demand not including sector *j*. The difference between the two measurements is considered as the total interdependence (linkage effect) of sector *j* on the rest of the sectors of the economy.

HEM is a useful method to identify the key sectors of the economy. Previous applications can be found in Harrigan and Mcgilvray (1988), Machado (1994), and Machado and Miller (1997). The drawbacks of this approach are discussed by Cella (1984). The major problems include the lack of any distinction between back and forward linkages,[4] possible underestimation of the effect of the total linkage of the extracted sector, and dependence of the result on the level of aggregation.[5]

5.4.2 Model description

For the convenience of explanation and understanding, a more specified rather than general model is introduced below. It has already been established in equation (5.7) that:

$$X = (I - A)^{-1} Y$$

Let

$$X^{*} = IX - X_{j}, \tag{5.16}$$

where

X^*: the total output after extracting the output of sector j

X_j: the output of sector j

I : $n \times 1$ vector with all elements equal to 1

Let

$$X_{(j)} = [I - A_{(j)}]^{-1} Y_{(j)} \tag{5.17}$$

where

$X_{(j)}$: the total output of *n-1* sector after extracting sector j from the economy

$A_{(j)}$: technical coefficients matrix from which row j and column j have been extracted

$Y_{(j)}$: the final demand from which the final demand of sector j has been removed

Then the total linkage can be defined as:

$$TL = X^* - X_{(j)} \tag{5.18}$$

TL shows the linkages effects of sector j on the total economy. One way to normalize TL is to calculate the ratio of TL and X^*, which represents the percentage of the linkages effects to the total gross output (after subtracting the output of sector j). Generally speaking, the larger the TL (or ratio) is, the higher the linkage effect, and the more important the sector is.

5.5 Structure decomposition analysis

5.5.1 Introduction

Structural decomposition analysis (SDA) is a relatively new methodology that has gained attention since the early 1970s (Leontief and Ford 1972). This analytical tool has made it possible to quantify fundamental “sources” of change in a wide range of variables, including economic growth, energy use, workforce requirement, trade, and material intensity of use (Rose and Casler 1996).

The formal definition of SDA emerged in the late 1980s and early 1990s. The central idea of SDA is to distinguish major sources of change in an economy by means of identifying a set of comparative static changes in key parameters in an input-output table (Rose and Miernyk 1989; Rose and Chen, 1991). The primary rationale for SDA is to split an identity into its components. This division can be as simple as the three-part basic form (technological change, mix, and level), or as complex as desired. Leontief and Ford (1972) first perform the formal three-part decomposition to identify the sources of change in air pollution emissions. Following their steps, more attempts have been practiced, with the most prominent jobs done by Skolka (1989) and Rose (Rose and Chen 1991).

SDA has several advantages. First, it overcomes many static features of the IO model and is able to examine changes over time in technical coefficients and a sectoral mix. Second, it requires much less input and has relatively insignificant restrictions compared to traditional econometric estimation. Third, SDA’s IO base makes it much easier to link the environmental and natural resource issues to intermediate sectors and to look at root causes of pollution and resource depletion.

Despite the criticism of its weak theoretical foundation, lack of verification of mutual exclusivity, and conceptual problems in defining the terms of decomposition, a wide variety of applications have been implemented concerning sources of change in international trade, technological change, energy use, workforce requirement, and development planning (Sterner 1985; Chen and Wu 1995; Lin and Polenske 1995; Han 1995; Dietzenbacher and Los 1998; Wier 1998; Kim 2002; Andreosso-O'Callaghan and Yue 2002). Stevens and Moore (1980) argue that the "persistence" of applications is due to the straightforwardness o SDA, which means it can be implemented with readily available data. However, no definitive test of its accuracy has yet been undertaken.

5.5.2 Model description

After summarizing the method proposed in the research paper of Fujimagari (1989) and Sawyer (1992), Wier (1998) suggests six components to be the sources influencing the change of pollutant emissions: the level of the final demand, the composition of the final demand, IO coefficients, emission factor, energy intensity, and fuel-mix in the production sectors. Wier's model is as follow:

Suppose there is an economy with *n* industry sectors, *m* fuel types for each industry, and *k* sectors of final demand, At a given point in time, production-based emissions of a certain pollutant (i.e. SO2) are given by:

$$
\begin{aligned}
&E_p^i = [(F_p^i M_p Q_p)' J]' (I - A)^{-1} Dd \\
&i = SO2, CO, NO_x etc.)
\end{aligned}
\tag{5.19}
$$

Where

E_p^i: a scalar of total emissions of type *i* from the production sectors

F_p^i: a $n \times m$ matrix of emission per unit of total demand for energy for all the production sectors

M_p: a $m \times n$ matrix of fuel mix in the production sectors

$Q_{p:}$ a $n \times n$ diagonal matrix of energy intensities

J: a $n \times 1$ matrix with all elements equal to 1

$(I-A)^{-1}$: $n \times n$ Leontief inverse matrix

D: a $n \times k$ matrix of the composition of final demand

d: a $k \times 1$ matrix of absolute level of final demand for all categories of final demand

The change in the level of emissions from sectors given by equation (1) from time *t-1* until time *t* is given by,

$$E_p^i(t) - E_p^i(t-1) \approx \Delta F_p^i + \Delta M_p + \Delta Q_p + \Delta(I-A)^{-1} + \Delta D + \Delta d \tag{5.20}$$

Each element in the decomposition formula has the same general form. Using the emission factor effect as an example, this element is given by

$$\begin{aligned} \Delta F_p^i = \frac{1}{2}\{&[F_p^i(t) - F_p^i(t-1)]M_p(t-1)Q_p(t-1)(I-A)^{-1}(t-1)D(t-1)d(t-1) \\ &+ [F_p^i(t) - F_p^i(t-1)]M_p(t)Q_p(t)(I-A)^{-1}(t)D(t)d(t)\} \end{aligned} \tag{5.21}$$

Kim (2002) took a very similar but more simplified approach than Wier (1998) did. The change in emissions from production is considered be related to three contributors: emission intensities, technical coefficients, and final demands. Kim's model is as follow:

$$TE^{p} = B^{p}(I-A)^{-1}(Y-Mz') \tag{5.22}$$

Where

TE^{p}**:** a scalar[6] of total quantity of emissions of type p pollutant from the all the production sectors

B^{p}**:** $1\times n$ vector of direct pollutant coefficient for pollutant p

$(I-A)^{-1}$: Leontief Inverse Matrix

Y: $n\times 4$ matrix of four components of final demand, household consumption government consumption, investment, and export

M: $n\times 1$ vector of imports

Z: a 4×1 vector of with all one element

The change in emissions from all the production sectors from time *t-1* to time *t* can be disaggregated into three components by equation 5.23,[7]

$$\begin{aligned} &TE_i^{p}(t) - TE_i^{p}(t-1) = \\ &\Delta B^{p}(I-A)^{-1}(t)(Y-Mz')(t) \\ &+ B^{p}(t-1)\Delta(I-A)^{-1}(t)(Y-Mz')(t) \\ &+ B^{p}(t-1)(I-A)^{-1}(t-1)\Delta(Y-Mz') \end{aligned} \tag{5.23}$$

Where

ΔB^{p}: change in emission intensity

$\Delta(I-A)^{-1}$: change in technical coefficient

$\Delta(Y-Mz')$: change in the composition of final demand and import

Since detailed fuel mix and energy mixture data is currently not available for the Austin MSA during the period studied, to simplify the calculation, Kim's approach is followed in this research. The three contributors for the change of pollutant emissions are: emission intensity, technical coefficients, and final demand.

5.6 Data sources

5.6.1 Input-output tables

In the U.S., every five years, the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce (USDC) compiles and publishes the input-output table of the U.S. economy. The table is available for each state and counties within states. Through Regional Economic Information System (REIS) and other sources, the USDC provides income and employment multipliers for counties throughout the U.S. It also provides multipliers for a designated group of counties, such as Metropolitan Statistical Area (MSA); the services are charged based on different requests (Jones 1997).

Another source of IO table is the commercial group called the Minnesota IMPLAN Group Incorporated, or MIG Inc. in Stillwater, Minnesota. This organization maintains and markets a national database and input-output analysis software known as IMPLAN (Input-output Model for PLANning). IMPLAN data files are compiled from a wide variety of sources including the U.S. Bureau of Economic Analysis, the U.S. Bureau of Labor, and the U.S. Census Bureau. IMPLAN data is available at the state, county, and custom Zip Code level (MIG 2003).

Three IO tables, (1990, 1994, and 1997) used in this research are collected from MIG. Each IO table includes 528 industrial sectors. IMPLAN version 2.0, the software developed by MIG, was used to build IO models and implement the IO analysis for the study.

5.6.2 Emission data sources

Point industrial air emission data is used as a proxy to explore the environmental impacts of the economic structure change in the Austin MSA. Starting from 1990, Texas Natural Resources Conservation Committee (TNRCC)[8] began to collect information about air pollutants emitted from industrial point sources in Texas for the State of Texas Air Reporting System (STARS). STARS is currently tracking about 50,000 plants of the state, in which about 3000 industrial point sources exceeding the reporting applicability levels are recorded in the database.[9] According to national ambient air quality standards (USEPA 2003b), seven pollutants are tracked and recorded: non-methane organic compound (NMOC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter less than ten microns in diameter (PM_{10}), total particulate matter (TSP), and Lead (Pb).

Twelve years of records (1990 –2001) in the Austin MSA were extracted from the STARS, which includes all the emission data of industrial point sources exceeding the reporting applicability level. The data was further aggregated according to 1987 four-digit SIC. Pb was excluded from the following analysis because most of the sources have zero or near zero emission.

5.7 Sectoral aggregation and classification

The problem of sectoral aggregation is noteworthy to any IO analysis. The level of aggregation not only influences the sensitivity of the model, but also impacts the data requirement of the research (Hawdon and Pearson 1995). The demand for data (especially environmental data) and computational load[12] will significantly increase when a less aggregated model is adopted. So it is always attractive to build an IO model at a very low level of aggregation to obtain more detailed information, but, due to data deficiencies, it is simply not practical in many cases.

This study takes a high-level aggregation approach because the point industrial emission data are highly concentrated into very few four-digit SIC sectors, as will be detailed in the following chapters. Both three-segment[13] and seven-segment models are constructed for the years of 1990, 1994, and 1999. The standard of aggregation is based on the industrial classification systems which are briefly introduced in the following section.

5.7.1 An introduction to SIC

The first Standard Industrial Classification (SIC) for the United States appeared in the late 1930s. The lists of manufacturing industries and non-manufacturing industries were published separately in 1938 and 1939. SIC was designed to classify industries based on various types of statistical data and to become the standard of industrial classification schemes of the federal government (Pierce 1957).

After its establishment, SIC has been revised periodically to reflect changes in the economic structure of the United States. The overall structure of SIC remains mostly unchanged since the 1930s despite the minor addition, deletion, and combination of the sectors. Releasing in 1987, the latest version of SIC was categorized into 10 divisions at the highest aggregation level.

Since the early 1990s, the adoption of the North American Free Trade Agreement (NAFTA) and the quick emergence of new sectors has made SIC outmoded and non-reflective of the economic situation of the United States. A new system, North American Industrial Classification System (NAICS), was released in 1997 to replace SIC in order to represent the new nature of the economy and to include Canada and Mexico in the system.

The 1997 NAICS recognized the change and growth of service sectors in the U.S. economy and its North American neighbors. At the highest aggregation level, 16 sectors were services-related in total 20 sectors of 1997 NAICS, compared to 10 divisions in 1987 SIC of which five were service-related. At sector level, 565 out of 1,170 industries were defined as service-based, while 416 out of 1,004 industries were service-related in 1987 SIC.

There are two major differences between NAICS and SIC. First, NAICS is a six-digit system that provides for comparability among the three countries at the five-digit level, albeit with a few exceptions. The SIC is a four-digit system that is not linked in any way to the systems of Canada and Mexico. A six-digit system is adopted for NAICS to provide more flexibility. NAICS allows each country to recognize activities that are important in the respective countries, but may not be large or significant enough to recognize in all three countries. The sixth-digit system is reserved for this purpose. Secondly, the highest level of aggregation in a NAICS system is called a sector, equivalent to a division in SIC. Table 5.2 shows difference of the nomenclature between NAICS and SIC.

Since early 1999, the 1997 NAICS has been applied in handling the economic census data. The latest version of NAICS is NAICS 2002, which included substantial revision within the construction and wholesale trade sectors and some revisions for the retail and information sectors. NAICS 2002 was adopted in the 2002 U.S. economic census.

Table 5.2. Nomenclature difference between NAICS and SIC

NAICS		SIC	
Level	Name	Level	Name
2-digit	Sector	Letter	Division
3-digit	Subsector	2-digit	Major Group
4-digit	Industry Group	3-digit	Industry Group
5-digit	NAICS Industry	4-digit	Industry
6-digit	National	N/A	N/A

Source: The U.S. Census Bureau (2003c).

5.7.2 Three-segment model

Machado (1994) concludes that there was a clear trend of informatization[14] in the U.S. using IO analysis on a highly aggregated three-segment economy during the period of 1963 to 1987. Machado's work confirms the results of several previous studies, all of which concluded that information sectors will eventually outgrow the production sectors as the major components of the economy (Machlup 1962; Porat 1977; Dizard 1989). These studies suggest that it is feasible to adopt highly aggregated models to investigate the trend of economic structure change.

Following Machado's (1994) approach, this study first divides the economy of the AUSTIN MSA into three segments, production, energy, and information, which makes the result comparable to Machado's previous work. It is relatively straightforward to define sectors of production and energy. However, the boundary of information sectors seems more vague and uncertain. The definitions of information sectors are not consistent in the literature (Machlup 1962; Porat 1977; Machado 1994). In this study, a more restricted but standard definition of information sectors in 1997 NAICS is followed because the definitions in literature are generally too broad to be objective. Thus the information segment contains 13 economic sectors out of 528 economic sectors in the IO tables. At the same time, eight sectors are selected and defined as the energy segment; the remaining 507 sectors fall into the production segment. The descriptions about the sectors in energy and information segments are listed in Tables 5.3 and 5.4. Detailed descriptions about the sectors in the production segment are available in Appendix 1 in order to simplify the text of the chapter.

5.7.3 Seven-segment model

Although the three-segment models are helpful in capturing the macro trend of economic structure change, they are also too aggregated to be useful in modeling the economy-environment interactions. So less aggregated, seven-segment models are developed to serve this end. Although the seven-segment models are still high in aggregation level, they are the least aggregated models that can be achieved in this study due to the availability of the matching environmental data.

The seven segments are production, energy, ICT, information, transportation, service, and education and public administration (Edu_PA). One primary assumption of the emerging digital economy is that some economic sectors such as ICT, information, and service sectors are growing, while some other sectors such as production, transportation, and energy are decreasing . The sectors are grouped into the above seven segments so that the assumption can be tested by empirical results and environmental consequences of the sectors change can also be examined. The Edu_PA is studied as an independent segment rather than part of the service segment because it was once one of the pillar segments in the Austin economy. Table 5.5 shows the number of sectors in each of the seven segments. More detailed descriptions about these sectors are again available in Appendix 2.

Table 5.3. Sectors in the energy segment

IO table Record number	Description	87 SIC code	Note
37	COAL MINING	1200	
38	NATURAL GAS & CRUDE PETROLEUM	1310	
39	NATURAL GAS LIQUIDS	1320	
213	LUBRICATING OILS AND GREASES	2992	
443	ELECTRIC SERVICES	4910	Also part of 4930
444	GAS PRODUCTION AND DISTRIBUTIO	4920	Also part of 4930
511	STATE AND LOCAL ELECTRIC UTILI	N/A	Part of 4910
512	OTHER STATE AND LOCAL GOVT ENT	N/A	

Source: The U.S. Census Bureau (2003c).

Table 5.4. Sectors in the information segment

IO table Record Number	Description	87 SIC code
174	NEWSPAPERS	2710
175	PERIODICALS	2720
176	BOOK PUBLISHING	2731
178	MISCELLANEOUS PUBLISHING	2740
181	GREETING CARD PUBLISHING	2770
371	PHONOGRAPH RECORDS AND TAPE	3652
441	COMMUNICATIONS, EXCEPT RADIO A	4810 4820 4840
442	RADIO AND TV BROADCASTING	4830
470	OTHER BUSINESS SERVICES	7320 7331 733
475	COMPUTER AND DATA PROCESSINGS	7370
483	MOTION PICTURES	7800
484	THEATRICAL PRODUCERS, BANDS ET	7920
497	OTHER EDUCATIONAL SERVICES	8230 8240 8290

Source: The U.S. Census Bureau (2003c).

Table 5.5. The number of sectors in economic segments of the Austin economy

Segment	Production	Energy	Information	ICT	Service	Transportation	Edu_PA
No. of Sectors	409	8	13	17	58	13	10

Source: Calculated by the author.

Notes

1 A later section in this chapter will give a more detailed description of the industry classification systems in North America.

2 A unique solution for X may not always exist; for a more detailed discussion see Miller and Blair (1985).

3 The format of this section was adapted from Jones (1997).

4 The backward linkage refers to the increase of gross output stimulated by the requirement of final demand. The forward linkage refers to the increase of gross output stimulated by the growth of supply.

5 For more detailed discussions and way of improvement see Cella (1984), and Meller and Marfan (1981).

6 If element-by-element multiplication rather than matrix multiplication is applied, more specific segment (sector) emissions can be obtained.

7 Step by step deduction of the formula can be found in Kim (2002).

8 TNRCC was officially renamed to the Texas Commission of Environmental Quality (TCEQ) on September 1 2002.

9 More detailed information on the reporting applicability levels can be found in 30 Texas Administrative Code 101.10.

12 The computation ability is no longer a major constraint as the computers are becoming more powerful and affordable in the digital age.

13 "Segment" is suggested by Machado (1994) to describe a group of economic sectors. It helps distinguish between one economic sector and a set of sectors in an economy because "sector" can be understood as either one or more economic activity in some cases. "Segment" has the same meaning as "sectors" in this research.

14 "Informatization" is defined as the process of development of information activities over time (Machado 1994).

generation, and pollution abatement activities. Miller and Blair (1985) summarizes three types of environmental input-output (EIO) models: (1) generalized input-output models introducing the technical coefficients matrix with additional rows and columns to represent the pollution generation and abatement activities, (2) Incorporating "ecosystem" sectors into the general input-output models, recording ecological inputs and residuals flows between economic sectors and ecosystem, and (3) commodity-by-industry models describing environmental factors as commodities in a commodity-by-industry input-output table.

Laurent and Hite (1971) illustrates the first type of EIO using a figure in the studies on economic-ecologic interactions in the Charleston, South Carolina, metropolitan area. The figure (Figure 5.2) presents a clear conceptual framework for the EIO adopted in this study. The figure also helps one understand the linkage between the standard IO model and ecological (environmental) imports and exports. The upper left corner is a standard IO matrix. a_{11} is the amount of output sector 1 required to produce one unit of gross output of sector 1 , a_{21} is the amount of output sector 2 required to produce one unit of gross output of sector 2, and so on. This matrix is labeled as *A* matrix. Below the *A* matrix, in the lower left-hand corner, is the *G* matrix. It shows that m types of ecological imports are required to generate gross outputs by the economic sectors in the *A* matrix. If G_1 is water, the G_{11} is the amount of water required to generate one unit of gross output by *A*, and so on. The *E* matrix, in the upper right-hand corner, is analogous to the *G* matrix, except it shows exports of residuals (pollutants) back to the environment from the economic sectors in the *A* matrix. Thus, if E_1 is carbon dioxide,

e_{11} is the amount of carbon dioxide associated with one unit of gross output by sector 1, and so on.

	1	2	...	...	n
1	a_{11}	a_{12}	...	...	a_{1n}
2	a_{21}				
...	...				
...	...				
n	a_{2n}				

Matrix A (Interindustry Matrix)

	1	2	...	...	k
	e_{11}	e_{12}	...	...	e_{1k}
	e_{21}				
	...				
	...				
	e_{n1}				

Matrix E (Ecological exports)

	1	2			n
1	g_{11}	g_{12}	...	...	g_{1n}
2	g_{21}				
...	...				
...	...				
m	g_{m1}				

Matrix G (Ecologic imports)

Figure 5.2. Simplified environmentally extended IO model.
Sources: After Laurent and Hite (1971).

When final demand requires output to increase (or decrease), the amount of pollutants generated also changes correspondently.[3] The direct pollution coefficient can be expressed as the ratio of total pollutants generated by a sector to total sector output. However, the total pollution coefficient is not enough to measure the total impact on pollution generation in the economy, since indirect pollution generation has not been taken into account. The Leontief inverse matrix can be used to estimate total pollution generated. The relationship between pollution generation and output can be stated as:

$$r_{kj} = b_{kj} X_j \tag{5.9}$$

Where

r_{kj} : the amount of pollutant k discharged from sector *j*

X_j : output of sector *j*

b_{kj} : the amount of pollutant k discharged per unit of output in sector *j*

$$b_{kj} = \frac{r_{kj}}{X_j} \tag{5.10}$$

Let R_k be equal to the total discharge of pollutant k. Then:

$$R_k = \sum_{j=1}^{n} r_{kj} = \sum_{j=1}^{n} b_{kj} X_j = b_{k1} X_1 + b_{k2} X_2 + \ldots + b_{kn} X_n \tag{5.11}$$

Expanding this equation, the discharges of pollutants $k = 1$ through m are:

$$R_1 = b_{11}X_1 + b_{12}X_2 + ... + b_{1n}X_n \tag{5.12}$$

$$R_2 = b_{21}X_1 + b_{22}X_2 + ... + b_{2n}X_n$$

$$R_m = b_{m1}X_1 + b_{m2}X_2 + ... + b_{mn}X_n$$

In matrix notation,

$$R = BX \tag{5.13}$$

Where

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \\ R_m \end{bmatrix}, \; B = \begin{bmatrix} b_{11} & b_{12} & ... & b_{1n} \\ b_{21} & b_{22} & ... & b_{2n} \\ \\ b_{m1} & b_{m2} & ... & b_{mn} \end{bmatrix}, \quad X = \begin{bmatrix} X_1 \\ X_2 \\ \\ X_n \end{bmatrix}$$

It has already been established in equation 5.7 that,

$$X = (I - A)^{-1}Y$$

Substituting X in equation 5.13 with equation 5.7, the discharges of the pollutants are,

$$R = B(I - A)^{-1}Y \tag{5.14}$$

or,

$$R = PY \qquad (5.15)$$

where $P = B(I - A)^{-1}$

The matrix P shows the direct and indirect effect of the final demand change on the various pollutants' emissions/discharges. Let P_{kj} be an element in the matrix P. Then, for every unit worth of final demand for products of sector j, P_{kj} units of pollutant k are discharged directly from producing sector j and indirectly through discharges induced by output changes in other sectors of the economy.

5.4 The hypothetical extraction measurement

5.4.1 Introduction

One important theme of this research is to identify the change in relative importance of the sectors in an economy as economic structure evolves. Hypothetical extraction measurement (HEM) is one of the indices to quantify the relative importance of an individual sector in an economy (Schultz 1977; Cella 1984; Blair and Miller 1990). HEM is built on the assumption that sectors with higher linkages to other sectors are more important than those with lower linkage, and the key sector is the sector that has the highest linkage with other sectors. The general idea of the HEM is to compare the difference of the gross output generated in sector (j) in an economy with n sectors in two situations: (1) the gross output from *n-1* sectors, when sector *j* is still part of the *n* sectors economy to meet the requirement of a specified level of final demand, and (2) the gross output of the same *n-1* sectors, when sector *j* has been extracted from the economy through the removal of the row and column from the technical coefficients matrix to meet the same level of final demand not including sector *j*. The difference between the two measurements is considered as the total interdependence (linkage effect) of sector *j* on the rest of the sectors of the economy.

HEM is a useful method to identify the key sectors of the economy. Previous applications can be found in Harrigan and Mcgilvray (1988), Machado (1994), and Machado and Miller (1997). The drawbacks of this approach are discussed by Cella (1984). The major problems include the lack of any distinction between back and forward linkages,[4] possible underestimation of the effect of the total linkage of the extracted sector, and dependence of the result on the level of aggregation.[5]

5.4.2 Model description

For the convenience of explanation and understanding, a more specified rather than general model is introduced below. It has already been established in equation (5.7) that:

$$X = (I - A)^{-1} Y$$

Let

$$X^* = IX - X_j, \tag{5.16}$$

where

X^* : the total output after extracting the output of sector j

X_j : the output of sector j

I : $n \times 1$ vector with all elements equal to 1

Let

$$X_{(j)} = [I - A_{(j)}]^{-1} Y_{(j)} \tag{5.17}$$

where

$X_{(j)}$: the total output of *n-1* sector after extracting sector j from the economy

$A_{(j)}$: technical coefficients matrix from which row j and column j have been extracted

$Y_{(j)}$: the final demand from which the final demand of sector j has been removed

Then the total linkage can be defined as:

$$TL = X^* - X_{(j)} \tag{5.18}$$

TL shows the linkages effects of sector j on the total economy. One way to normalize TL is to calculate the ratio of TL and *X**, which represents the percentage of the linkages effects to the total gross output (after subtracting the output of sector *j*). Generally speaking, the larger the TL (or ratio) is, the higher the linkage effect, and the more important the sector is.

5.5 Structure decomposition analysis

5.5.1 Introduction

Structural decomposition analysis (SDA) is a relatively new methodology that has gained attention since the early 1970s (Leontief and Ford 1972). This analytical tool has made it possible to quantify fundamental "sources" of change in a wide range of variables, including economic growth, energy use, workforce requirement, trade, and material intensity of use (Rose and Casler 1996).

The formal definition of SDA emerged in the late 1980s and early 1990s. The central idea of SDA is to distinguish major sources of change in an economy by means of identifying a set of comparative static changes in key parameters in an input-output table (Rose and Miernyk 1989; Rose and Chen, 1991). The primary rationale for SDA is to split an identity into its components. This division can be as simple as the three-part basic form (technological change, mix, and level), or as complex as desired. Leontief and Ford (1972) first perform the formal three-part decomposition to identify the sources of change in air pollution emissions. Following their steps, more attempts have been practiced, with the most prominent jobs done by Skolka (1989) and Rose (Rose and Chen 1991).

SDA has several advantages. First, it overcomes many static features of the IO model and is able to examine changes over time in technical coefficients and a sectoral mix. Second, it requires much less input and has relatively insignificant restrictions compared to traditional econometric estimation. Third, SDA's IO base makes it much easier to link the environmental and natural resource issues to intermediate sectors and to look at root causes of pollution and resource depletion.

Despite the criticism of its weak theoretical foundation, lack of verification of mutual exclusivity, and conceptual problems in defining the terms of decomposition, a wide variety of applications have been implemented concerning sources of change in international trade, technological change, energy use, workforce requirement, and development planning (Sterner 1985; Chen and Wu 1995; Lin and Polenske 1995; Han 1995; Dietzenbacher and Los 1998; Wier 1998; Kim 2002; Andreosso-O'Callaghan and Yue 2002). Stevens and Moore (1980) argue that the "persistence" of applications is due to the straightforwardness o SDA, which means it can be implemented with readily available data. However, no definitive test of its accuracy has yet been undertaken.

5.5.2 Model description

After summarizing the method proposed in the research paper of Fujimagari (1989) and Sawyer (1992), Wier (1998) suggests six components to be the sources influencing the change of pollutant emissions: the level of the final demand, the composition of the final demand, IO coefficients, emission factor, energy intensity, and fuel-mix in the production sectors. Wier's model is as follow:

Suppose there is an economy with *n* industry sectors, *m* fuel types for each industry, and *k* sectors of final demand, At a given point in time, production-based emissions of a certain pollutant (i.e. SO2) are given by:

$$\begin{aligned} &E_p^i = [(F_p^i M_p Q_p)' J]' (I - A)^{-1} Dd \\ &i = SO2, CO, NO_x etc.) \end{aligned} \tag{5.19}$$

Where

E_p^i: a scalar of total emissions of type *i* from the production sectors

F_p^i: a $n \times m$ matrix of emission per unit of total demand for energy for all the production sectors

M_p: a $m \times n$ matrix of fuel mix in the production sectors

Q_p: a $n \times n$ diagonal matrix of energy intensities

J: a $n \times 1$ matrix with all elements equal to 1

$(I - A)^{-1}$: $n \times n$ Leontief inverse matrix

D: a $n \times k$ matrix of the composition of final demand

d: a $k \times 1$ matrix of absolute level of final demand for all categories of final demand

The change in the level of emissions from sectors given by equation (1) from time *t-1* until time *t* is given by,

$$E_p^i(t) - E_p^i(t-1) \approx \Delta F_p^i + \Delta M_p + \Delta Q_p + \Delta (I - A)^{-1} + \Delta D + \Delta d \tag{5.20}$$

Each element in the decomposition formula has the same general form. Using the emission factor effect as an example, this element is given by

$$\begin{aligned}\Delta F_p^i = \frac{1}{2}\{&[F_p^i(t) - F_p^i(t-1)]M_p(t-1)Q_p(t-1)(I-A)^{-1}(t-1)D(t-1)d(t-1) \\ &+ [F_p^i(t) - F_p^i(t-1)]M_p(t)Q_p(t)(I-A)^{-1}(t)D(t)d(t)\}\end{aligned} \tag{5.21}$$

Kim (2002) took a very similar but more simplified approach than Wier (1998) did. The change in emissions from production is considered be related to three contributors: emission intensities, technical coefficients, and final demands. Kim's model is as follow:

$$TE^{p} = B^{p}(I-A)^{-1}(Y-Mz') \tag{5.22}$$

Where

TE^{p}**:** a scalar[6] of total quantity of emissions of type p pollutant from the all the production sectors

B^{p}**:** $1\times n$ vector of direct pollutant coefficient for pollutant p

$(I-A)^{-1}$: Leontief Inverse Matrix

Y : $n\times 4$ matrix of four components of final demand, household consumption government consumption, investment, and export

M : $n\times 1$ vector of imports

Z: a 4×1 vector of with all one element

The change in emissions from all the production sectors from time *t-1* to time *t* can be disaggregated into three components by equation 5.23,[7]

$$\begin{aligned} &TE_{i}^{p}(t) - TE_{i}^{p}(t-1) = \\ &\Delta B^{p}(I-A)^{-1}(t)(Y-Mz')(t) \\ &+ B^{p}(t-1)\Delta(I-A)^{-1}(t)(Y-Mz')(t) \\ &+ B^{p}(t-1)(I-A)^{-1}(t-1)\Delta(Y-Mz') \end{aligned} \tag{5.23}$$

Where

ΔB^{p}: change in emission intensity

$\Delta(I-A)^{-1}$: change in technical coefficient

$\Delta(Y-Mz')$: change in the composition of final demand and import

Since detailed fuel mix and energy mixture data is currently not available for the Austin MSA during the period studied, to simplify the calculation, Kim's approach is followed in this research. The three contributors for the change of pollutant emissions are: emission intensity, technical coefficients, and final demand.

5.6 Data sources

5.6.1 Input-output tables

In the U.S., every five years, the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce (USDC) compiles and publishes the input-output table of the U.S. economy. The table is available for each state and counties within states. Through Regional Economic Information System (REIS) and other sources, the USDC provides income and employment multipliers for counties throughout the U.S. It also provides multipliers for a designated group of counties, such as Metropolitan Statistical Area (MSA); the services are charged based on different requests (Jones 1997).

Another source of IO table is the commercial group called the Minnesota IMPLAN Group Incorporated, or MIG Inc. in Stillwater, Minnesota. This organization maintains and markets a national database and input-output analysis software known as IMPLAN (Input-output Model for PLANning). IMPLAN data files are compiled from a wide variety of sources including the U.S. Bureau of Economic Analysis, the U.S. Bureau of Labor, and the U.S. Census Bureau. IMPLAN data is available at the state, county, and custom Zip Code level (MIG 2003).

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There are two major differences between NAICS and SIC. First, NAICS is a six-digit system that provides for comparability among the three countries at the five-digit level, albeit with a few exceptions. The SIC is a four-digit system that is not linked in any way to the systems of Canada and Mexico. A six-digit system is adopted for NAICS to provide more flexibility. NAICS allows each country to recognize activities that are important in the respective countries, but may not be large or significant enough to recognize in all three countries. The sixth-digit system is reserved for this purpose. Secondly, the highest level of aggregation in a NAICS system is called a sector, equivalent to a division in SIC. Table 5.2 shows difference of the nomenclature between NAICS and SIC.

Since early 1999, the 1997 NAICS has been applied in handling the economic census data. The latest version of NAICS is NAICS 2002, which included substantial revision within the construction and wholesale trade sectors and some revisions for the retail and information sectors. NAICS 2002 was adopted in the 2002 U.S. economic census.

Table 5.2. Nomenclature difference between NAICS and SIC

NAICS		SIC	
Level	Name	Level	Name
2-digit	Sector	Letter	Division
3-digit	Subsector	2-digit	Major Group
4-digit	Industry Group	3-digit	Industry Group
5-digit	NAICS Industry	4-digit	Industry
6-digit	National	N/A	N/A

Source: The U.S. Census Bureau (2003c).

5.7.2 Three-segment model

Machado (1994) concludes that there was a clear trend of informatization[14] in the U.S. using IO analysis on a highly aggregated three-segment economy during the period of 1963 to 1987. Machado's work confirms the results of several previous studies, all of which concluded that information sectors will eventually outgrow the production sectors as the major components of the economy (Machlup 1962; Porat 1977; Dizard 1989). These studies suggest that it is feasible to adopt highly aggregated models to investigate the trend of economic structure change.

Following Machado's (1994) approach, this study first divides the economy of the AUSTIN MSA into three segments, production, energy, and information, which makes the result comparable to Machado's previous work. It is relatively straightforward to define sectors of production and energy. However, the boundary of information sectors seems more vague and uncertain. The definitions of information sectors are not consistent in the literature (Machlup 1962; Porat 1977; Machado 1994). In this study, a more restricted but standard definition of information sectors in 1997 NAICS is followed because the definitions in literature are generally too broad to be objective. Thus the information segment contains 13 economic sectors out of 528 economic sectors in the IO tables. At the same time, eight sectors are selected and defined as the energy segment; the remaining 507 sectors fall into the production segment. The descriptions about the sectors in energy and information segments are listed in Tables 5.3 and 5.4. Detailed descriptions about the sectors in the production segment are available in Appendix 1 in order to simplify the text of the chapter.

5.7.3 Seven-segment model

Although the three-segment models are helpful in capturing the macro trend of economic structure change, they are also too aggregated to be useful in modeling the economy-environment interactions. So less aggregated, seven-segment models are developed to serve this end. Although the seven-segment models are still high in aggregation level, they are the least aggregated models that can be achieved in this study due to the availability of the matching environmental data.

The seven segments are production, energy, ICT, information, transportation, service, and education and public administration (Edu_PA). One primary assumption of the emerging digital economy is that some economic sectors such as ICT, information, and service sectors are growing, while some other sectors such as production, transportation, and energy are decreasing . The sectors are grouped into the above seven segments so that the assumption can be tested by empirical results and environmental consequences of the sectors change can also be examined. The Edu_PA is studied as an independent segment rather than part of the service segment because it was once one of the pillar segments in the Austin economy. Table 5.5 shows the number of sectors in each of the seven segments. More detailed descriptions about these sectors are again available in Appendix 2.

Table 5.3. Sectors in the energy segment

IO table Record number	Description	87 SIC code	Note
37	COAL MINING	1200	
38	NATURAL GAS & CRUDE PETROLEUM	1310	
39	NATURAL GAS LIQUIDS	1320	
213	LUBRICATING OILS AND GREASES	2992	
443	ELECTRIC SERVICES	4910	Also part of 4930
444	GAS PRODUCTION AND DISTRIBUTIO	4920	Also part of 4930
511	STATE AND LOCAL ELECTRIC UTILI	N/A	Part of 4910
512	OTHER STATE AND LOCAL GOVT ENT	N/A	

Source: The U.S. Census Bureau (2003c).

Table 5.4. Sectors in the information segment

IO table Record Number	Description	87 SIC code
174	NEWSPAPERS	2710
175	PERIODICALS	2720
176	BOOK PUBLISHING	2731
178	MISCELLANEOUS PUBLISHING	2740
181	GREETING CARD PUBLISHING	2770
371	PHONOGRAPH RECORDS AND TAPE	3652
441	COMMUNICATIONS, EXCEPT RADIO A	4810 4820 4840
442	RADIO AND TV BROADCASTING	4830
470	OTHER BUSINESS SERVICES	7320 7331 733
475	COMPUTER AND DATA PROCESSINGS	7370
483	MOTION PICTURES	7800
484	THEATRICAL PRODUCERS, BANDS ET	7920
497	OTHER EDUCATIONAL SERVICES	8230 8240 8290

Source: The U.S. Census Bureau (2003c).

Table 5.5. The number of sectors in economic segments of the Austin economy

Segment	Production	Energy	Information	ICT	Service	Transportation	Edu_PA
No. of Sectors	409	8	13	17	58	13	10

Source: Calculated by the author.

Notes

[1] A later section in this chapter will give a more detailed description of the industry classification systems in North America.

[2] A unique solution for X may not always exist; for a more detailed discussion see Miller and Blair (1985).

[3] The format of this section was adapted from Jones (1997).

[4] The backward linkage refers to the increase of gross output stimulated by the requirement of final demand. The forward linkage refers to the increase of gross output stimulated by the growth of supply.

[5] For more detailed discussions and way of improvement see Cella (1984), and Meller and Marfan (1981).

[6] If element-by-element multiplication rather than matrix multiplication is applied, more specific segment (sector) emissions can be obtained.

[7] Step by step deduction of the formula can be found in Kim (2002).

[8] TNRCC was officially renamed to the Texas Commission of Environmental Quality (TCEQ) on September 1 2002.

[9] More detailed information on the reporting applicability levels can be found in 30 Texas Administrative Code 101.10.

[12] The computation ability is no longer a major constraint as the computers are becoming more powerful and affordable in the digital age.

[13] “Segment” is suggested by Machado (1994) to describe a group of economic sectors. It helps distinguish between one economic sector and a set of sectors in an economy because “sector” can be understood as either one or more economic activity in some cases. “Segment” has the same meaning as “sectors” in this research.

[14] “Informatization” is defined as the process of development of information activities over time (Machado 1994).

CHAPTER VI

THE DYNAMICS OF THE AUSTIN MSA'S ECONOMIC STRUCTURE: 1990 - 1999

If we could first know where we are, and whither we are tending, we could better judge what to do, and how to do it.

- A. Lincoln

6.1 Introduction

Two important arguments have been made in the previous chapters. First, environmental problems are closely connected to the types and structure of the economy. Second, environmental policies must evolve along with economic structure change. What is important now is to supply empirical evidence to either support or rebuff these arguments. The dynamics of the economy in the Austin MSA of the 1990s will be examined first to set the context for the further exploration of economy-environment interactions and the environmental policies in the emerging digital economy.

This research is not the first attempt to use IO analysis to examine the economic issues in Austin. In the early 1970s, the City of Austin adopted IO analysis to provide "more complete and more accurate information to guide planning and policy-making functions" (City of Austin 1976, 1). Social and economic growth in the 1960s was studied using the IO models for the Austin Standard Metropolitan Statistical Area (SMSA[1]), and results were used as economic base data for the Austin Development Plan.

The Austin SMSA has expanded quickly with the rapid regional economic growth. In the early 1980s, Bastrop and Caldwell County, in addition to Travis, Hayes, and Williamson County, became two new members of the Austin-San Marcos Metropolitan statistical area (Austin MSA). Austin's economy, especially the high-tech and ICT sectors, has continued to evolve during the past two decades with an unprecedented growth rate. However, a comprehensive examination of Austin's economic structure change and its new social and economic identity as the "Silicon Hills" has yet to be accomplished, even though IO analysis has long been recognized as a comprehensive, multi-purposes planning tool to serve urban economic analysis section of the urban master plan (City of Austin 1976).

This chapter provides answers to the first two major research questions of the study: "What kind of economic structure transformation was accruing in the Austin MSA during the 1990s? and "Were there any observable trends (e.g., informatization)? These questions are further disaggregated into four tasks to be accomplished using IO analysis and hypothetical extraction measurement

1) Trends based on input-output accounts of the economy.

2) Trends based on the direct effects of the input-output models (technical coefficient matrices).

3) Trends based on the total effects-direct plus indirect effects (Leontief inverse)

4) Trends based on the hypothetical extraction measurement.

All the analysis is conducted based on the IO models in the years of 1990, 1994, and 1999. This chapter presents the results for the period of 1990 to 1999 which will depict a general picture of the trend of the economic structure change in the Austin MSA. Results of the two intervals of the study period – 1990 to 1994 and 1994 to 1999 – are detailed in Appendix 2 to keep the main text concise.

6.2 Trends based on input-output account of the economy

6.2.1 Three-segment aggregation

The Austin economy is first aggregated into three sectors: production, energy and information. Three IO tables (1990, 1994, and 1999[2]) of Austin MSA are constructed to compare the change of transactions among the three segments regarding total output, intermediate flow, and final demand.[3] It is a common practice to use five-year intervals in a time series IO analysis concerning economic structure change (Machado and Miller 1997; Wier 1998; Kim 2002).

Table 6.1 shows the percentage changes in intermediate output, final demand, and total output of the three segments from 1990 to 1999. The percentage changes are calculated using the formula 7.1,

$$\frac{X_p^t - X_p^{t-1}}{X_p^{t-1}} \times 100\% \tag{7.1}$$

Where

X_p^t : Value of intermediate output, final demand or total output at time t

p : Intermediate output, final demand or total out

t time

Table 6.1 indicates that the information segment had a much higher growth rate than the production segment, in sales both to other segments (174%) and to final consumers (87%). The energy segment decreased about 24 percent in intermediate output, about 3 percent in final demand, and over 14 percent in total output. The decreasing of the energy segment in both intermediate and total output can be explained partly by the dropping energy price in the 1990s (especially in the first half of the decade), and partly by the absolute reduction in energy consumption due to the rising of energy efficiency brought by the technical advancement.

Tables 6.2, 6.3, and 6.4, show the evolution of the share of each of the three segments in the totals of intermediate output, final demand, and output. Looking across the rows of production segment in the three tables, production's share of the economic activity increased from 1990 to 1994; the increase was partly counterbalanced by the decrease during the period of 1994 to 1999, resulting in a slight increase of production's share in all of the three measures in the 1990s. The share of energy segment monotonically decreased in all the three measures with an average rate of about 70 percent, indicating its declining importance in the regional economy in the 1990s. The information segment, on the contrary, increased in all of the three measures, over 110 percent in intermediate output, over 40 percent in final demand, and close to 58 percent in total output, showing the strong trend of growth of the segment during the period studied.

The figures in these tables illustrate a crude but clear picture of the trend of the economic structure change in Austin's economy during the 1990s. The growing importance of the information segment and declining significance of the energy segment supports the argument that Austin is evolving into the digital economy, in which the significance of information activities (bits) are competing with the traditional economic activities (atoms). In addition, the changing pattern of the segments' shares in total intermediate outputs possibly indicates that so-called "dematerialization" was occurring in the manufacturing processes during the period studied.

Table 6.1. Change of intermediate output, final demand, and total output in the Austin economy, 1990 - 1999 (three-segment model)[4]

	Intermediate Output	Final demand	Total Output
Production	165.72%	187.57%	182.38%
Energy	-23.84%	-2.94%	-14.54%
Information	453.13%	304.38%	340.22%

Table 6.2. Shares of the production, information, and energy segments in the total output, 1990 - 1999 (three-segment model)

	1990	1994	1999	Change (1990 - 1999)
Production	86.91%	89.07%	87.99%	1.25%
Energy	6.81%	3.34%	2.09%	-69.36%
Information	6.29%	7.59%	9.92%	57.84%

Table 6.3. Shares of the production, information, and energy segments in the intermediate output, 1990 - 1999 (three-segment model)

	1990	1994	1999	Change (1990 - 1999)
Production	79.57%	85.04%	82.96%	4.26%
Energy	14.58%	6.09%	4.36%	-70.12%
Information	5.84%	8.87%	12.68%	117.03%

Table 6.4. Shares of the production, information, and energy segments in the final demand, 1990 - 1999 (three-segment model)

	1990	1994	1999	Change (1990 - 1999)
Production	89.47%	90.34%	89.55%	0.09%
Energy	4.09%	2.47%	1.38%	-66.22%
Information	6.44%	7.19%	9.07%	40.75%

6.2.2 Seven-segments aggregation

The same analysis of three-segment models is repeated on the seven-segment models. The results, as expected, are very similar to what has been shown in the three-segment model except that the trend of the economic structure change is delineated in a more detailed manner (Tables 6.5, 6.6, 6.7, and 6.8). Table 6.5 shows that six segments have experienced the significant growth in terms of intermediate output, final demand, and gross output in the 1990s, leaving the energy as an outliner segment with negative growth rates in all the three measures. The ICT and information segments apparently had a much higher growth rate than the other segments in all of the three measures. In the mean while, the energy segment lost about 25 percent in final demand and 15 percent in total output in 1999, compared to those of 1990. The argument that in the digital economy the ICT and information segments will increase with the accompaniment of the declining of the traditional segments (e.g., production, energy, transportation) has been approved in the situation of the AMSA during the 1990s.

Table 6.6 shows that the top three segments in Austin's economy in terms of the absolute share in gross output did not change during the 1990s. What has been changed is the relative importance of the segments. While the ICT, information, and service segments were expanding, production, energy, transportation, and Edu_PA were shrinking in the entire economic pie of Austin during 1990s. Table 6.7 further illustrates what was going on in terms of material flows among segments in the manufacturing processes. It shows that in general relatively fewer inputs were required by the production, energy, transportation, and Edu_PA, while more inputs were required by into ICT, information, service segments.

The shares of ICT and information segments in total final demand increased about 44 percent and 39 percent during the 1990s respectively, while the shares of all the other segments in total final demand decreased (Table 6.8). The share of energy segment dropped about 67 percent; transportation, Edu_PA, service, and production segment declined about 30, 14, five, and four percent.

Table 6.5. Change of the intermediate output, final demand, and total output in the segments in the Austin economy, 1990 - 1999 (seven-segment model).

	Intermediate output	Final demand	Total output
Production	172.86%	120.58%	156.22%
Energy	-4.87%	-24.90%	-14.54%
ICT	312.52%	407.71%	340.22%
Information	298.89%	251.27%	298.37%
Transportation	97.93%	86.99%	92.51%
Service	171.35%	207.78%	179.36%
Edu_PA	145.36%	35.07%	139.49%

Table 6.6. Segment shares in the total output, 1990 - 1999 (seven-segment model)

	1990	1994	1999	Change (1990 - 1999)
Production	17.65%	16.75%	16.21%	-8.13%
Energy	6.81%	3.34%	2.09%	-69.36%
ICT	6.29%	7.59%	9.92%	57.84%
Information	11.09%	15.13%	15.85%	42.84%
Transportation	2.73%	2.82%	1.88%	-30.97%
Service	45.09%	45.26%	45.16%	0.17%
Edu_PA	10.35%	9.11%	8.89%	-14.13%

Table 6.7. Segment shares in the intermediate output, 1990 - 1999 (seven-segment model)

	1990	1994	1999	Change (1990 - 1999)
Production	24.78%	24.20%	21.24%	-14.30%
Energy	14.50%	5.46%	4.23%	-70.82%
ICT	8.07%	10.29%	15.91%	97.25%
Information	0.52%	1.33%	0.71%	36.47%
Transportation	5.96%	7.50%	4.33%	-27.35%
Service	43.74%	50.23%	52.30%	19.58%
Edu_PA	2.43%	0.99%	1.27%	-47.52%

Table 6.8. Segment shares in the final demand, 1990 - 1999 (seven-segment model)

	1990	1994	1999	Change (1990-1999)
Production	15.55%	14.61%	14.88%	-4.33%
Energy	4.55%	2.73%	1.52%	-66.64%
ICT	5.76%	6.82%	8.34%	44.64%
Information	14.19%	19.10%	19.85%	39.86%
Transportation	1.78%	1.47%	1.23%	-30.60%
Service	45.48%	43.83%	43.27%	-4.86%
Edu_PA	12.67%	11.45%	10.90%	-13.97%

6.3 Trends based on direct effect

So far we have observed Austin's economic structure change in the 1990s with an aggregated macroeconomic approach. The next step is to investigate the changes concerning the required inputs from the segments to produce outputs, which will help provide a sharper vision on the trend of the economic structure change in the region during the period studied.

6.3.1 Three-segment aggregation

Again, the three-segment economy of AMSA in the years 1990, 1994 and 1999 is examined first. The technical coefficients matrices (A) for all the three years are extracted using IMPLAN and are presented in Appendix 2. Columns in an A matrix record the inputs from all other segments to one segment in order to produce one unit of output for that segment. Table 6.9 shows the percentage change of the elements in A matrix from 1990 to 1999. To produce one unit of the output of the production segment, the required inputs from the energy and production segments decreased 67 percent and 6 percent, but the input from the information segment increased 67 percent. The input requirements of information segment to the energy and production segments dropped 70 percent and five percent, but 91 percent more input was required from itself. The situation is a little different in terms of the energy segment. It required more inputs from both the production and information segments, 24 percent and 175 percent respectively, while the input from the segment itself decreased 37 percent.

It can also be noted that the direct input of the information and energy segments went in the opposite direction. In general, the significant growth in the requirements of information segment and dropping requirements of the production and energy segments suggest not only more efficient (less energy and material inputs), but also more information-intensive (more information inputs) production processes during the 1990s in the Austin MSA. These figures reveal two possible consequences of the economic structure change in the Austin MSA during the 1990s: First, information was substituting for energy as the input to economic segments; second, information was contributing to energy savings. The results are identical to what has been observed by Machado and Miller (1997) on the trend of economic structure change in the U.S. economy between 1963 and 1987. But it must be noted that the definition of information segment are different in the two studies.

The input required by per unit output comes from not only manufacturing but also non-manufacturing factors, such as capital and labor. The direct input of these non-manufacturing factors also changes over time. In order to eliminate the influence of the non-production factors on the total inputs, it is necessary to calculate the share of each of the technical coefficients in the column sum, creating figures representing the proportions of the intermediate inputs in the per unit worth of output of that column (segment), eliminating the influence of non-manufacturing factors. The results for all the segments in 1990, 1994, and 1999 are listed in Table 6.10, which shows a similar pattern as that in the element change of A (Table 6.9). The only difference is that the input of production required by the segment itself increased slightly rather than decreased. The shares of the technical coefficient of the energy segment decreased remarkably in all the segments, and the shares of the technical coefficient of information increased in all the three segments. The shares of the technical coefficient of the production segment increased 2.25 percent and 47 percent in production and energy segments respectively, and decreased 20 percent in the information segment. Again all these figures can be interpreted in general as the substitution effect between the energy and information segments as the input to gross output in all the segments.

6.3.2 Seven-segment aggregation

Table 6.11 presents the change of A coefficients of the IO models with seven segments from 1990 to 1999. The direct input of energy, transportation, and Edu_PA decreased in all segments, indicating less energy, transportation, and Edu_PA products were required in producing one unit of output in all segments. The direct input of production also decreased in all but the energy segment, suggesting less production was required to produce one unit of output in most of the segments. The requirement of information, ICT, and service for one unit of output for all the segments increased except for the direct ICT input to the production segment, which decreased slightly. The all-negative numbers in the Edu_PA segment can be explained by the increasing input share from those non-manufacturing factors, and the figures can be normalized by calculating the change the share of the factors in the column of A matrix (Table 6.12). The results painted a picture of economic structure change similar to that from the three-segment model, with more detailed segmental information.

Table 6.12 shows the change of shares in column sum of A. These results conveyed the same messages presented in Table 6.11 exclusive of the possible influence from non-manufacturing factors. In general, the economy was less dependent on the production, energy, transportation, and the Edu_PA segment, and more dependent on the information, ICT, and the service segment, showing that the digital economy had emerged in the AMSA during the period studied.

Table 6.9. Change in the elements of A matrix, 1990 - 1999 (three-segment model)

	Production	Energy	Information
Production	-6.36%	24.90%	-4.90%
Energy	-67.03%	-37.66%	-70.13%
Information	66.80%	175.13%	91.47%

Table 6.10. Change in the share of column sum of A 1990 - 1999 (three-segment model)

	Production	Energy	Information
Production	2.25%	47.61%	-20.31%
Energy	-64.00%	-26.33%	-74.97%
Information	82.13%	225.15%	60.44%

Table 6.11. Change in the elements of A matrix, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	-1.63%	44.48%	-24.93%	-50.70%	-2.71%	-25.45%	-57.14%
Energy	-57.52%	-34.13%	-68.10%	-71.28%	-74.99%	-64.22%	-92.91%
Information	92.13%	174.61%	90.59%	68.11%	100.53%	43.40%	-13.83%
ICT	-3.12%	52.60%	138.17%	2.94%	16.57%	30.25%	-47.76%
Transportation	-9.71%	-19.54%	-47.29%	-35.92%	-19.38%	-35.70%	-73.07%
Service	35.50%	35.65%	20.43%	9.16%	49.39%	0.71%	-58.66%
Edu_PA	-34.80%	-47.77%	-50.86%	-65.03%	-21.31%	-53.80%	-50.21%

Table 6.12. Change in the share of column sum of A, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	-2.92%	67.13%	-39.90%	-40.50%	-10.20%	-21.94%	20.00%
Energy	-58.07%	-23.80%	-74.46%	-65.34%	-76.91%	-62.54%	-80.14%
Information	89.62%	217.66%	52.59%	102.89%	85.10%	50.16%	141.23%
ICT	-4.39%	76.52%	90.69%	24.24%	7.60%	36.39%	46.24%
Transportation	-10.89%	-6.93%	-57.80%	-22.66%	-25.58%	-32.67%	-24.60%
Service	33.73%	56.91%	-3.58%	31.74%	37.89%	5.45%	15.74%
Edu_PA	-35.65%	-39.58%	-60.66%	-57.80%	-27.36%	-51.62%	39.39%

6.4 Trends based on total effect

This section seeks more evidence for the changing nature of Austin's economy by examining two sets of different but closely related data from the results of IO analysis, Leontief inverse matrix (L), and total flow multiplier. L matrix is derived from the A matrix by inversing the (I-A) matrix. The elements of L matrix can be interpreted as the changes of gross output of segment (i) in response to the change of final demand of the segment (j). Total flow multiplier is the ratio of change in total output of segment j and change of total output of segment i. The formula used to calculate the total flow multiplier is as follows. Notice that the diagonal elements of the total flow matrix are all ones by definition, and the changes in diagonal elements are all zero as shown in the following result tables.

$$a^*_{ij} = {a_{ij}}/{ajj} = ({\Delta X_i}/{\Delta Y_j}) / ({\Delta X_j}/{\Delta Y_j}) = {\Delta X_i}/{\Delta Y_j} \tag{7.2}$$

Where

a_{ij}: an element in a Leontief inverse matrix

ΔX_i: gross output change for segment i

ΔY_j: final demand change for segment j

6.4.1 Three-segments aggregation

The three original *L* matrices of 1990, 1994, and 1999 are provided in Appendix 2. Table 6.13 shows the changes of each element in *L* from 1990 to 1999. The total energy requirements to satisfy one unit of final demand of production, energy, and information all decreased. Both the production and information segments required about 71 percent less of the inputs from the energy segment to satisfy the increasing of one unit of final demand of the two segments. In contrast, more information was required to satisfy one unit of final demand of all the three segments; especially for the production and energy segments. The information requirements were up about 141 percent and 72 percent respectively. Both the production and information segments required slightly less from the production segment to satisfy one unit of final demand. But the energy segment required about 10 percent more from the production segment to satisfy one unit growth of final demand.

The pattern observed in the changes of *L* matrix is comparable to that in A matrix (Tables 6.9 and 6.11). The only difference is that the total (direct and indirect) rather than the direct effect is calculated in *L* matrix. Once again, the substitution effect of information and production to energy segment is confirmed.

Table 6.14 presents the results of the changes of elements in total flow matrices. The figures in Table 6.14 generally repeat the results shown in Tables 6.9 and 6.10, except that all elements have more dramatic change rates. Direct and indirect input from the energy segment for one unit of the production and information segments decreased more than 70 percent, while information requirements for the production and energy segments increased 75 percent and 171 percent respectively. The production input for one unit of the energy output increased almost 34 percent, but the information input increased more than 170 percent.

Table 6.13. Changes in the elements of Leontief inverse matrices (*L*), 1990 - 1999 (three-segment model)

	Production	Energy	Information
Production	-1.86%	10.43%	-1.57%
Energy	-71.04%	-10.93%	-71.37%
Information	72.13%	141.45%	5.97%

Table 6.14. Changes of elements in the total flow matrix, 1990 - 1999 (three-segment model)

	Production	Energy	Information
Production	0	23.97%	-7.12%
Energy	-70.50%	0	-72.99%
Information	75.39%	171.06%	0

The change of relative importance of individual elements in the Leontief inverse matrix can also provide valuable information about the economic structure change. The column sum of the Leontief inverse is termed as total output multiplier, which indicates the total output required for one unit change in final demand of segment. Table 6.15 lists the total output multipliers of the three segments for the years of 1990, 1994 and 1999. The decreasing multipliers of the production and energy segments and the increasing multiplier of the information segment indicate the economy is more sensitive to the stimulus of final demand from information segment and less sensitive to the production and energy segments. . In another words, more information is required to satisfy the increase of final demands of the segments, but less production and energy are required to satisfy the increase of final demands of the segments in 1999 than that in 1990. The share in multiplier reflects the relative response from a segment in the total response to the stimulus of the change of a unit of final demand for production, energy, or information.

Changing rates of energy's share in output multipliers for all three segments are negative, suggesting the decreasing importance of the energy segment to economic activities (Table 6.15). In contrast, changing rates of information's share in output multipliers for all three segments are positive, reflecting the rising importance of the information segment to the economic activity. The share of production in the production segment increased 1.17 percent, which is much less significant than the changing rate of the energy and information segments. Compared to the over 160 percent growth of the share of information segment, the 20 percent increase of the share of production in the energy segment is still relatively insignificant.

Table 6.15. Total multipliers, 1990 - 1999 (three-segment model)

	Production	Energy	Information
1990	1.346973	1.520797	1.281477
1994	1.310183	1.422201	1.332519
1999	1.306626	1.409119	1.332025

Table 6.16. Changes in the shares of Leontief inverse in the total output multiplier, 1990 - 1994 (three-segment model)

	Production	Energy	Information
Production	1.17%	19.18%	-5.31%
Energy	-70.15%	-3.87%	-72.46%
Information	77.45%	160.58%	1.95%

6.4.2 Seven-segment aggregation

Tables 6.17, 6.18, 6.19, and 6.20 present results strikingly similar to those of the three-segment models. Table 6.17 indicates a monotonic increasing requirement for the information, ICT, and service segments for one unit of final demand growth from all the segments, a monotonic decreasing requirement for the production, energy, transportation, and Edu_PA segment. The all-negative figures of the Edu_PA suggest that the segment relies more on the inputs from non-manufacturing than those from manufacturing factors. Compared to the 1990 figures, all the multipliers in 1999 dropped except those of the information and transportation segments (Table 6.18). The results from the analysis of total flow matrices and shares of Leontief inverse generally show that the economy is more dependent on the information, ICT, and service segments, while less dependent on the production, energy, transportation, and Edu_PA segments at the end of the 1990s (Tables 6.19 and 6.20).

Table 6.17. Changes in Leontief inverse elements, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	-0.40%	26.27%	-20.47%	-48.89%	-4.57%	-25.49%	-59.25%
Energy	-61.88%	-9.73%	-69.21%	-75.35%	-73.99%	-68.68%	-92.90%
Information	98.10%	141.62%	5.97%	71.32%	107.94%	51.55%	-14.86%
ICT	-0.71%	38.86%	124.92%	0.01%	18.86%	27.13%	-49.32%
Transportation	-14.39%	-25.91%	-43.08%	-39.62%	-1.96%	-36.88%	-73.90%
Service	32.90%	27.04%	25.64%	6.28%	45.42%	0.24%	-57.93%
Edu_PA	-38.08%	-51.01%	-48.21%	-64.04%	-26.33%	-53.69%	-0.19%

Table 6.18. Total multipliers, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
1990	1.418596	1.497040	1.253906	1.279526	1.344000	1.283445	1.127036
1994	1.347125	1.418960	1.323957	1.240772	1.527500	1.327881	1.053527
1999	1.414487	1.407752	1.317813	1.226320	1.368653	1.267953	1.043865

Table 6.19. Changes of elements in the total flow matrix, 1990 - 1999 (Seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0	39.89%	-24.95%	-48.89%	-2.66%	-13.29%	-59.18%
Energy	-61.73%	0	-70.95%	-75.36%	-73.47%	-68.75%	-92.89%
Information	98.91%	167.66%	0	71.31%	112.10%	51.19%	-14.71%
ICT	-0.31%	53.83%	112.24%	0	21.24%	26.82%	-49.23%
Transportation	-14.04%	-17.92%	-46.29%	-39.62%	0	-37.03%	-73.85%
Service	33.44%	40.74%	18.56%	6.27%	48.33%	0	-57.86%
Edu_PA	-37.83%	-45.73%	-51.13%	-64.05%	-24.85%	-53.80%	0

Table 6.20. Changes in the shares of Leontief inverse in the total output multiplier, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	-0.40%	26.27%	-20.47%	-48.89%	-4.57%	-25.49%	-59.25%
Energy	-61.88%	-9.73%	-69.21%	-75.35%	-73.99%	-68.68%	-92.90%
Information	98.10%	141.62%	5.97%	71.32%	107.94%	51.55%	-14.86%
ICT	-0.71%	38.86%	124.92%	0.01%	18.86%	27.13%	-49.32%
Transportation	-14.39%	-25.91%	-43.08%	-39.62%	-1.96%	-36.88%	-73.90%
Service	32.90%	27.04%	25.64%	6.28%	45.42%	0.24%	-57.93%
Edu_PA	-38.08%	-51.01%	-48.21%	-64.04%	-26.33%	-53.69%	-0.19%

6.5 Trends based on the hypothetical extraction measurement

6.5.1 Three-segment aggregation

The purpose of hypothetical extraction analysis is to compare the relative importance of a segment (*j*) by calculating the total linkage of the segment (*j*) to all the other segments. The result of the analysis shows the difference between the output of n segments (after extracting the output of segment *j* from the total output of the n segment economy) and the output of *n-1* segment economy (Segment *j* has been removed from the *n* segment economy).

As discussed in Chapter V, the results of the hypothetical extraction measurement are sensitive to the aggregation level of the IO models. So the interpolation of the results should be focused on the relative rather than absolute values. As clearly shown in Table 6.21, the information segment was gaining significance, and the importance of the production and energy segment was slipping during the 1990s. For example, in 1990 the linkage effect of the information segment to all the other segments was about 1.4 percent of the total output (not including the output of the information segment). In 1999, the figure increased to 2.0 percent. In the meanwhile, the production and energy segments were less significant to the economy in 1999 than in 1990, as the linkages of the two segments dropped 5.71 and 1.23 percent from 1990 to 1999.

6.5.2 Seven-segment aggregation

Table 6.22 shows the results of hypothetical extraction analysis on seven-segment economy. It is clear that the ICT and information segments were becoming more significant to Austin's economy, but the relative importance of the other five segments all decreased during the same period of time. In 1990, the linkage effect of the information segment brought 3.43 percent more output into the economy than it would have had without it, and the linkage effect of the segment reached 4.17 percent in 1999. In the meantime, the linkage effect of the production segment dropped from 4.61 to 4.19 percent, energy down from 1.02 to 0.40 percent, and so on.

6.6 Summary

The results from the above analyses help unfold some trends in the economic structure change in the Austin MSA during the 1990s. Tables 6.23 and 6.24 show the rankings of the segments in terms of gross output in 1990 and 1999. The share of the energy segment in the entire economy dropped approximately 70 percent, transportation, Edu_PA, production were down 31, 14, and 8 percent respectively compared to the approximately 58 and 43 percent growth of the share of the ICT and information segments. The service segment remained almost unchanged. In terms of the ranking by gross output, ICT was up two steps; energy and Edu_PA were down two and one step respectively. The gross output tends to concentrate in fewer segments. It is also obvious that the service segment has dominated the Austin MSA economy since 1990, accounting for over half of the gross output. If the information and Edu_PA segments were counted as part of the service segment, service would have accounted for over two-thirds of the gross output in the Austin MSA economy. Similarly, the production segment would have actually increased in its share in the economy during the period studied, provided that the ICT segment was counted as part of the production.

Both direct and indirect inputs of information, ICT, and service to one unit of gross output increased in almost all the segments, while direct and indirect inputs of production, energy, transportation, and Edu_PA decreased in general, indicating the economy is more dependent on “bits” than on “atoms” in the emerging digital economy. The empirical study of this chapter provides evidence to support the argument that the digital economy was emerging in the AMSA in the 1990s, where new segments such as information, and ICT grew quickly and traditional segments such as production, energy, transportation, and Edu_PA continued to decrease. However, the shares of the information and ICT segment are much less significant than of the service and production segments in the entire economic pie, suggesting that it is still on the early stage of the new kind of economy.

Tables 6.25, 6.26, 6.27, and 6.28 show that there is no significant change in terms of shares of imports and factors of value-added in the total inputs to the economic segments, which not only excludes the possible influence of non-production factors to the economic structure change, but also further supports the conclusions on the trends of economic structure change in Austin during the 1990s.

Table 6.21. Results of the hypothetical extraction analysis, 1990 - 1999 (three-segment model)

	1990	1994	1999	Change rate (90 - 99)
Production	30.51%	23.75%	24.80%	-18.72%
Information	1.38%	1.55%	2.01%	45.83%
Energy	1.65%	0.76%	0.42%	-74.73%

Table 6.22. Results of the hypothetical extraction analysis, 1990 - 1999 (seven-segment model)

	1990	1994	1999	Change rate (90 - 99)
Production	4.61%	3.16%	4.19%	-9.13%
Energy	1.02%	0.77%	0.40%	-60.90%
ICT	1.20%	1.53%	1.87%	55.25%
Information	3.43%	4.18%	4.17%	21.74%
Transportation	0.61%	0.86%	0.51%	-16.79%
Service	8.33%	8.18%	7.04%	-15.43%
Edu_PA	1.43%	0.53%	0.41%	-70.91%

Table 6.23. Segment ranking in terms of output, 1990

	Rank	Output share	Cumulative percentage
Service	1	45.09%	45.09%
Production	2	17.65%	62.73%
Information	3	11.09%	73.83%
Edu_PA	4	10.35%	84.18%
Energy	5	6.81%	90.99%
ICT	6	6.29%	97.27%
Transportation	7	2.73%	100.00%

Table.6.24. Segment ranking in terms of output, 1999

	Rank	Output share	Cumulative percentage
Service	1	45.16%	45.16%
Production	2	16.21%	61.38%
Information	3	15.85%	77.22%
ICT	4	9.92%	87.14%
Edu_PA	5	8.89%	96.03%
Energy	6	2.09%	98.12%
Transportation	7	1.88%	100.00%

Table 6.25. The change of segment output share, 1990 - 1999

	Output share1999	Output share 1990	Change of shares 1990 - 1999
Service	45.16%	45.09%	0.2%
Production	16.21%	17.65%	-8.2%
Information	15.85%	11.09%	42.9%
ICT	9.92%	10.35%	57.7%
Edu_PA	8.89%	6.81%	-14.1%
Energy	2.09%	6.29%	-69.3%
Transportation	1.88%	2.73%	-31.1%

Table 6.26. Shares of value-added, 1990 - 1999 (three-segment model)

	Production	Energy	Information
1990	0.744908	0.644184	0.788929
1994	0.764435	0.689817	0.748207
1999	0.766378	0.698917	0.748111

Table 6.27. Shares of value-added, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
1990	0.6956728	0.6550288	0.805171	0.791476	0.743264	0.783646	0.90729
1994	0.7437154	0.6971963	0.75729	0.821128	0.62531	0.755261	0.960235
1999	0.6916445	0.7017792	0.756656	0.827221	0.721861	0.793385	0.966884

Table 6.28. Shares of import, 1990 - 1999 (three-segment model)

	1990	1994	1999
Production	14.95%	14.83%	12.85%
Energy	15.14%	18.32%	17.25%
Information	14.32%	15.82%	13.46%

Table 6.29. Shares of import, 1990 - 1999 (seven-segment model)

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
1990	0.292556	0.162737	0.159977	0.376091	0.174608	0.125175	0.066006
1994	0.22122	0.189866	0.167069	0.344276	0.181578	0.110782	0.027105
1999	0.260656	0.176974	0.14293	0.336226	0.173736	0.089522	0.022243

Notes

[1] The term SMSA was changed to metropolitan statistical area (MSA) in 1983 (The U.S. Census Bureau 2003d).

[2] When the analysis of the study started, the latest IO table available in MIG, Inc was for the year of 1999. As of February 28, 2004, the newest IO table available in MIG is 2001.

[3] The format of the rest of the chapter is adapted from Machado (1994).

[4] All data are original except indicated otherwise.

CHAPTER VII

ENVIRONMENTAL IMPACTS OF THE EMERGING DIGITAL ECONOMY IN THE AUSTIN MSA, TEXAS, 1990 - 2008

That which is good and helpful ought to be growing and that which is bad and hindering ought to be diminishing . . . We therefore need, above all else, . . . concepts that enable us to choose the right direction of our movement and not merely to measure its speed.

- E. F. Schumacher

7.1 Introduction

Chapter VI discussed the changing nature of the economic structure in the Austin MSA during the 1990s. The empirical results indicate the emergence of the digital economy in the region. With the rapid rise of the information and ICT segments, mild growth in the service segment, and the declining of the energy, transportation, education and public administration (Edu_PA), and the production segments, the nature of the Austin MSA's economy was very different by the end of the 1990s than what it was at the beginning of the 1990. This chapter continues to answer the remaining research questions according to the answers to the trends of the economic structure change in the Austin MSA. These questions include, "Are there any changes in terms of the source and quantity of pollutant emissions?" "Are there any changes in terms of the relative contributions of the segments to the emission of one particular pollutant?" "What are the pollutant emissions of Austin MSA in terms of quantity and structure along the different development scenarios in the first decade of the 21st Century?"

Answers to these questions will be beneficial to further explore the strategies of the new generation of environmental policies in the age of the digital economy. A positive rather than normative research method is taken since a series of "what if" and "what are" rather than "what should be" questions are asked and answered in the following sections. The results from EIO analysis, structure decomposition analysis, and scenario simulations are presented, including direct and total environmental coefficient matrices, change of the sources to industrial point emissions from different factors from 1990 to 1999, and simulated quantity and structure of emissions from 1999 to 2008.

7.2 Anatomy of pollutant emissions, 1990 - 1999

The yearly total emissions for five pollutants increased during the 1990s, with CO experiencing the most remarkable growth rate, at over 311 percent (Table 7.1 and Figure 7.1). The only exception is the emission of SO_2, which dropped nearly 3 percent during the same time period. In general, the pollution emissions have relatively slower average growth rates than those of the gross output with the exception of CO. Table 7.2 shows the elasticity[1] of the six pollutants. SO_2 is the only pollutant with negative elasticity, indicating that the emission of SO_2 increased more slowly than the final demand during the 1990s. CO is the only pollutant with elasticity greater than 1, indicating that the emission of CO grew faster than the final demand during the 1990s. Elasticity for the single segment cannot be obtained because the complete emission data are only available for the production and energy segments.

7.3 The changing emission pattern of economic segments, 1990 - 1999

Taking a close look at the point industrial emissions data provided by the TCEQ, we will find that the emissions are concentrated in the production, energy, ICT, and service segments. Only two years of data are available for the transportation segment. There is simply no record available for the information and Edu_PA segments[2] (Table 7.3). Compared to the rich and detailed economic data in IO tables[3], the environmental data is very limited. The study has to choose highly aggregated rather than less aggregated IO models due to the asymmetry between economic and environmental data.

Table 7.1. Annual industrial point air pollutant emissions, 1990 - 1999

	TSP	PM_{10}	SO_2	NO_X	NMOC	CO
1990	985.66	565.64	2746.66	6858.72	405.64	887.5
1992	872.73	495.89	2594.23	6908.89	744.14	1304.77
1993	1080.3	516.24	3111.9	7214.91	700.34	3210.61
1994	1174.83	407.8	1349.65	8058.71	914.16	3759.87
1995	1233.88	470.13	1754.2	8773.51	481.78	3594.51
1996	1213.27	448.77	1646.84	8731.62	644.61	3791.37
1997	1011.01	487.64	1875.25	8110.62	444.94	3587.94
1998	1181.2	905.26	1521.14	9006.63	570.68	5183.68
1999	1228.03	898.64	2671.42	9223.05	546.97	3653.5
Change rate (1990 - 1999)	24.59%	58.87%	-2.74%	34.47%	34.84%	311.66%

Source: Raw data from TCEQ (2003), summarized by the author.
Note: There is no record available in 1991.

Table 7.2. Elasticity of the pollutants[4]

Pollutants	TSP	PM_{10}	SO_2	NO_X	NMOC	CO
Elasticity	15.11%	36.18%	-1.68%	21.19%	21.41%	191.54%

Table 7.3. Number of emission sources in each of the segments, 1990 - 1999

	1990	1992	1993	1994	1995	1996	1997	1998	1999
Production	2	5	4	6	7	8	7	6	5
Energy	3	3	3	3	3	3	3	3	3
Information	0	0	0	0	0	0	0	0	0
ICT	0	2	1	2	2	2	2	1	2
transportation	0	0	0	0	0	1	1	0	0
Service	1	2	1	2	1	1	1	1	3
Edu_PA	0	0	0	0	0	0	0	0	0
Total	6	12	9	14	13	15	14	11	13

Source: TCEQ (2003), summarized by the author.

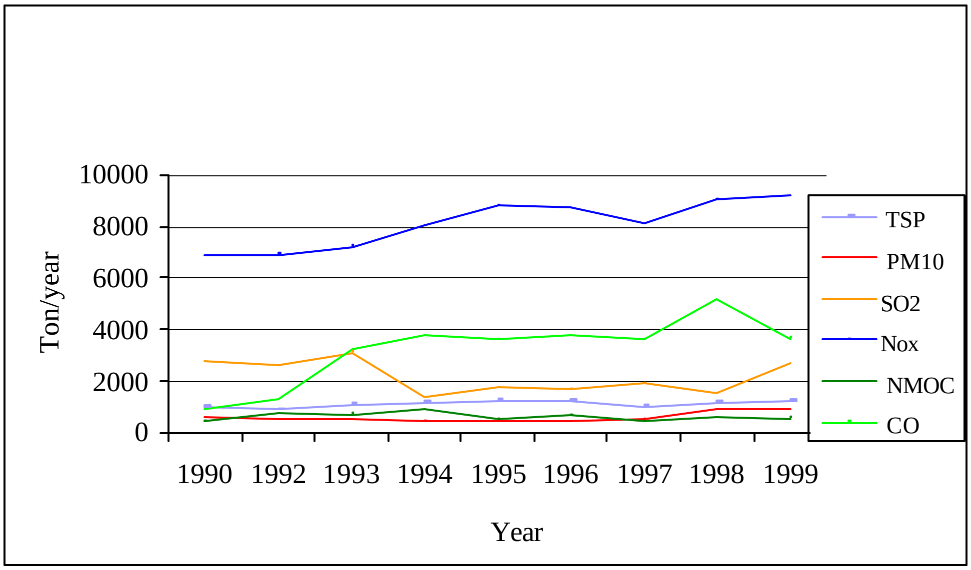

Figure 7.1. Annual industrial point air pollutant emission in the Austin MSA, 1990 - 1999.
Source: TECQ (2003).

7.3.1 Direct pollution coefficients

Direct pollution coefficients are calculated using Formula 7.1. Tables 7.3, 7.4, and 7.5 show the direct pollution coefficients of seven segments in the years of 1990, 1994, and 1999. The many zero items indicate the coefficients are not available for all the segments, or all the pollutants for certain segments. The coefficients are available for all the pollutants for production and energy in all the three years (except NMOC for the production segment in 1990). For the segment of transportation, service, and ICT, the coefficients are only partially available for certain pollutants in certain years. For the segments of information and Edu_PA, the coefficients are simply unavailable.

Changes of direct pollution coefficients for each of the six pollutants in the years of 1990, 1994, and 1999 are presented in Figures 7.2 - 7.7. For the production segment, all the coefficients declined, indicating a "cleaner" or more efficient production process. The service segment also had declining coefficients. For the ICT segment, all the coefficients decreased except for TSP. In contrast, the pollution coefficients of the energy segment increased in all the pollutants except for SO_2.

$$b_{kj} = P_{kj} / X_j \tag{7.1}$$

Where
b_{ki} : direct pollution coefficient of pollutant k for sector j
P_{kj} : total emission of pollutant k in sector j
X_j : total output of sector j

Table 7.4. Direct air pollution coefficients, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	175.24	27.78	0.00	0.00	0.00	0.00	0.00
PM_{10}	106.13	1.50	0.00	0.00	0.00	0.00	0.00
SO_2	204.09	814.27	0.00	0.00	0.00	0.00	0.00
NO_X	445.20	2200.37	0.00	0.00	0.00	0.00	0.00
NMOC	0.00	80.62	0.00	0.00	0.00	17.78	0.00
CO	20.55	380.82	0.00	0.00	0.00	0.00	0.00

Unit: Kg/million USD.

Table 7.5. Direct air pollution coefficients, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	138.0215	50.17758	0	5.973525	0	0.17256	0
PM_{10}	49.8867	17.60063	0	0.023198	0	0	0
SO_2	48.54026	636.668	0	0.213133	0	0.464846	0
NO_X	307.5233	3654.117	0	13.95079	0	2.853057	0
NMOC	68.26547	107.9782	0	20.64201	1.4803272	4.096847	0
CO	322.3867	723.7306	0	6.272201	0	7.506362	0

Unit: kg/million USD

Table 7.6. Direct air pollution coefficients, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	66.49413	125.6289	0	7.697966	0	0.085631	0
PM_{10}	49.74193	125.6289	0	0.024856	0	0.085631	0
SO_2	141.3725	424.3682	0	0.098673	0	0.227293	0
NO_X	204.3	3623.362	0	5.298189	0	1.248526	0
NMOC	10.38692	152.6034	0	9.601367	0	0.311867	0
CO	136.5718	922.5742	0	2.609927	0	4.019123	0

Unit: kg/million USD

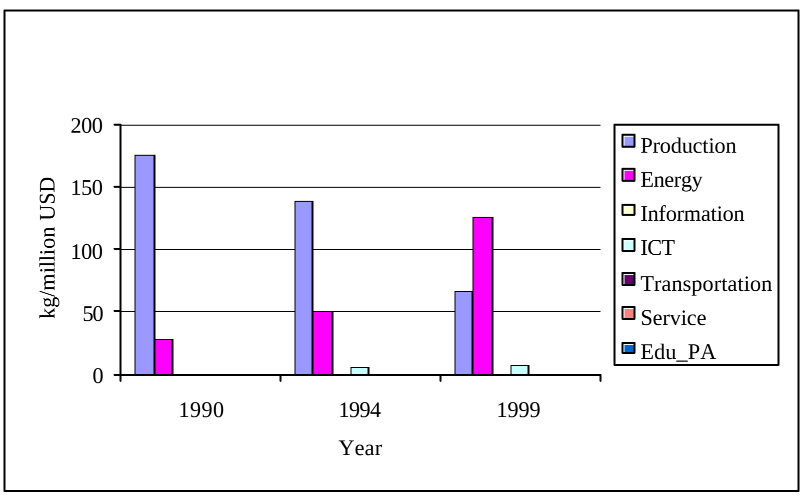

Figure 7.2. Direct air pollution coefficients, TSP, 1990, 1994, and 1999.

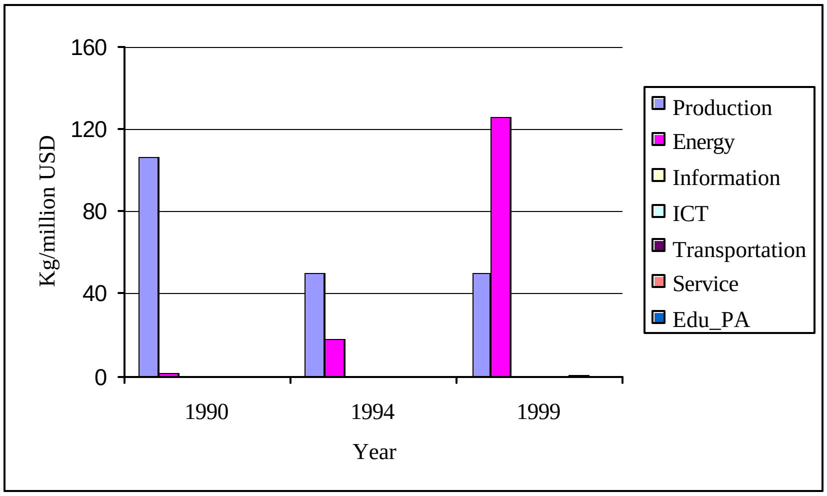

Figure 7.3. Direct air pollution coefficients, PM_{10}, 1990, 1994, and 1999.

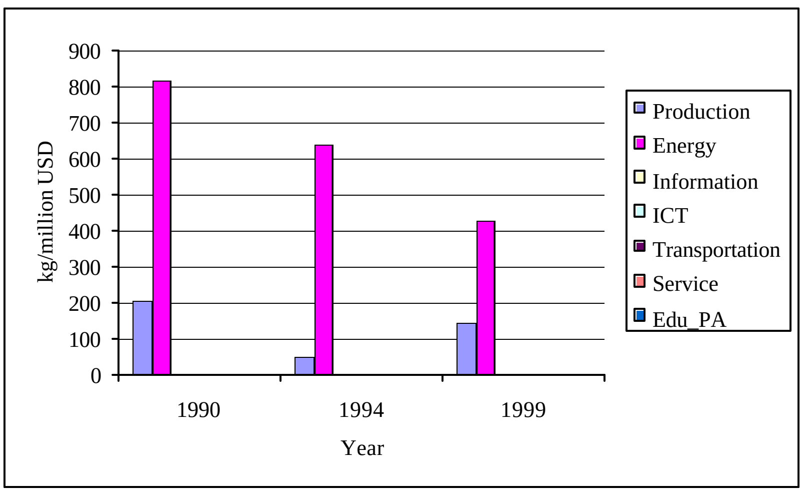

Figure 7.4. Direct air pollution coefficients, SO_2, 1990, 1994, and 1999.

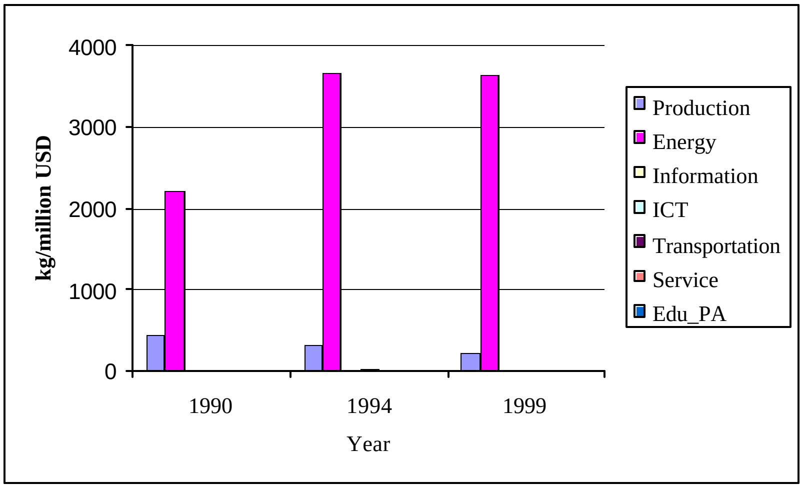

Figure 7.5. Direct air pollution coefficients, NO_x, 1990, 1994, and 1999.

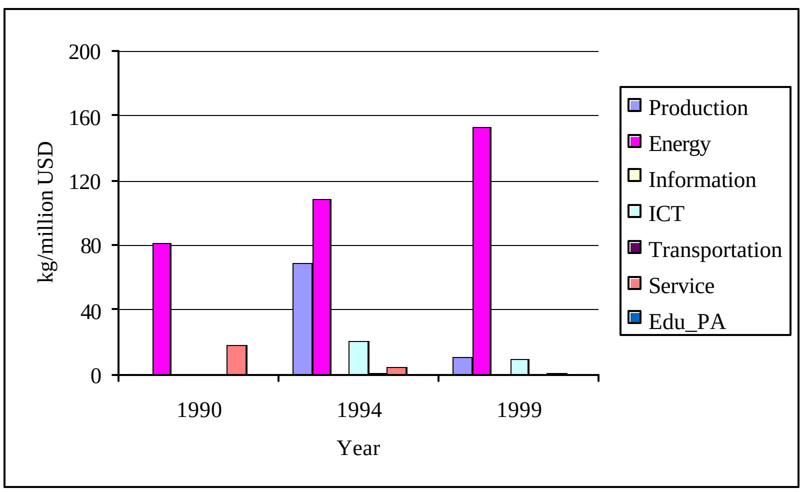

Figure 7.6. Direct air pollution coefficients, NMOC, 1990, 1994, and 1999.

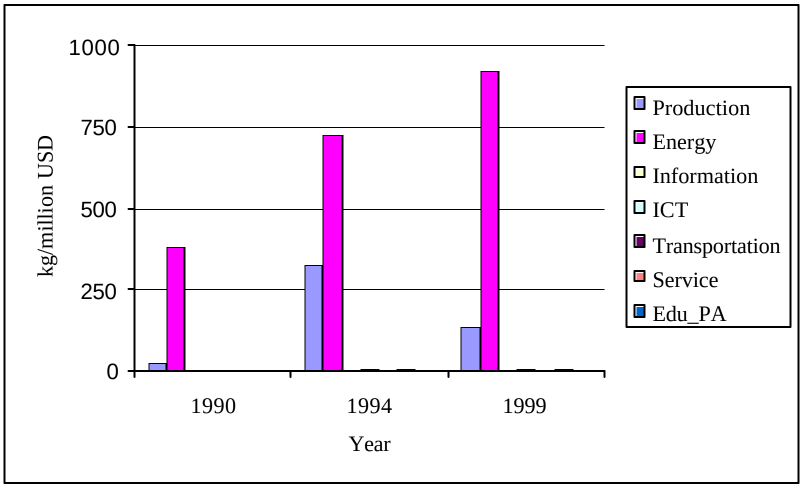

Figure 7.7. Direct air pollution coefficients, CO, 1990, 1994, and 1999.

7.3.2 Total pollution coefficients

Direct pollution coefficients represent only the impacts from direct polluters, but not the indirect effects that occur because of inter-industry linkages. Total pollution coefficients are calculated by multiplying the Leontief inverse by the direct coefficients (Formula 7.2). The results are shown in Tables 7.4 - 7.6 and Figures 7.8 - 7.13. Production and energy remained as two segments with the highest indirect pollution coefficients. The zero elements disappeared in the total pollution coefficient matrices because all the segments contributed to emissions either directly or indirectly through linkage effects of the economic segments.

$$T = B(1 - A)^{-1} \tag{7.2}$$

Where

T: total pollution coefficient matrix

B: direct pollution coefficient matrix

$(1-A)^{-1}$: Leontief inverse matrix

Table 7.7. Total air pollution coefficients, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	209.18	47.17	8.48	17.54	14.18	9.21	6.77
PM_{10}	125.55	8.18	4.95	10.26	8.18	5.31	3.58
SO_2	301.94	1095.28	19.18	38.82	37.38	24.79	34.40
NO_X	690.27	2953.52	46.88	94.65	92.86	61.69	89.43
NMOC	8.27	108.72	2.89	3.95	4.11	22.43	3.52
CO	52.69	507.87	5.49	10.94	11.74	7.87	13.60

Table 7.8. Total air pollution coefficients, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	162.17	71.84	7.82	16.72	13.53	7.53	2.79
PM_{10}	58.58	25.33	2.80	3.89	4.86	2.63	1.00
SO_2	74.85	744.28	6.24	10.36	13.93	8.81	3.90
NO_X	463.33	4274.64	37.48	74.41	82.71	52.27	22.96
NMOC	83.16	132.65	4.99	27.37	10.56	9.42	1.87
CO	396.94	872.98	22.44	38.32	41.93	31.71	9.52

Table 7.9. Total air pollution coefficients, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
TSP	77.79	148.01	2.80	11.25	5.48	3.12	1.15
PM_{10}	59.03	146.83	2.20	3.05	4.30	2.52	0.93
SO_2	169.60	494.12	6.47	9.07	12.66	7.50	2.80
NO_X	326.54	4148.71	19.96	34.77	38.29	27.98	10.94
NMOC	15.81	174.89	0.96	10.63	1.79	1.54	0.49
CO	178.30	1062.62	8.53	14.46	16.20	14.26	3.94

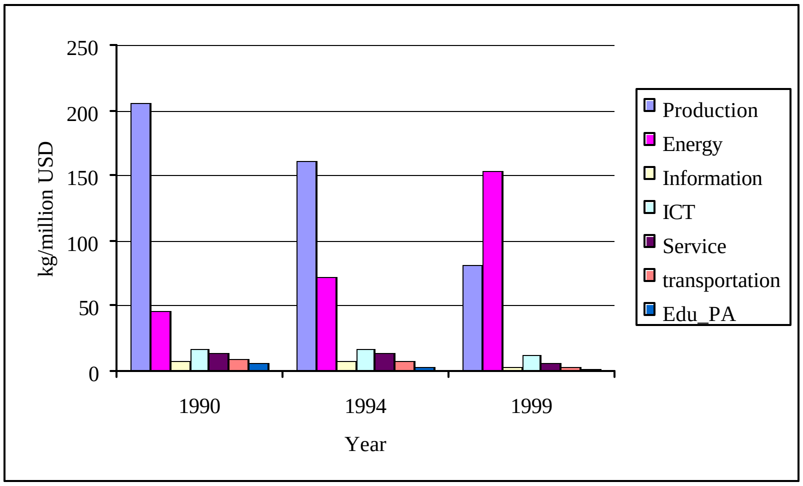

Figure 7.8. Total air pollution coefficients, TSP, 1990, 1994, and 1999.

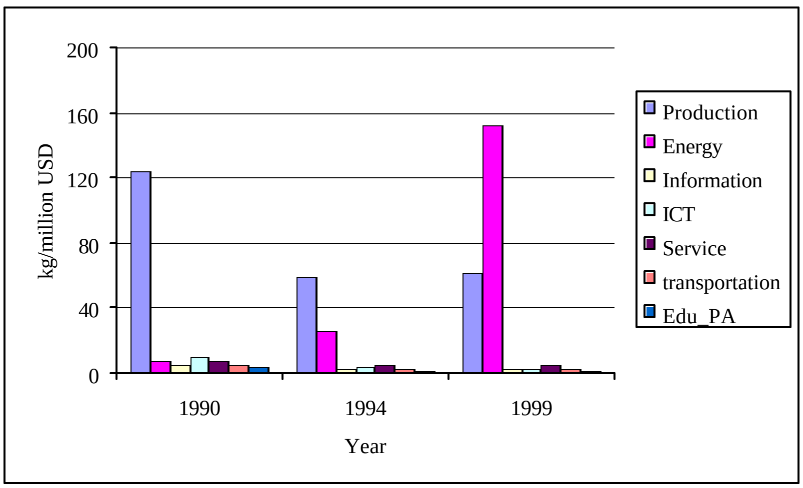

Figure 7.9. Total air pollution coefficients, PM_{10}, 1990, 1994, and 1999.

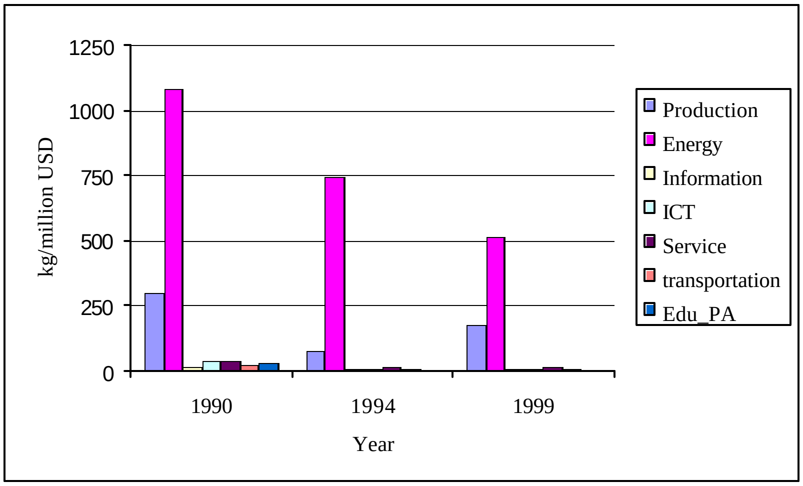

Figure 7.10. Total air pollution coefficients, SO_2, 1990, 1994, and 1999.

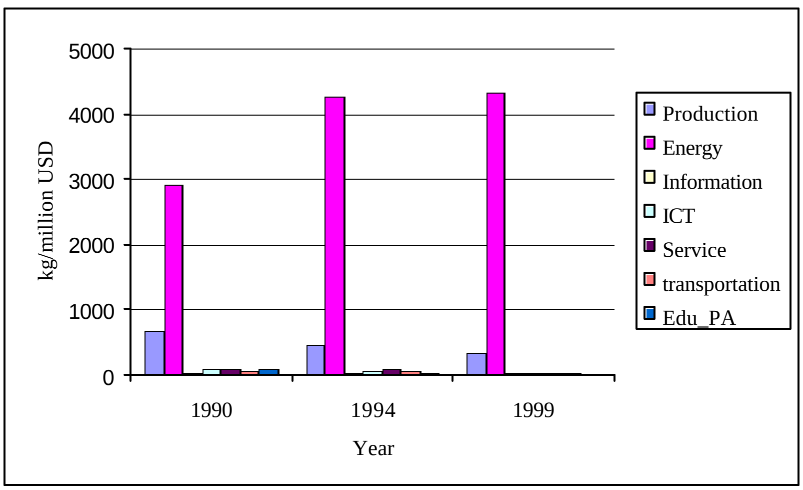

Figure 7.11. Total air pollution coefficients, NO_x, 1990, 1994, and 1999.

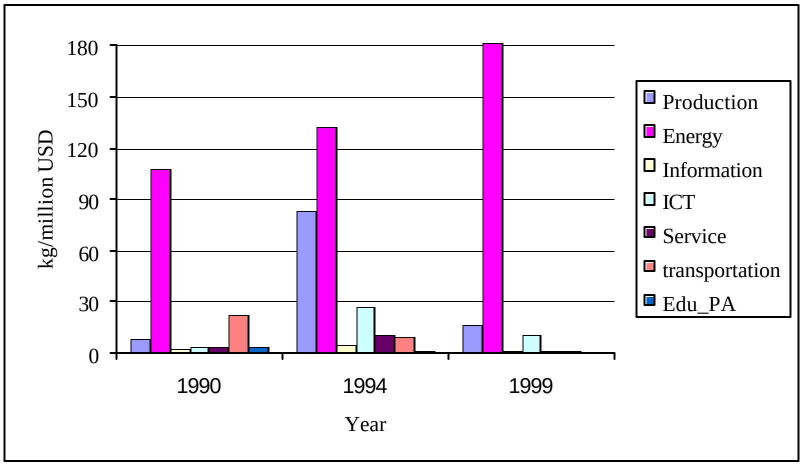

Figure 7.12. Total air pollution coefficients, NMOC, 1990, 1994, and 1999.

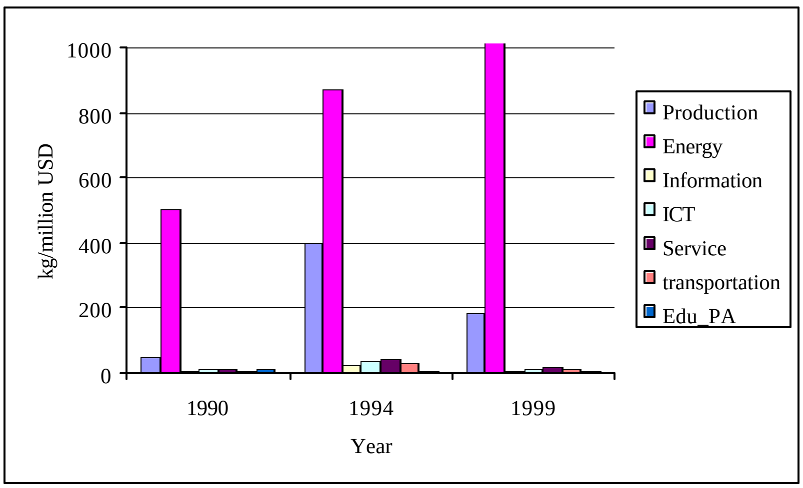

Figure 7.13. Total air pollution coefficients, CO, 1990, 1994, and 1999.

7.4 The change of pollution sources

This section presents the results of SDA, another analytic tool used to explore the change of the sources of point air pollutant emissions during the 1990s. The total emission change of pollutants from time (t-1) to time (t) is decomposed into three factors: (1) the change of the direct pollution coefficient, (2) the change of the technical coefficient, and (3) the change of the final demand. The first two factors are considered as technical effects, and the third factor, the final demand is associated with the consumption side of the economy, and can be further disaggregated into four components: household consumption, government consumption, investment, and export.

The results of the SDA of the six air pollutants for the segment sum are shown in Tables 7.10 - 7.15. The period of 1990 to 1999 is divided by two intervals: 1990 to 1994, and 1994 to 1999. Tables 7.16 - 7.21 show the results of the SDA at the segmental level between 1990 and 1999. More detailed SDA results at the segment level of the two intervals are provided in Appendix 3. Please note that the total change (1990 to 1999) cannot be derived by simple addition of the changes during the two intervals (1990 to 1994, and 1994 to 1999), because all the changes in a component are initially multiplied by the other components in the period.

As shown in Table 7.10, TSP emission increased 242 tons between 1990 and 1999. Technological advancement contributed approximately 1000 tons of TSP reduction, which was offset by emission growth caused by the increase of the level of the final demand. Among the four components of the final demand, the contribution of government consumption was noticeable, which was responsible for about 48 percent of the total emission increase. Table 7.16 provides more detailed data at the segmental level. It is clear that the growth of the final demand in the segments of production, service, and ICT contributed most to the growth of TSP emission. Table 7.16 also offers detailed information on the contribution of each of the four components of the final demand to the emission growth. For example, the growth of government consumption, investment, and household consumption for the production segment were the most significant contributors to growth of the TSP emission. It is also evident that the improvement of pollution coefficients, especially in the production segment, contributed the most to the reduction of the TSP emission.

The 333 tons of increase in the PM_{10} emission can be explained by the fact that the growth of the final demand outpaced technology advancement (Table 7.11). Government consumption was the most significant contributor to the emission growth. During an economic boom, government tends to spend more on all kinds of activities, such as public infrastructures and education, which indirectly contributes to the total pollution emissions through linkage effects. The increase of PM_{10} may be an indicator of the growth in the construction projects. Table 7.17 indicates that the final demand growth in the production, service, and ICT segments, and the increasing of the pollution coefficient in the energy segment were the major contributors to the emission growth at segmental level. Improvement of the pollution in production segment remained the major source of the reduction of the PM_{10} emission.

Table 7.12 shows that SO_2 emission decreased 75 tons from 1990 to 1999. The gain from technical advancement surpassed the loss caused by the growth of the final demand during the first interval, but the increasing pollution coefficient in the production segment largely cancelled gains from the first interval. At the segmental level, the main factors for emission reduction are from the declining exports in the energy segment, the reduction of technical coefficients in the production, information, service, and Edu_PA segments, and the reduction of the pollution coefficient in the production, energy, and service segments (Table 7.18). The growth of household consumption in the energy, production, and service segments, and the growth of government consumption in the energy and production segments, and the growth of investment in the production segment were the major contributors to the increase of SO_2 emissions.

The same exercises are repeated on all the rest of the pollutants with the results shown in Tables 7.13 - 7.21 and Figures 7.14 - 7.19. Although the causes of the change of the pollutant emissions are quite diverse, several common patterns can be summarized: (1) technical coefficient (change of the economic structure) contributed to the emission reduction for all the pollutants. In the case of CO and SO_2, the effects were quite substantial compared to the total emission change, (2) the pollution coefficients decreased in all the pollutants, except for CO, and pollution coefficients turned out to be the major contributors for emission reductions. However, the situation did exist when the pollution coefficient decreased in the first interval but rebounded in the second, such as NO_x and NMOC, indicating that technology may not always bring positive environmental consequences, (3) the final demand was the major contributor to the emission growth. Among the four components of the final demand: household consumption and government consumption appeared to be the two most significant factors to the emission growth. The increasing final demand at both household and governmental level can be interpreted as one of the direct results of the economic boom, and (4) at the segment level, production, energy, and ICT are the top three segments that contributed the most to the emissions increase. Edu_PA was the only segment that contributed to the emission reduction for all the pollutants, which also indicates the decreasing significance of traditional industries at the Austin MSA. No answers can be easily found to explain why the energy segment contributed the most to the SO_2 reduction. But it may be helpful to investigate the fuel mixture of the segment during the period studied.

Table 7.10. Result of SDA of TSP, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution Coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-192	-792	1198	228	581	262	127	28	242
1990 - 1994	-35	-143	386	63	73	49	201	-19	189
1994 - 1999	-104	-541	656	133	354	156	14	43	53

Table 7.11. Result of SDA of PM_{10}, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution Coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-99	-354	712	132	342	157	80	74	333
1990 - 1994	-12	-280	230	37	43	30	121	-96	-158
1994 - 1999	-37	134	227	47	128	56	-5	167	491

Table 7.12. Result of SDA on SO_2, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-1086	-1038	2103	565	1172	394	-27	-55	-75
1990 - 1994	-477	-1007	624	117	138	71	297	-536	-1397
1994 - 1999	-127	569	410	136	244	79	-49	470	1322

Table 7.13. Result of SDA of NO_x, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-2836	-339	4972	1395	2825	907	-155	568	2364
1990 - 1994	-1277	959	1455	280	330	162	682	63	1200
1994 - 1999	-753	-1099	2539	806	1476	487	-230	476	1164

Table 7.14. Result of SDA of NMOC, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-82	-301	446	186	95	46	118	79	141
1990 - 1994	-37	249	119	44	9	8	57	178	509
1994 - 1999	-69	-690	491	105	201	88	97	-100	-367

Table 7.15. Result of SDA of CO, segmental sum, 1990 - 1999, Unit: Ton

Period	Technology		Final demand subtotal	Final demand				Import	Sum
	Technical Coefficient	Pollution coefficient		Household Consumption	Government consumption	Investment	Exports		
1990 - 1999	-439	1868	482	171	307	74	-70	854	2766
1990 - 1994	-215	2128	129	29	34	12	54	829	2872
1994 - 1999	-335	-1580	1788	443	959	398	-13	21	-106

Table 7.16. Result of SDA of TSP, 1990 - 1999 (Disaggregated into segment level), Unit:Ton

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Expo.	import	
Production	-13	-781	875	146	526	245	-41	-30	51
Energy	-1	75	-1	6	10	0	-17	32	105
Information	-8	-16	28	5	3	1	19	1	5
ICT	-75	26	115	0	1	1	113	31	97
Trans.	-1	-4	4	1	1	0	1	0	-1
Service	-64	-84	149	67	15	15	53	-4	-3
Edu_PA	-30	-9	29	3	26	0	0	-1	-11
Total	-192	-792	1198	228	581	262	127	28	242

Table 7.17. Result of SDA of PM_{10}, 1990 - 1999 (Disaggregated into segment level), Unit:Ton

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Expo.	import	
Production	-4	-392	525	88	316	147	-25	27	157
Energy	1	100	0	1	2	0	-3	45	145
Information	-4	-7	16	3	1	1	11	1	6
ICT	-43	-17	67	0	0	0	66	2	8
Trans.	0	-2	2	1	1	0	1	0	0
Service	-34	-32	86	38	9	9	30	0	20
Edu_PA	-15	-3	15	2	14	0	0	-1	-3
Total	-4	-392	525	88	316	147	-25	27	157

Table 7.18. Result of SDA of SO_2, 1990 - 1999 (Disaggregated into segment level), Unit: Ton

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Expo.	import	
Production	-241	-530	1264	211	759	353	-59	167	661
Energy	-70	-325	-35	145	229	-5	-404	-197	-627
Information	-37	-16	62	10	6	2	44	2	12
ICT	-206	-45	254	1	1	2	250	-5	-2
Trans.	-9	-4	10	3	4	1	3	-2	-4
Service	-316	-106	401	179	40	40	142	-15	-35
Edu_PA	-207	-12	147	15	133	1	-2	-6	-79
Total	-1086	-1038	2103	565	1172	394	-27	-55	-75

Table 7.19. Result of SDA of NO_x, 1990-1999 (Disaggregated into segment level), Unit: Ton

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Expo.	import	
Production	-647	-1516	2889	482	1735	808	-136	158	884
Energy	-191	1163	-94	392	618	-15	-1089	375	1254
Information	-96	-15	153	25	14	6	107	11	53
ICT	-515	16	620	1	4	4	611	46	167
Trans.	-24	-4	25	8	10	1	7	-2	-5
Service	-819	14	999	446	100	100	352	-3	190
Edu_PA	-544	1	381	40	345	2	-6	-16	-178
Total	-2836	-339	4972	1395	2825	907	-155	568	2364

Table 7.20. Result of SDA of NMOC, 1990 - 1999 (Disaggregated into segment level), Unit: Ton

Segm ent	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Expo.	import	
Production	-19	71	35	6	21	10	-2	46	133
Energy	-7	59	-3	14	23	-1	-40	21	69
Information	-1	-7	9	2	1	0	7	0	2
ICT	-11	73	26	0	0	0	25	45	133
Trans.	0	-1	1	0	0	0	0	0	0
Service	-24	-496	363	162	36	36	128	-32	-188
Edu_PA	-21	0	15	2	14	0	0	-1	-7
Total	-82	-301	446	186	95	46	118	79	141

Table 7.21. Result of SDA of CO, 1990 - 1999 (Disaggregated into segment level), Unit: Ton

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution coefficient	Final demand subtotal	Household Consumption	Government consumption	Investment	Export s	import	
Production	-110	953	220	37	132	62	-10	577	1639
Energy	-34	454	-16	67	106	-3	-187	177	581
Information	-14	29	18	3	2	1	13	9	42
ICT	-66	103	72	0	0	0	71	54	162
Trans.	-4	7	3	1	1	0	1	3	9
Service	-124	302	127	57	13	13	45	37	343
Edu_PA	-86	21	58	6	53	0	-1	-2	-10
Total	-439	1868	482	171	307	74	-70	854	2766

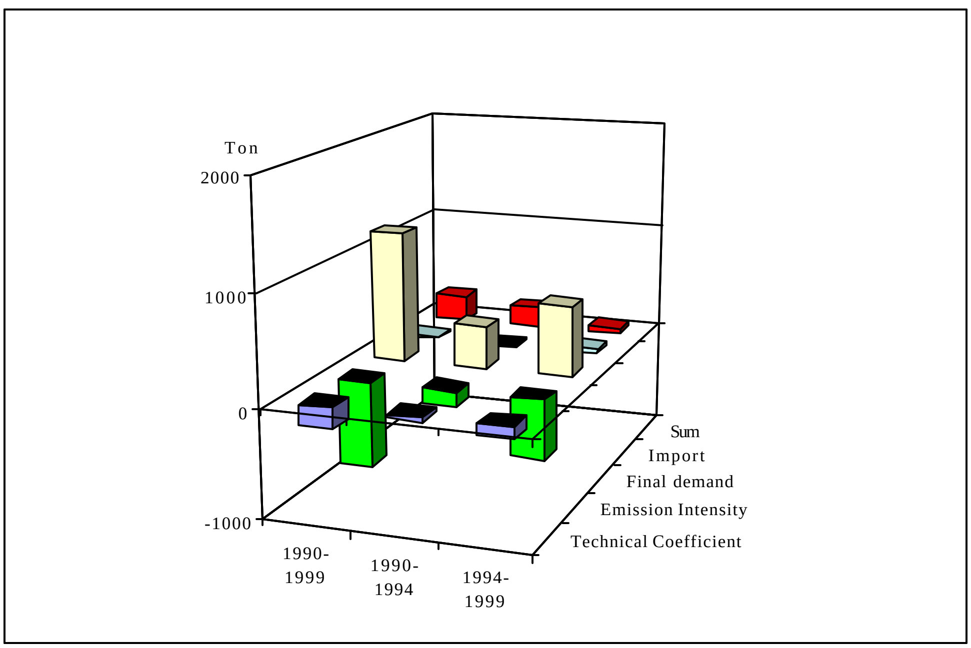

Figure 7.14. Result of SDA on TSP, 1990 - 1999.

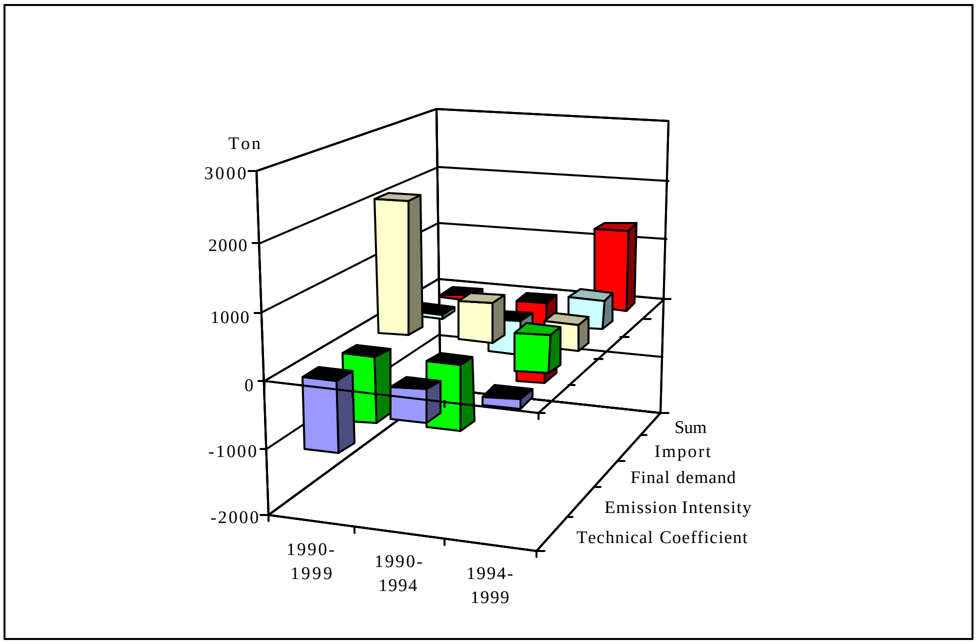

Figure 7.15. Result of SDA of PM_{10}, 1990-1999.

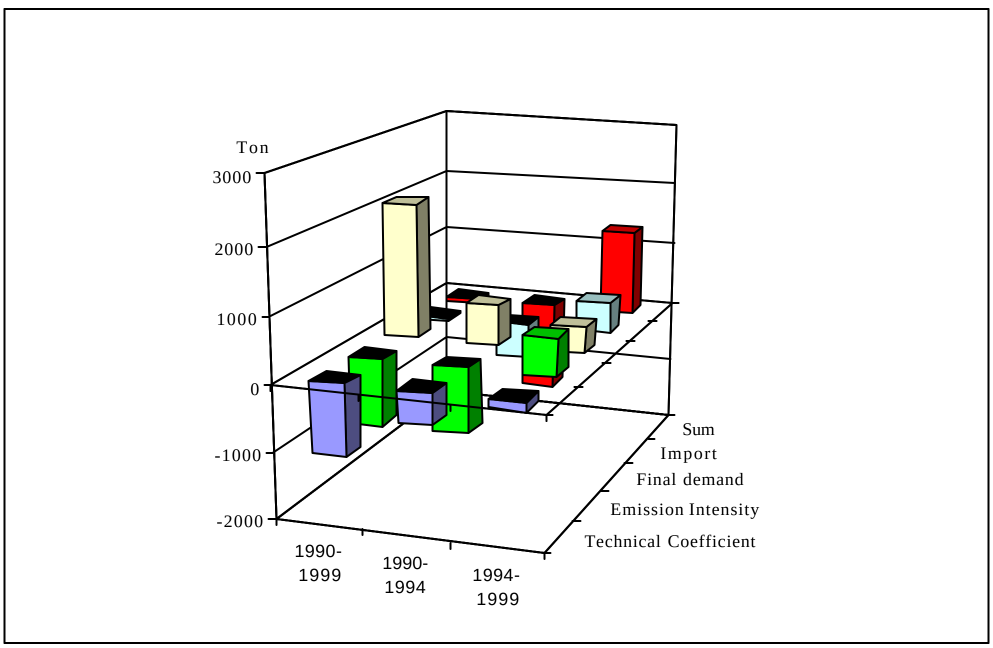

Figure 7.16. Result of SDA of SO_2, 1990 - 1999.

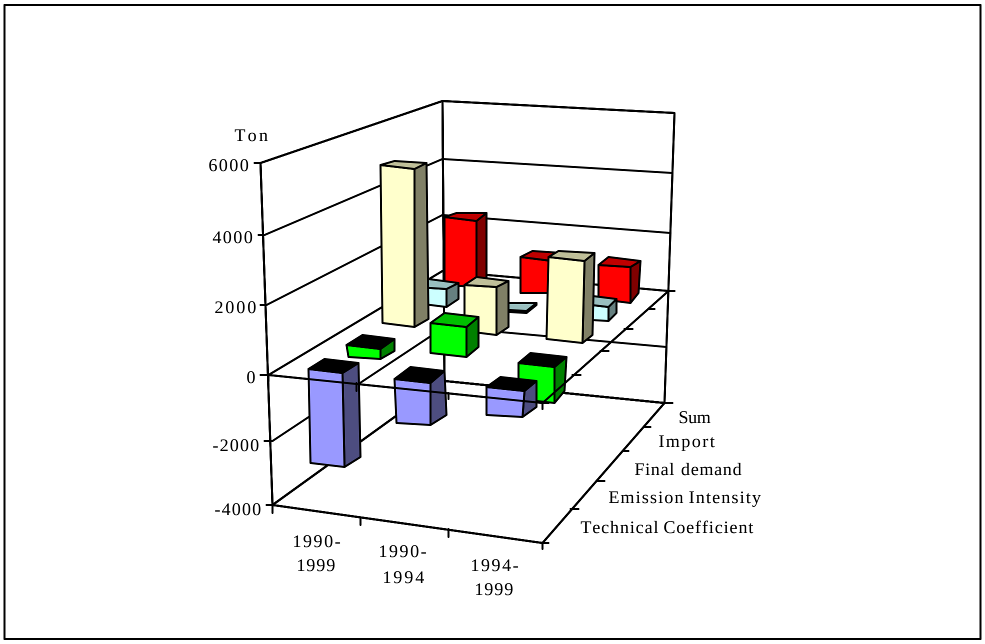

Figure 7.17. Result of SDA of NO_x, 1990 - 1999.

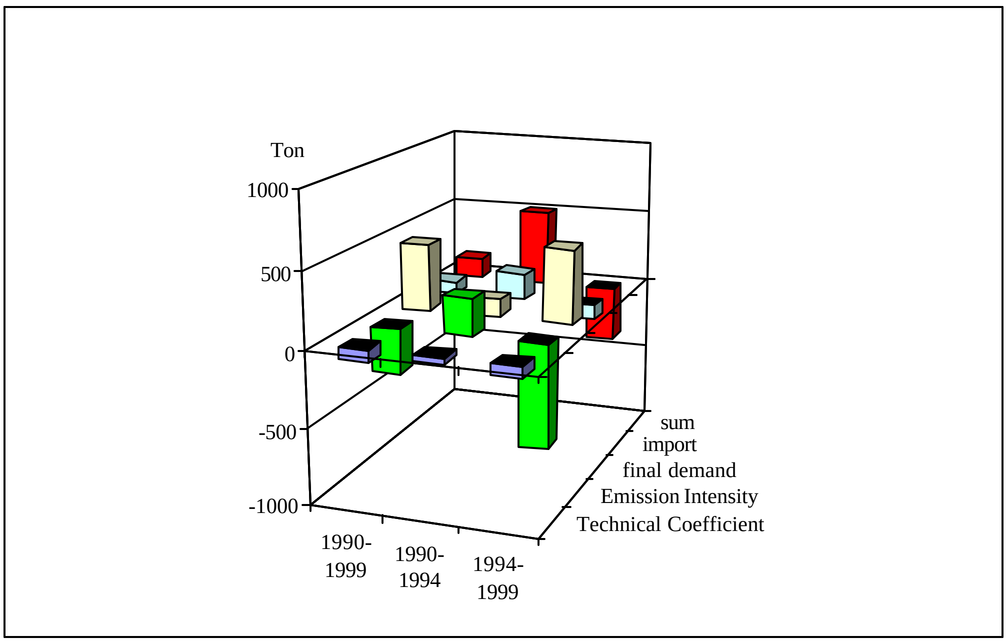

Figure 7.18. Result of SDA of NMOC, 1990 - 1999.

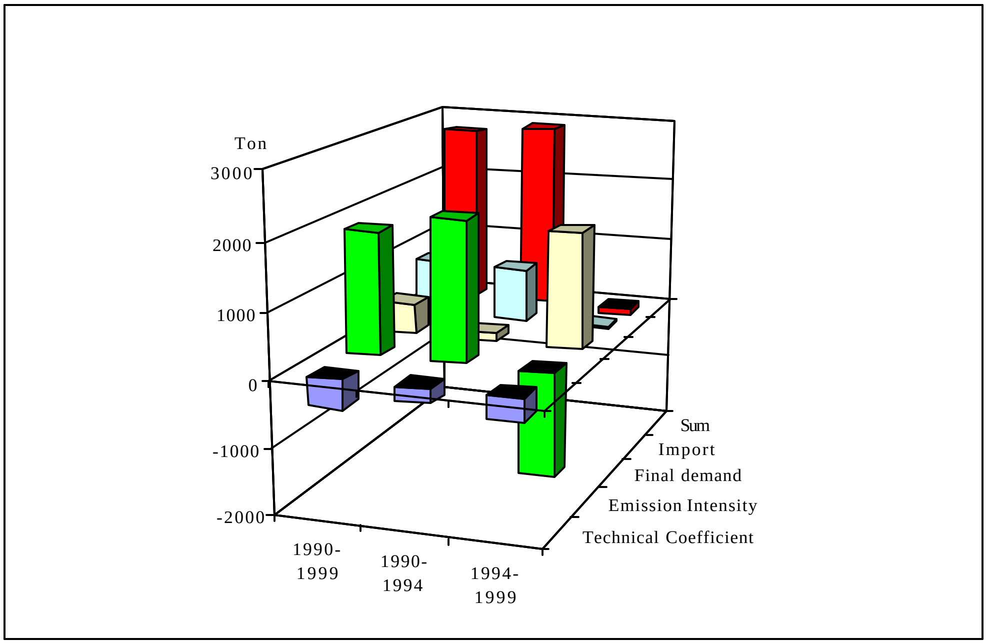

Figure 7.19. Result of SDA of CO, 1990 - 1999.

7.5 Industrial point air pollutant emission simulation, 2000 - 2008

The previous analysis has demonstrated how the quantity, the pattern, and the source of the industrial point air pollution emissions have evolved as the result of the dramatic transformation in the structure of the AUSTIN MSA's economy. A logical step of the subsequent exploration is to forecast the trend of pollutant emissions as Austin's economy continues to evolve in the context of the digital economy in the years to come. The results from such exercises will greatly facilitate decision makers to develop more effective and efficient policies to cope with environmental problems in various scenarios.

It is a common practice to apply IO analysis to investigate the interactions between the environment and economy, and to simulate the effects of a variety of environmental policies and possibilities (Ketkar 1984; Jorgenson and Wilcoxen 1990; Hawdon and Pearson 1995; Steenge 1999; Kebede, Schreiner and Huluka 2002). The assumption of linearity between the final demand and emissions is usually maintained because the data necessary to fully evaluate the dependence of emissions on the final demand and other factors are usually not available (Fritz 1996). Even though the constraints posed by the strict linearity assumption are severe, the results of the forecast are still valuable because: (1) it can serve as a benchmark forecast; (2) the comparison between different scenarios will shed light on how the changes of emission factors (direct emission coefficient, Leontief inverse matrix, and the final demand) affect the total emissions in the near future; (3) the segmental emission patterns will also be estimated under different "what . . . if" scenarios.

The main purpose of the following forecast, then, is not to provide accurate quantity of emissions, but to identify trends of emissions as the result of different development scenarios based on a series of "what . . . if" questions. IO analysis serves as a positive planning tool rather than a valuation tool, thus it is appropriate and beneficial to the major objective of the study.

Local economic growth has been extraordinary in the Austin MSA during the 1990s. However, in the background of the national recession and dot.com implosion,[5] the rapid growth halted at the beginning of the new millennium and is not expected to resume the same growth rate as was experienced in the 1990s in near future. The City of Austin economic development white paper (City of Austin 2003c) reports that, with the gradual (still modest) recovery of the U.S. economy, Austin-area job growth will become positive by 2003, up about 1.4 percent from the level of 2002, with most new jobs occurring in the secondary segments of services, trade, and government.

Over the 2002 to 2006 period, growth in the Austin region should begin to accelerate, although expansion most likely will not be as rapid as that in the period of

1997 - 2001. The forecast growth rate is about half of the peak rate during the period of 1997 - 2001. The Austin MSA job base is expected to expand at a rate of 2.4 percent from 2002 through 2006, compared to a compound annual growth rate of 4.5 percent from 1997 to 2001. The forecast increase of Travis County personal income is 6.3 percent annually from 2002 through 2006, compared to an astonishing 13.2 percent annual growth from 1997 - 2001 (Tables 7.22 - 7.23).

Table 7.22. Austin area economic forecast, 2000 - 2006

	2000	2001	2002	2003	2004	2005	2006
MSA Employment (000s)	672.7	675.7	672.1	682.0	700.2	720.0	741.7
City Employment (000s)	382.5	383.0	380.9	382.6	388.9	395.9	403.8
County Population (000s)	818.8	833.8	846.9	860.6	875.0	890.1	905.4
County Personal Income (Billion USD.)	32.1	32.7	33.0	34.4	37.0	39.5	41.9

Source: City of Austin (2003c).

Table 7.23. Austin area employment forecast, 2000 - 2006

	2000	2001	2002	2003	2004	2005	2006
Mining	1.5	1.7	1.8	1.9	2.0	2.0	2.1
Construction	39.1	40.3	40.0	38.8	40.1	41.4	42.4
Non-durable Manufacturing	13.9	13.4	13.0	13.4	13.8	14.1	14.4
Durable Manufacturing	71.2	65.9	56.0	56.5	58.9	62.1	65.5
Wholesale Trade	38.7	38.5	37.5	38.0	38.8	39.7	40.7
Retail Trade	114.5	116.4	117.5	119.0	122.8	125.7	128.9
Finance/Real Estate	33.5	34.2	34.6	34.4	34.7	35.2	35.7
Transportation/Utilities	21.6	21.5	20.7	21.2	21.8	22.4	23.1
Services	201.9	203.3	204.0	208.4	214.0	221.3	230.0
Government	136.8	140.5	147.0	150.4	153.3	156.1	158.9
Total	672.7	675.7	672.1	683.0	700.2	720.0	741.7

Unit: 1,000 of jobs
Source: City of Austin (2003c).

Thus a relatively realistic prediction of the growth of industrial point emission in the foreseeable future will be based upon the assumption of a moderate economic growth rate. However, considering the uncertainties of the future growth trajectory and major objective of the research, it will also be valuable to experiment on some other possibilities. The results from a wide variety of development scenarios offer a good opportunity to examine various possible environmental consequences along different growth trajectories with varied types of economic structure, levels of technologic advancement, stimulus of the final demand, and the combinations of these factors.

Four scenarios are designed on the basis of two general assumptions on the trend of future economic development in the Austin MSA. The benchmark year was set to be 1999. Scenarios 1 and 2 assume the annual direct pollution coefficients from 1999 to 2008 will change at the average rates of those between 1990 and 1999. The difference between Scenarios 1 and 2 is the growth rate of the final demand. Scenario1 assumes that the annual final demand from 1999 to 2008 will grow at the average rate of the

1990s; Scenario2 assumes that the annual final demand will grow at half of the rate of Scenario1. Scenarios 3 and 4 assume the direct pollution coefficients from 2000 to 2008 will be the same as those of 1999. Scenario 3 assumes that the annual final demand will grow at the average rate of the 1990s. Scenario 4 assumes that the annual final demand from 2000 to 2008 will grow at half of the rate as of Scenario 3.

Scenarios 2 and 4 are more conservative (realistic) estimations of the future development, while scenarios 1 and 3 take more optimistic views. There are two sub-scenarios – a and b – under each of the four scenarios. All the conditions of the two sub-scenarios, except the Leontief (L) matrix, are kept the same. Sub-scenario a uses the 1999 L inverse, and sub-scenario b uses the 1990 L inverse. The purpose is to examine how the economic structure change impacts pollution emissions. Figure 7.20 illustrates four development scenarios.

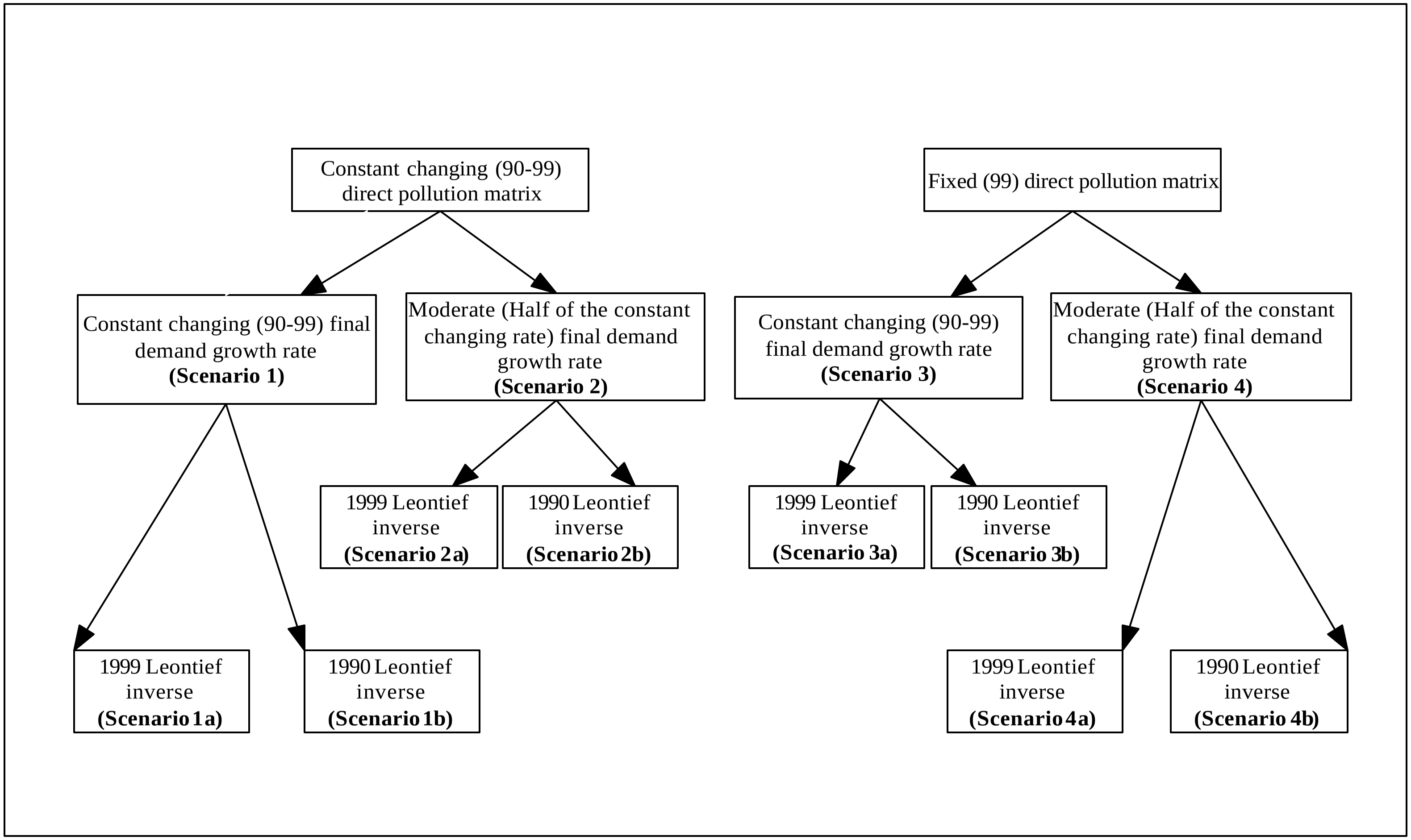

Figure 7.20. The Four Development Scenarios

7.5.1 Scenario 1

This scenario assumes that the growth trend of the economy during the 1990s will continue through the year of 2008, and the direct pollutant Pollution coefficients are assumed the same as the 1990s' average. Based on these assumption, the average final demand growth rate for each segment and the average change rates of direct pollution coefficients of the 1990s are calculated first, and then the future emissions are extrapolated by multiplying the 1999 total emissions by the above two change rates.

1 Scenario 1a[6]

CO emission is forecast to grow the fastest, and SO_2 the slowest because of the difference in the pollution elasticity (Table 7.24 and Figure 7.21). Figure 7.22 shows the changing pattern of the relative contribution of segments to the total pollution.

For the TSP, the contribution from the production segment will decrease about 15 percent, while the share from the energy and ICT segments will increase about 10 percent. The growing share of the energy segment can be interpreted by the segment's increasing direct pollution coefficient. In contrast, the increasing share of the ICT segment is largely pushed by the rapid growth in the final demand. For PM_{10}, the total shares of two segments, the production and the energy are over 80 percent in both 1999 and 2008. But the relative distributions of the two segments are quite different in the beginning and the end of the simulation period. In 1999, the share from the production and energy segments were 67 and 17 percent respectively, but the share is projected to be 25 and 68 percent in 2008. Thus the relative importance is projected to shift between the two segments. The quickly increasing contribution of the energy segment is due to the remarkable increase in the direct pollution coefficient.

For SO_2, the share from the production segment will increase from 65 percent in 1999 to 80 percent in 2008, while the share from the energy segment will drop from 19 percent in 1999 to 7 percent in 2008. The changing pattern can be explained by the fact that the direct pollution coefficient of energy segment dropped much more quickly than that of the production sector from 1990 to 1999 (50 percent vs. 20 percent). For NO_x, the contribution of the segments is not expected to change dramatically in general. The production and energy segments remain to be the two largest contributors, and the share from the ICT segment is expected to have a slight growth of about 1.3 percent.

For NMOC, the contribution from the ICT segment will increase from 27 percent in 1999 to close to 58 percent in 2008 compared to the declining contribution from the energy segment from 30 percent in 1999 to about 10 percent in 2008. The changes in the remaining segments are much less insignificant than those of the ICT and energy segments. For CO, the share from the production segment will decrease from over 74 percent in 1999 to about 50 percent in 2008, while the share from the energy segment is projected to increase 30 percent in 2008, a 20 percent jump from the level of 1999.

Table 7.24. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 1a

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1393.54	1570.57	1699.10	1799.15	1870.71	2028.02	2056.85	2057.19	2029.04
PM_{10}	898.64	1295.16	1680.48	2040.21	2379.16	2697.32	2794.80	3081.77	3347.96	3593.37
SO_2	2671.43	2924.57	3159.98	3335.18	3464.31	3547.40	3864.57	3878.57	3846.51	3768.40
NO_X	9223.13	10044.93	10856.49	11490.07	12001.59	12391.03	13078.53	13284.88	13369.15	13331.36
NMOC	546.97	681.10	887.94	1094.87	1326.09	1581.61	1732.19	2024.16	2340.42	2680.97
CO	3653.52	4975.37	6571.45	8363.56	10377.76	12614.07	13684.18	16253.63	19045.18	22058.82

Unit: ton.

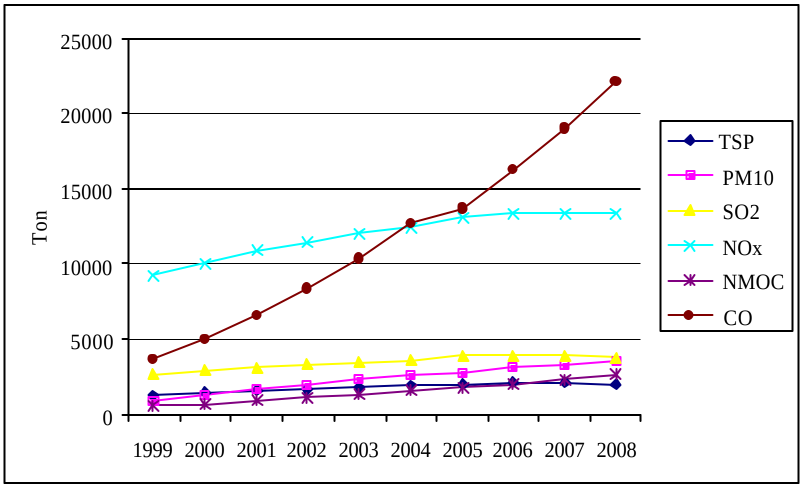

Figure 7.21. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 1a.

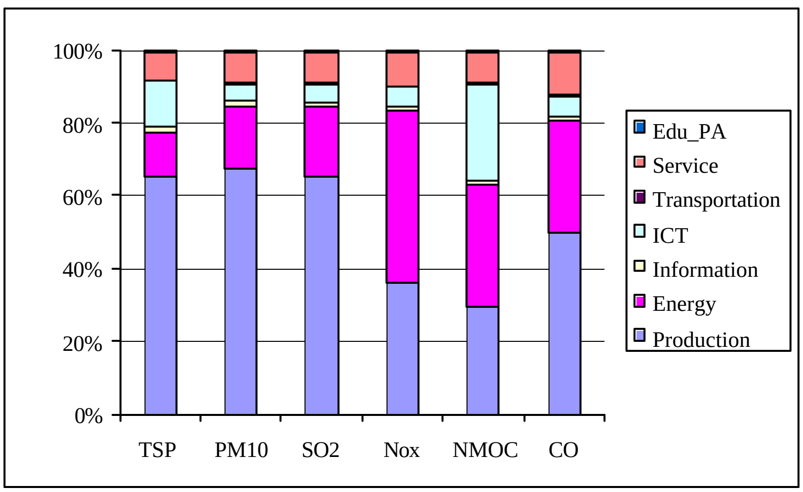

Figure 7.22. Segment contributions to the total emissions, 1999.

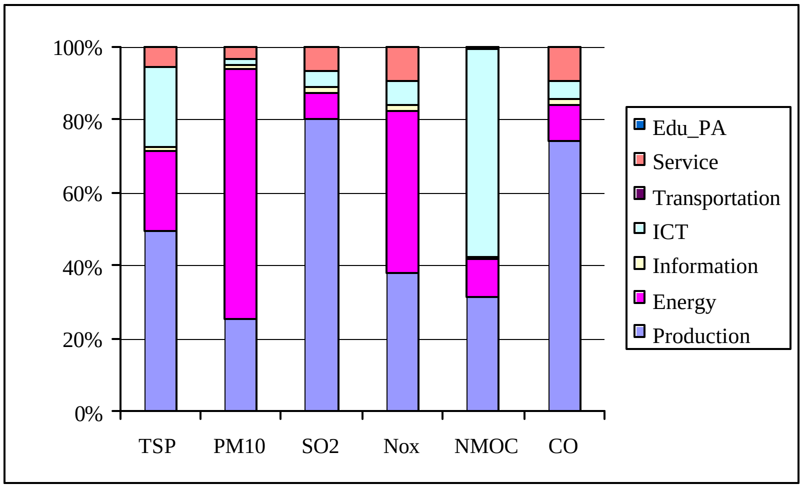

Figure 7.23. Segment contributions to the total emissions, 2008, Scenario 1a.

2 Scenario 1b

Table 7.25, and Figures 7.24 and 7.25 present the simulation results of scenario 1b, under which all other factors are kept the same as those in scenario 1a, except that the 1999 Leontief inverse matrix is substituted with the 1990 Leontief matrix. As expected, the forecast emissions for all six pollutants are higher under scenario 1b than under scenario 1a (Table 7.26), indicating that the economic structure of 1999 is more environmentally friendly than that of 1990 in the Austin MSA.

Table 7.25. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 1b

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1687.97	1908.09	2064.94	2186.61	2273.09	2470.46	2504.16	2502.69	2466.02
PM_{10}	898.64	1593.32	2041.61	2450.71	2831.82	3184.96	3315.89	3627.06	3910.24	4165.44
SO_2	2671.43	3782.89	4109.58	4331.85	4483.46	4564.42	4985.29	4960.26	4864.57	4698.23
NO_X	9223.13	16134.12	17608.91	18667.61	19461.32	19990.06	21408.45	21539.71	21406.00	21007.30
NMOC	546.97	964.26	1238.15	1511.25	1813.48	2144.84	2353.84	2728.90	3133.09	3566.41
CO	3653.52	6941.36	9145.74	11576.69	14295.06	17300.87	18838.01	22274.96	25999.35	30011.17

Unit: ton.

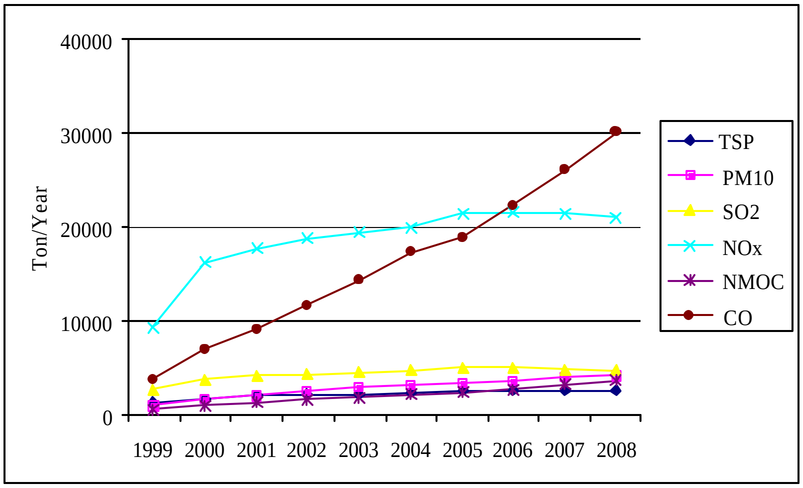

Figure 7.24. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 1b.

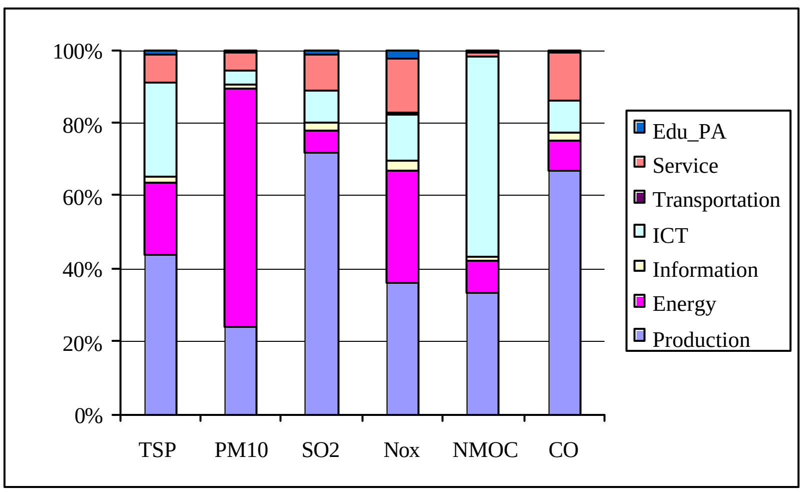

Figure 7.25. Segment contributions to the total emissions, 2008, scenario 1b.

Table 7.26. Forecast emissions in 2008: Scenario1a vs. 1b

	Scenario 1a Ton/year	Scenario 1b Ton/year	Difference
TSP	2029.04	2466.02	17.72%
PM_{10}	3593.37	4165.44	13.73%
SO_2	3768.40	4698.23	19.79%
NO_X	13331.36	21007.30	36.54%
NMOC	2680.97	3566.41	24.83%
CO	22058.82	30011.17	26.50%

7.5.2 Scenario 2

This scenario assumes that the average growth rate of the final demand between 1999 and 2008 will keep a moderate pace, which is half of the 1990s' average A more pessimistic rather than optimistic stance is held under this development scenario, while direct pollution coefficients are assumed to be the same as the 1990s' average. Based on these assumption, again both the average economic growth rate for each segment and the average change rate of the direct pollution matrix in Austin are calculated first, and then the future emissions are extrapolated by multiplying the 1999 total emissions with the average changing rate of the direct pollution matrix and half the average final demand growth rate of 1990 - 1999. Leontief inverse matrices of are used separately to examine the difference of total emissions induced by economic structure change.

1 Scenario 2a[7]

The emissions at the end of the simulation period are forecast to be much lower than those of Scenario 1 due to the much lower growth in the final demand (Table 7.27, Figure 7.26). CO emission is still expected to have the highest growth rate. The emission of SO_2 in 2008, however, is projected to be even slightly lower than the level of 1999, indicating that the decreasing rate of the direct pollution coefficient will finally outpace the growth in the final demand.

The patterns (the relative emission contribution of the segments) of the total emissions generally remain unchanged from those in Scenario 1, as indicated in Figure 7.27. Compared to the patterns of Scenario 1, the relative contributions from the production and ICT segments will decrease, but the energy segment will contribute relatively more because slowing growth in the final demand will have a much greater impact on the production and ICT segments than the energy segment which had a much lower growth in final demand in the 1990s than the other two segments.

Table 7.27. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 2a

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1306.40	1370.53	1420.41	1456.04	1477.44	1556.09	1556.12	1541.90	1513.44
PM_{10}	898.64	1230.43	1551.82	1862.82	2163.42	2453.63	2502.37	2776.99	3041.22	3295.05
SO_2	2671.43	2734.09	2773.73	2790.34	2783.92	2754.47	2913.06	2849.07	2762.05	2652.01
NO_X	9223.13	9635.03	9985.89	10275.73	10504.52	10672.29	11016.04	11092.25	11107.43	11061.57
NMOC	546.97	654.31	773.80	905.44	1049.22	1205.15	1280.44	1454.60	1640.90	1839.35
CO	3653.52	4688.48	5834.49	7091.54	8459.65	9938.80	10473.85	12119.58	13876.35	15744.18

Unit: ton.

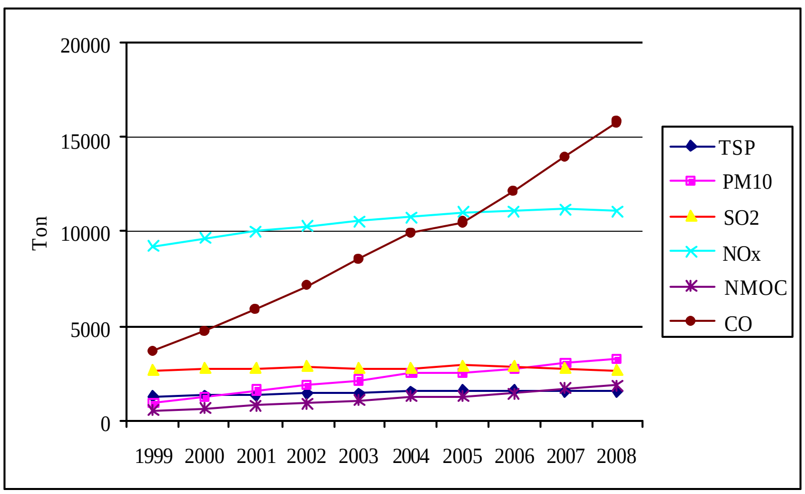

Figure 7.26. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 2a.

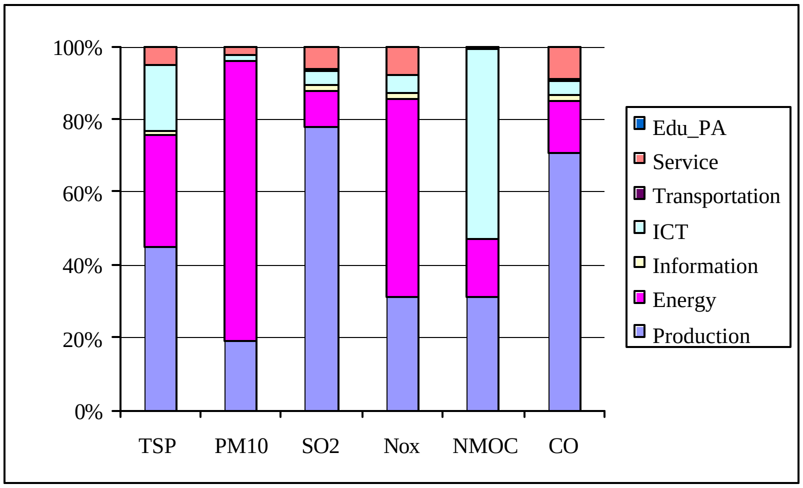

Figure 7.27. Segment contributions to the total emissions, 2008, scenario 2a.

2 Scenario 2b

The simulation results of Scenario 2b are presented in Table 7.28 and Figure 7.28. The difference between Scenarios 2a and 2b is shown in Table 8.8. Again the simulated emissions in this scenario are higher than those in Scenario 2a, showing the effect of the structural change of the economy. As for the segment contributions, there is no significant difference between Scenarios 2b and 1b (Figure 7.29).

Table 7.28. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 2b

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1582.18	1657.94	1716.11	1756.69	1779.67	1878.35	1874.95	1853.95	1815.36
PM_{10}	898.64	1511.09	1868.70	2212.33	2541.97	2857.62	2923.08	3217.75	3498.42	3765.10
SO_2	2671.43	3535.56	3582.72	3594.55	3571.05	3512.23	3722.67	3610.85	3463.70	3281.23
NO_X	9223.13	15311.05	15793.04	16142.55	16359.56	16444.08	17153.28	17039.06	16792.36	16413.16
NMOC	546.97	918.81	1072.84	1241.44	1424.60	1622.33	1726.83	1946.41	2180.55	2429.26
CO	3653.52	6521.08	8039.75	9702.13	11508.22	13458.04	14226.60	16391.99	18701.09	21153.90

Unit: ton.

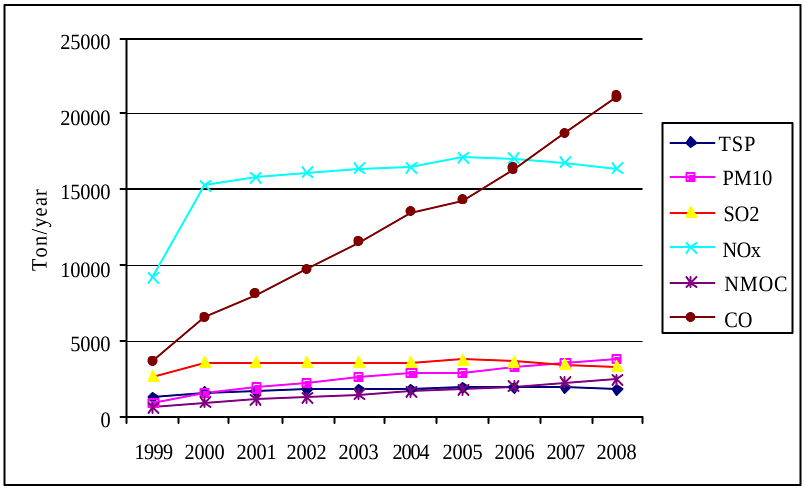

Figure 7.28. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 2b.

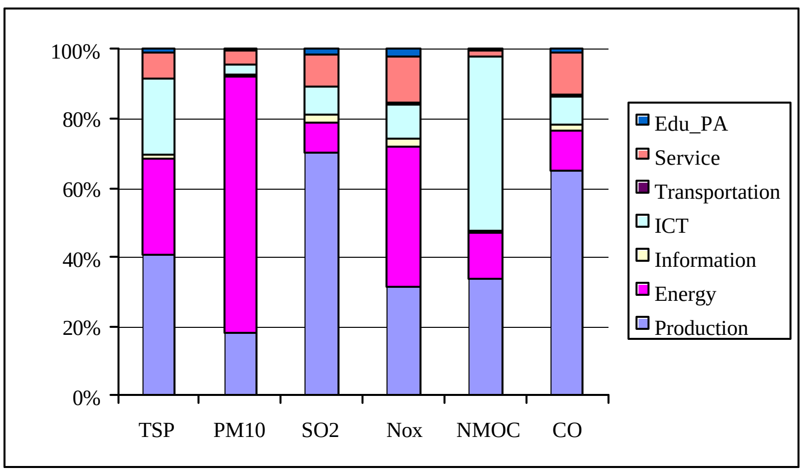

Figure 7.29. Segment contributions to the total emissions, 2008, scenario 2a.

Table 7.29. Forecast emissions in 2008: Scenarios 2a Vs. 2b

	Scenario 2a Ton/year	Scenario 2b Ton/year	Difference
TSP	1513.44	1815.36	16.63%
PM_{10}	3295.05	3765.10	12.48%
SO_2	2652.01	3281.23	19.18%
NO_X	11061.57	16413.16	32.61%
NMOC	1839.35	2429.26	24.28%
CO	15744.18	21153.90	25.57%

7.5.3 Scenario 3

This scenario assumes, as does Scenario 1 that the economic trends of 1990 - 1999 will continue through the year 2008, but the direct pollutant Pollution coefficients remain the same as those in 1999, rather than changing annually with the average rates of the 1990s. Based on these assumptions, the average final demand growth rate for each segment in the 1990s is calculated first, and then the future emissions are extrapolated by multiplying the 1999 total emissions with the average final demand growth rate of 1990 - 1999. The 1999 and 1990 Leontief inverse matrices are used to compare the environmental impacts caused by economic structure change.

1 Scenario 3a

By 2008, the total pollutant emissions will show a very different picture under this scenario than under Scenario 1 (Table 7.30, Figures 7.30, 7.31). The share of emission of the production segment will increase for all the pollutants, making the production segment the most important contributor of the pollutant emissions among all the segments. The shares from the ICT and service segments are also projected to increase slightly. At the same time, the contributions from the energy and transportation segments are expected to decline.

The differences between Scenarios 1a and 3a are presented in Table 7.31. In 2008, the total emissions of PM_{10}, NMOC, and CO are predicted to be much lower than those in scenario 1a, while the total emissions of the remaining four pollutants are predicted to be much higher than those in scenario 1a. Under scenario 3a, the growth rate of the final demand is the only influencing factor of the change of total emissions. Under scenario 1a, the change of total emissions is the affected by both the rate of the final demand growth and the changing rate of the direct pollution coefficient. The high elasticity of CO in 1990s is assumed to continue in Scenario 1a, but not in 3a, thus the projected total CO emission in 2008 is much higher under Scenario1a than that of Scenario 3a, in which the growth rate of CO is actually equal to the growth rate of the final demand.

Table 7.30. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 3a

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1228.03	1685.09	1913.62	2142.14	2370.67	2599.20	2827.73	3056.26	3284.28
PM10	898.64	898.64	1197.53	1346.98	1496.42	1645.87	1795.31	1944.76	2094.20	2243.25
NO_X	9223.13	9223.13	3536.05	3968.36	4400.66	4832.97	5265.28	5697.59	6129.90	6561.03
NMOC	546.97	546.97	11208.47	12201.13	13193.80	14186.47	15179.13	16171.80	17164.47	18153.59
CO	3653.52	3653.52	726.66	816.50	906.35	996.19	1086.03	1175.88	1265.72	1355.40
TSP	1228.03	1228.03	4683.25	5198.11	5712.98	6227.84	6742.71	7257.7	7772.44	8285.80

Unit: ton.

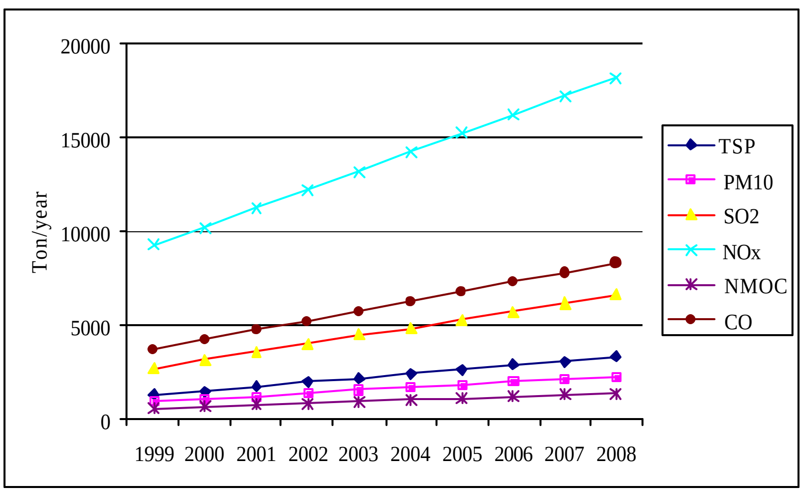

Figure 7.30. Industrial point air pollutant emission forecast, 1999-2008, Scenario 3a.

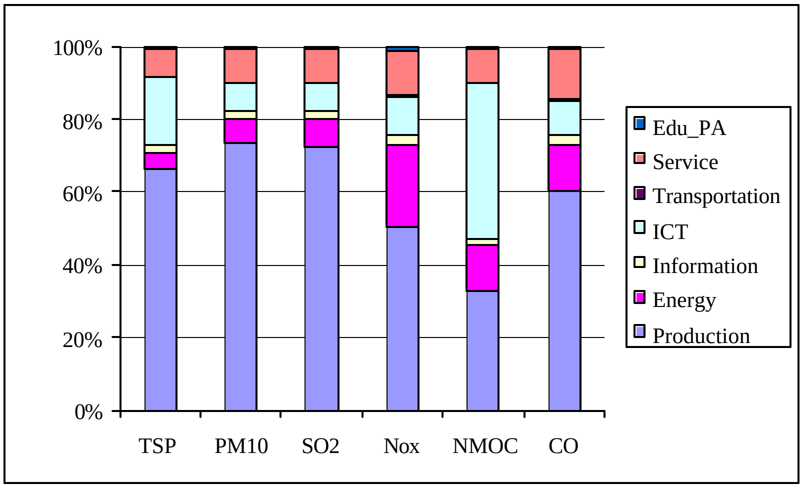

Figure 7.31 Segment contributions to the total emissions, 2008, scenario 3a.

Table 7.31. Forecast emissions in 2008: Scenarios 1a vs. 3a

	Scenario 1a Ton/year	Scenario 3a Ton/year	Difference
TSP	2029.04	3284.28	38.22%
PM_{10}	3593.37	2243.25	-60.19%
SO_2	3768.40	6561.03	42.56%
NO_X	13331.36	18153.59	26.56%
NMOC	2680.97	1355.40	-97.80%
CO	22058.82	8285.80	-166.22%

2 Scenario 3b

The simulation results of this scenario are listed in Table 7.32 and Figures 7.32 - 7.33. In 2008, the forecast emissions of all the pollutants under this scenario will be higher than those under 3a due to the differences in Leonitef inverse matrices (Table 7.33).

Table 7.32. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 3b

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.033	1745.14	2059.49	2344.82	2630.15	2915.48	3200.81	3486.14	3771.47	4056.06
PM_{10}	898.6434	1328.21	1541.25	1742.14	1943.03	2143.91	2344.80	2545.69	2746.58	2946.83
SO_2	2671.431	4013.80	4648.11	5245.62	5843.14	6440.66	7038.17	7635.69	8233.21	8828.77
NO_X	9223.133	16616.04	18858.25	20939.10	23019.94	25100.78	27181.63	29262.47	31343.31	33414.27
NMOC	546.9729	891.07	1051.70	1187.87	1324.04	1460.22	1596.39	1732.56	1868.74	2004.48
CO	3653.522	5907.19	6783.25	7601.81	8420.37	9238.92	10057.48	10876.04	11694.60	12510.04

Unit: ton.

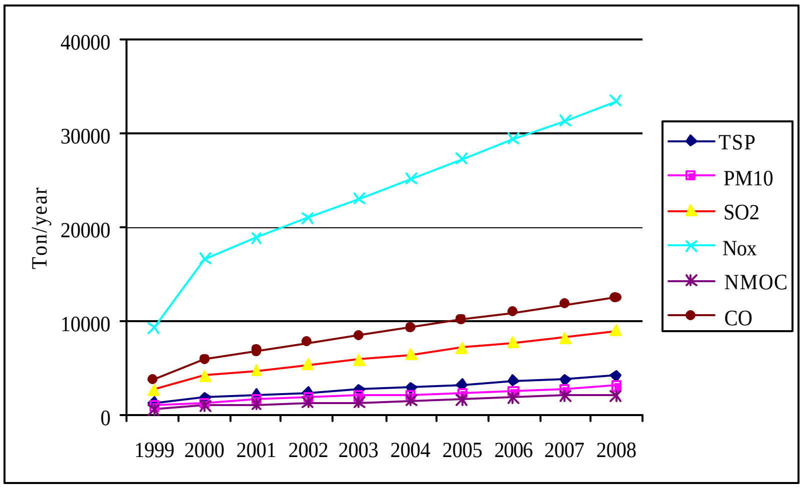

Figure 7.32. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 3b.

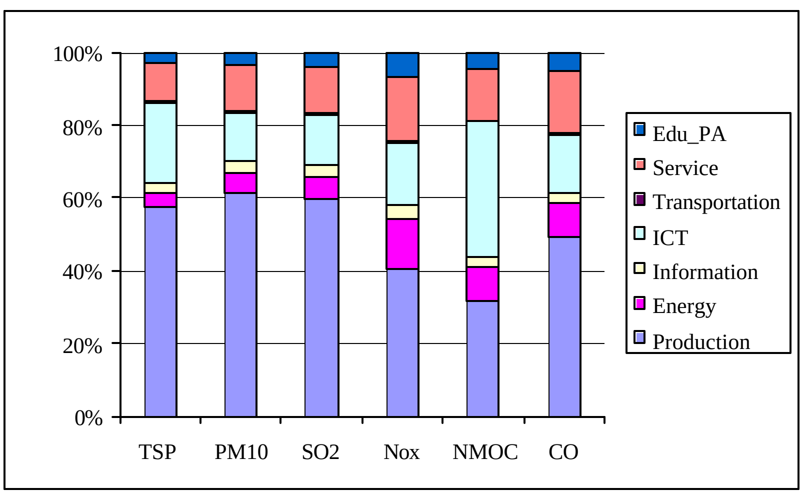

Figure 7.33. Segment contributions to the total emissions, 2008, scenario 3b.

Table 7.33. Forecast emissions in 2008: Scenarios 3a vs. 3b

	Scenario 1a Ton/year	Scenario 3a Ton/year	Difference
TSP	3284.28	4056.06	19.03%
PM_{10}	2243.25	2946.83	23.88%
SO_2	6561.03	8828.77	25.69%
NO_X	18153.59	33414.27	45.67%
NMOC	1355.40	2004.48	32.38%
CO	8285.80	12510.04	33.77%

7.5.4 Scenario 4: Fixed direct pollution coefficients with moderate final demand growth rate

This scenario assumes that the annual growth rate of the final demand between 1999 and 2008 will be half of the 1990s' average, and the direct pollution coefficients are assumed to be the same as those of 1999. Based on these assumptions, the average annual final demand growth rate of each segment is calculated first, and then the future emissions are extrapolated by multiplying the known 1999 total emissions with half of the average final demand growth rate of 1990 - 1999.

1 Scenario 4a

Scenario 4 is based on a much slower growth rate of the final demand than that of Scenario 3. Thus the total emissions in 2008 under scenario 4 are forecast to be much lower than those of Scenario 3 (Table 7.34, Figure 7.34). The segment contributions to the total emissions in 2008 are displayed in Figure 7.35.

Table 7.34. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 4a

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1342.30	1456.56	1570.83	1685.09	1799.35	1913.62	2027.88	2142.14	2256.16
PM_{10}	898.64	973.37	1048.09	1122.81	1197.53	1272.26	1346.98	1421.70	1496.42	1570.95
SO_2	2671.43	2887.59	3103.74	3319.89	3536.05	3752.20	3968.36	4184.51	4400.66	4616.23
NO_X	9223.13	9719.47	10215.80	10712.13	11208.47	11704.80	12201.13	12697.47	13193.80	13688.36
NMOC	546.97	591.89	636.82	681.74	726.66	771.58	816.50	861.42	906.35	951.18
CO	3653.52	3910.95	4168.39	4425.82	4683.25	4940.68	5198.11	5455.55	5712.98	5969.66

Unit: ton.

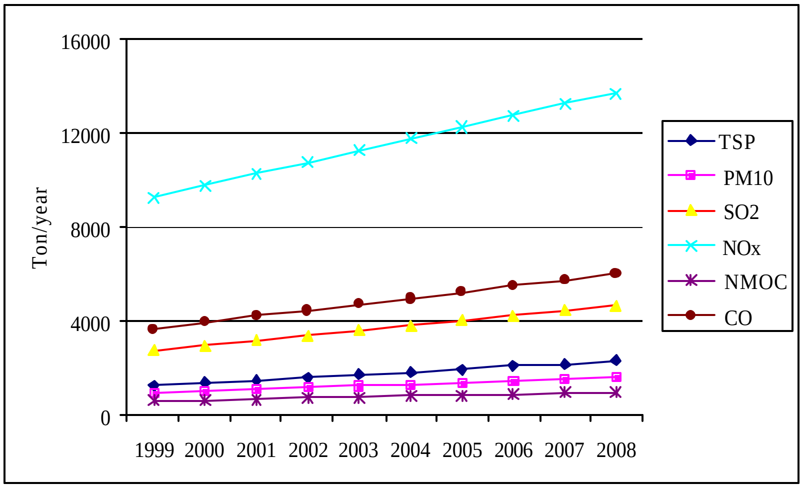

Figure 7.34. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 4a.

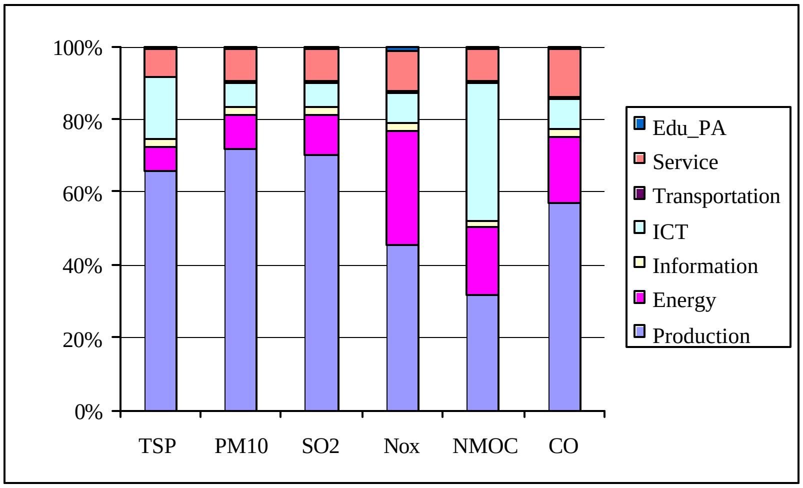

Figure 7.35. Segment **c**ontributions to the total emissions, 2008**,** Scenario 4a.

2 Scenario 4b

The simulation results of Scenario 4b are provided in Table 7.35 and Figures 7.36 - 7.37. The difference between Scenarios 4a and 4b is shown in Table 7.36.

Table 7.35. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 4b

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
TSP	1228.03	1631.49	1774.16	1916.82	2059.49	2202.16	2344.82	2487.49	2630.15	2772.44
PM_{10}	898.64	1239.92	1340.36	1440.81	1541.25	1641.70	1742.14	1842.58	1943.03	2043.15
SO_2	2671.43	3751.83	4050.59	4349.35	4648.11	4946.87	5245.62	5544.38	5843.14	6140.92
NO_X	9223.13	15736.99	16777.41	17817.83	18858.25	19898.68	20939.10	21979.52	23019.94	24055.42
NMOC	546.97	847.44	915.52	983.61	1051.70	1119.78	1187.87	1255.96	1324.04	1391.91
CO	3653.52	5555.41	5964.69	6373.97	6783.25	7192.53	7601.81	8011.09	8420.37	8828.08

Unit: ton.

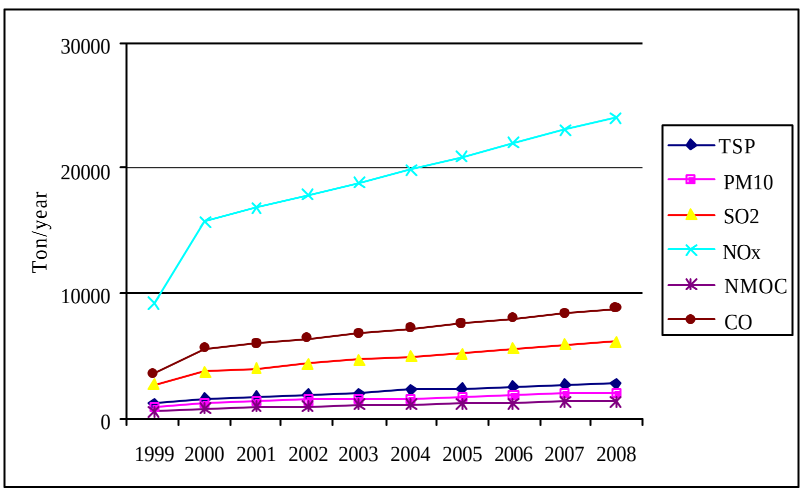

Figure 7.36. Industrial point air pollutant emission forecast, 1999 - 2008, Scenario 4b.

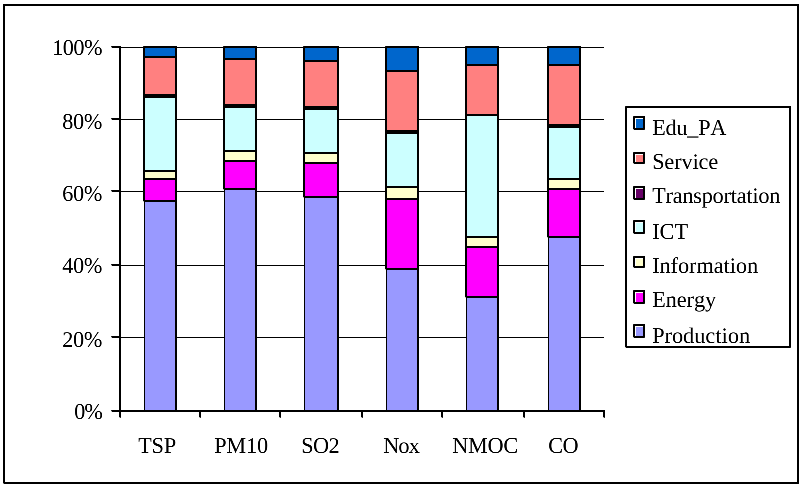

Figure 7.37. Segment contributions to the total emissions, 2008, Scenario 4b.

Table 7.36. Forecast emissions in 2008: Scenarios 4a Vs. 4b

	Scenario 4a Ton/year	Scenario 4b Ton/year	Difference
TSP	2256.16	2772.44	18.62%
PM_{10}	1570.95	2043.15	23.11%
SO_2	4616.23	6140.92	24.83%
NO_X	13688.36	24055.42	43.10%
NMOC	951.18	1391.91	31.66%
CO	5969.66	8828.08	32.38%

7.5.5 Forecast accuracy

It is a common practice to examine the accuracy of the forecast results. Three years of emission inventory data (2000, 2001, and 2002) are available for checking the accuracy of the forecast results. The comparison between actual and simulated total emissions of the years 2000 to 2002 is presented in Tables 7.37 - 7.40 and Figures 7.38 - 7.43. The simulated results from Scenarios 1b, 2b, 3b, and 4b are not used for error checking because the 1990 Leontief matrix is far less realistic than that of the 1999. The residual standard deviation (r) of all the pollutants for each of the four scenarios was calculated, and the results are presented in Table 7.41. The formula used to calculate residual standard deviation is as follows:

$$r_a = \frac{\sum_{i=1}^{k} \sqrt{\frac{\sum_{t=1}^{n} (X_{mt} - 1)^2}{n}}}{k} \tag{7.3}$$

$$X_{mt} = \frac{Y_{ft}}{Y_{mt}} \tag{7.4}$$

Where

r_a : residual standard deviation of scenario a, a = 1-4

X_{mt} : ratio of forecast emission and actual emission

n : n = 1-3

k : type of pollutant, k =1-6

Y_{ft} : forecast emission at time t

Y_{mt} : actual emission at time t

The results in Table 7.41 indicate that Scenario 2a has the best estimation (having the smallest r value). The result is under expectation because it is closer to the actual situation to assume a moderate final demand growth rate and to assume the direct pollution coefficients to be the same as the 1990 average. It is also noticeable that emissions of 2001 are significantly lower than those of the years of 2000 and 2002 in terms of the inventory data, but no reasonable explanation could be easily obtained.[8]

There are both overestimations and underestimations of the actual emissions in each of the scenarios forecast.

Table 7.37. Actual vs. forecast total emissions, 2000 - 2002, Scenario 1a

	2000 forecast	2000 actual	Forecast error	2001 forecast	2001 actual	Forecast error	2002 forecast	2002 actual	Forecast error
TSP	1435.84	1644.90	-12.71%	1685.09	1344.40	25.34%	1913.62	1929.50	-0.82%
PM_{10}	1042.89	1108.50	-5.92%	1197.53	945.80	26.62%	1346.98	1270.70	6.00%
SO_2	3088.28	2761.90	11.82%	3536.05	2672.10	32.33%	3968.36	3035.10	30.75%
NO_X	10155.84	9845.70	3.15%	11208.47	9294.80	20.59%	12201.13	10424.90	17.04%
NMOC	616.77	932.00	-33.82%	726.66	840.50	-13.54%	816.50	1227.40	-33.48%
CO	4143.47	5667.60	-26.89%	4683.25	5393.70	-13.17%	5198.11	8293.50	-37.32%

Table 7.38. Actual vs. forecast total emissions, 2000 - 2002, Scenario 2a

	2000 forecast	2000 actual	Forecast error	2001 forecast	2001 actual	Forecast error	2002 forecast	2002 actual	Forecast error
TSP	1342.30	1644.90	-18.40%	1456.56	1344.40	8.34%	1570.83	1929.50	-18.59%
PM_{10}	973.37	1108.50	-12.19%	1048.09	945.80	10.81%	1122.81	1270.70	-11.64%
SO_2	2887.59	2761.90	4.55%	3103.74	2672.10	16.15%	3319.89	3035.10	9.38%
NO_X	9719.47	9845.70	-1.28%	10215.80	9294.80	9.91%	10712.13	10424.90	2.76%
NMOC	591.89	932.00	-36.49%	636.82	840.50	-24.23%	681.74	1227.40	-44.46%
CO	3910.95	5667.60	-30.99%	4168.39	5393.70	-22.72%	4425.82	8293.50	-46.64%

Table 7.39. Actual vs. forecast total emissions, 2000 - 2002, Scenario 3a

	2000 forecast	2000 actual	Forecast error	2001 forecast	2001 actual	Forecast error	2002 forecast	2002 actual	Forecast error
TSP	1393.54	1644.90	-15.28%	1570.57	1344.40	16.82%	1699.10	1929.50	-11.94%
PM_{10}	1295.16	1108.50	16.84%	1680.48	945.80	77.68%	2040.21	1270.70	60.56%
SO_2	2924.57	2761.90	5.89%	3159.98	2672.10	18.26%	3335.18	3035.10	9.89%
NO_X	10044.93	9845.70	2.02%	10856.49	9294.80	16.80%	11490.07	10424.90	10.22%
NMOC	681.10	932.00	-26.92%	887.94	840.50	5.64%	1094.87	1227.40	-10.80%
CO	4975.37	5667.60	-12.21%	6571.45	5393.70	21.84%	8363.56	8293.50	0.84%

Table 7.40. Actual vs. forecast total emissions, 2000 - 2002, Scenario 4a

	2000 forecast	2000 actual	Forecast error	2001 forecast	2001 actual	Forecast error	2002 forecast	2002 actual	Forecast error
TSP	1306.40	1644.90	-20.58%	1370.53	1344.40	1.94%	1420.41	1929.50	-26.38%
PM_{10}	1230.43	1108.50	11.00%	1551.82	945.80	64.08%	1862.82	1270.70	46.60%
SO_2	2734.09	2761.90	-1.01%	2773.73	2672.10	3.80%	2790.34	3035.10	-8.06%
NO_X	9635.03	9845.70	-2.14%	9985.89	9294.80	7.44%	10275.73	10424.90	-1.43%
NMOC	654.31	932.00	-29.79%	773.80	840.50	-7.94%	905.44	1227.40	-26.23%
CO	4688.48	5667.60	-17.28%	5834.49	5393.70	8.17%	7091.54	8293.50	-14.49%

Table 7.41 Standard deviation of forecast emissions (Actual value = 1)

	TSP	PM_{10}	SO_2	NOx	NMOC	CO	Average RSD
1a	0.20	0.20	0.33	0.19	0.35	0.34	0.27
2a	0.19	0.14	0.14	0.07	0.44	0.17	0.20
3a	0.18	0.71	0.15	0.14	0.21	0.18	0.26
4a	0.24	0.57	0.06	0.06	0.29	0.17	0.23

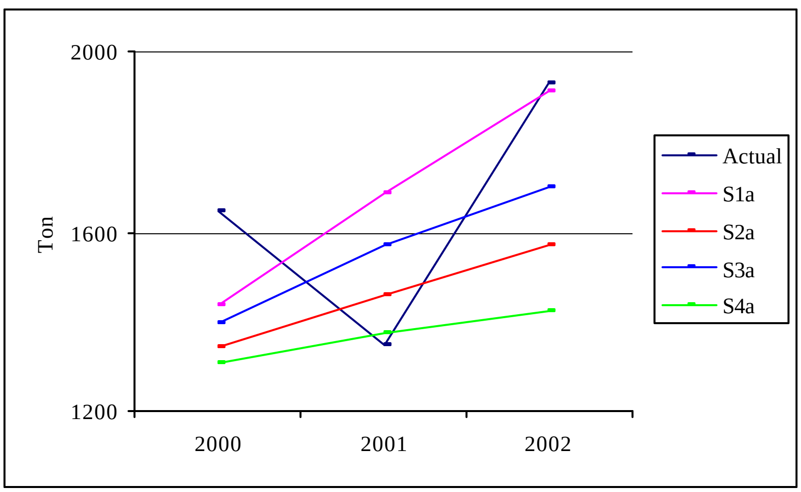

Figure 7.38. Actual vs. forecast TSP emissions, 2000 - 2002.

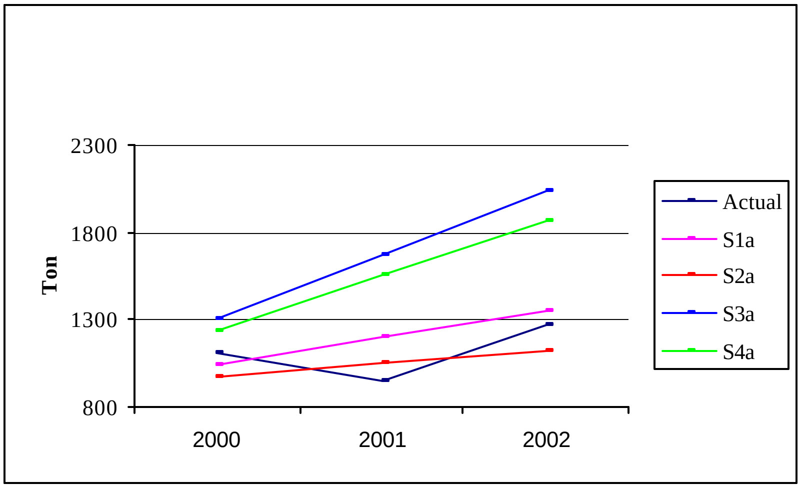

Figure 7.39. Actual vs. forecast PM_{10} emissions, 2000 - 2002.

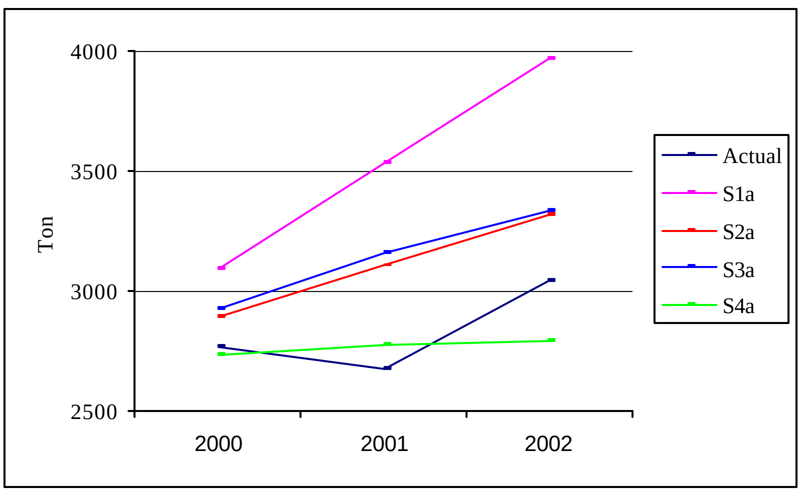

Figure 7.40. Actual vs. forecast SO_2 emissions, 2000 - 2002.

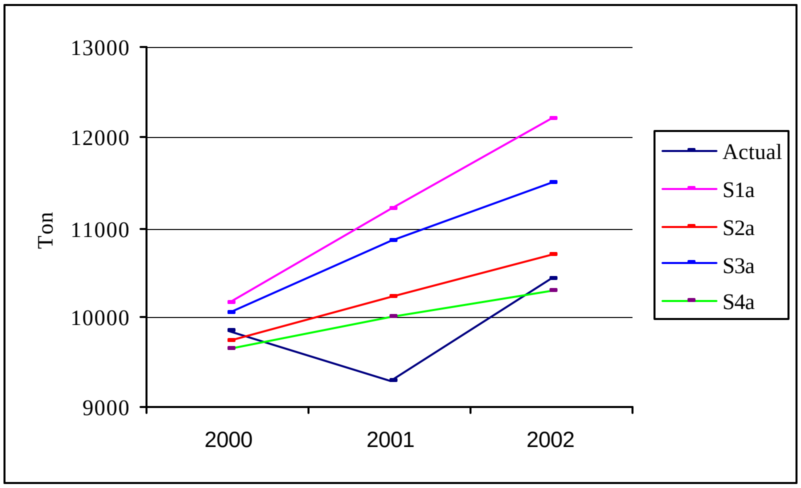

Figure 7.41. Actual vs. forecast NO_x emissions, 2000 - 2002.

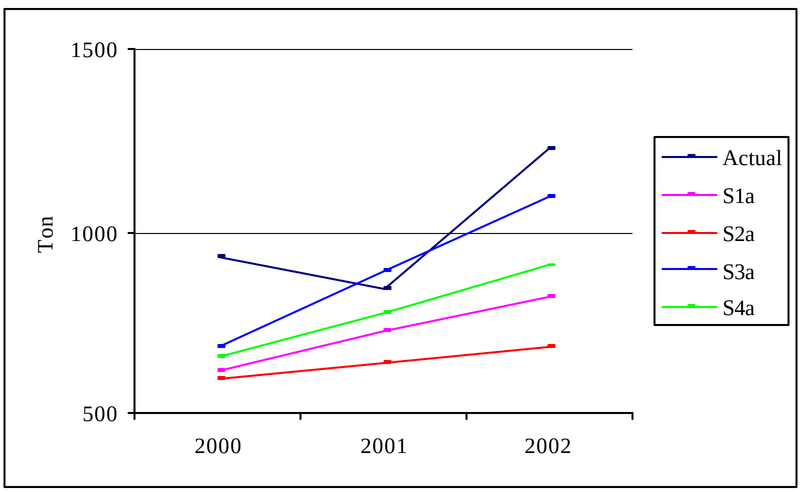

Figure 7.42. Actual vs. forecast NMOC emissions, 2000 - 2002.

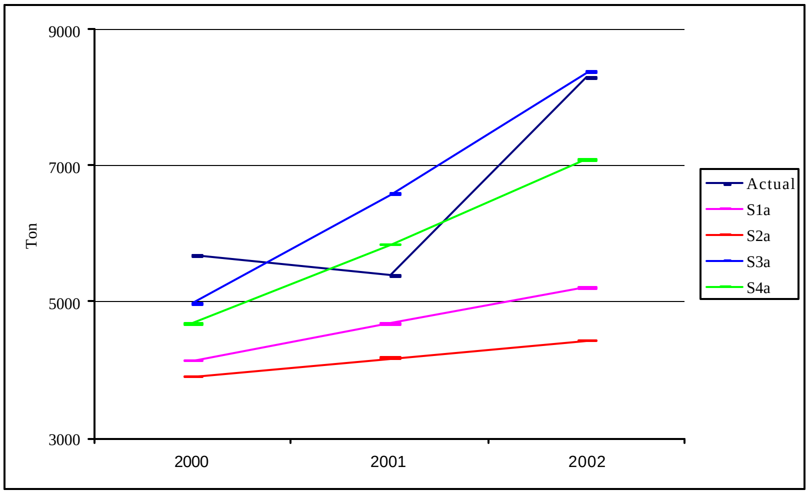

Figure 7.43. Actual vs. forecast CO emissions, 2000 - 2002.

7.6 Summary

7.6.1 Trends of industrial point air pollutants emission in the Austin MSA, 1990 - 1999

The economic and environmental data are linked by an environmentally extended I-O model to explore the environmental impacts of the emerging digital economy in the Austin MSA during the 1990s. It has been demonstrated that EIO can effectively facilitate this type of comprehensive analysis. By examining the direct and total pollution coefficients using three years of EIO models, the contributors to the growth of the pollutant emissions using the SDA, and the quantity and pattern of pollutant emissions by the year of 2008 using linear extrapolation, the environmental consequences of economic structure change have been gradually, if not completely, unfolded at least from angle of the changing pattern of industrial point pollutant emissions.

The results clearly indicate that the technological advancement and the economic structural transformation do help relieve the burden of the industrial point pollution in general in the Austin MSA during the 1990s. The direct pollution coefficients decreased substantially in most of the economic segments, suggesting the decoupling of the pollutant emissions from the manufacturing processes. But the increasing of the direct pollution coefficients of NO_x and NMOC in the second interval of the 1990s, the monotonic increase of CO may also indicate the unstable conditions or uneven development in technological advancement for the different pollutants and economic segments. Decreasing technical coefficients also suggest that the Austin's economy is more "clean" and more "efficient" as it evolves toward the digital economy.

Since five out of the six direct pollution coefficients of the energy segment increased from 1990 to 1999, it might indicate a significant change in terms of fuel mixture in the energy segment, but the conclusions cannot be made, and further investigation is needed. Although the production segment remains the most substantial contributor to most of the pollutant emissions, its relative contribution is declining. On the other hand, the final demand is playing an increasingly important role as the indirect contributor to the emissions. Increasing household consumption, government spending, and exports require more production, which may be consequently translated into more emissions as the byproducts of the manufacturing process. Substantial growth of the final demand has been observed in the household consumption, the government consumption, and the exports in the production, energy, ICT, and service segments. It is thus not unfair to charge the rapid growth of the final demand to be the major contributor of the growth of the pollutant emissions in emerging digital economy in the Austin MSA.

It is also noticeable that only a few economic segments are responsible for the airborne emissions from industrial point sources in the Austin MSA during the period studied. The direct pollution coefficients of the new rising economic segments, such as information, ICT, and service, are generally lower than those of the traditional segments such as production and energy. However, the total environmental impacts of these new rising segments are still substantial. And in some cases, they are even comparable to the impacts from the traditional segments due to their tight economic linkage and significant shares of total output in the economy.

It is equally important to be aware of the source of the data which influences how the results of the study can be interpreted. The industrial point pollutant emission represents only a small portion of the total air emissions in the region, and the environmental data used in the analysis is not even the whole set of the industrial point emission data (only the facilities exceeding the report criteria). Non-point sources (such as household energy consumption and transportation vehicles) have also not been considered in the above analysis.

7.6.2 Perspective of point industrial emissions in the Austin MSA, 1999 - 2008

Four development scenarios are proposed to simulate the environmental consequences of the economic structure change using the IO analysis in the AUSTIN MSA from 2000 to 2008. IO has been approved to be an effective analytical tool for examining the complex segmental linkages and economic-environmental interrelationships along different growth trajectories, and 10 years is probably the longest reasonable simulation period for IO models considering the stability of the economic structure in a region.

Table 7.42 compares the simulated emissions of the six pollutants in four scenarios in the year of 2008. In general, the influence from the growth of the final demand is the most significant, while the other two factors may also cause remarkable changes to the total emissions in certain scenarios. Each segment is quite different in terms of the growth rate of the final demand and changing rate of direct pollution coefficients. The total emissions are actually the results of interactions of these factors.

Two points can be made concerning the segment contributions to the total emissions by the year of 2008. First, the segments of production, energy, ICT, and service are the four major contributors to the total emissions. In contrast, the contributions from the other three segments are too insignificant to be counted. Second, the patterns of relative contributions of the segments to a particular pollutant may be quite different in the four scenarios. The importance of one specific segment to the total emission of any one of the six pollutants is determined by the combined effects of the changing rate of direct pollution coefficients and the final demand (Leontief inverse is assumed to be the same). Figure 7.44 shows the different patterns of segment contributions to TSP emission in the year of 2008 under four different scenarios. The patterns for the rest of the pollutants are provided in Appendix 3.

IO analysis has been approved to be very helpful in investigating the environmental consequences of economic structure change. The study would be more valuable if the investigation could have been continued using more disaggregated environmental data. However, the inadequacy of data became a major obstacle of further investigation. In fact, the data issue (especially environmental-related data) is a common difficulty of all kinds of IO applications. Some researchers tried to use proxy data to estimate environmental data. For example, airborne pollutant emissions were estimated using energy consumption data. But these studies were conducted at national level where detailed survey data is more likely to be available and complete, rather than at regional or lower level of geographical region (Joshi 1998; Wier 1998; Matthews 1999; Kim 2002). According to the author's knowledge of the study area, county-level energy consumption data arranged by SIC is currently not available, preventing the further examination at more disaggregated geographical level.[9]

Table 7.42. Summary of simulation results, four scenarios in the year of 2008

	1999	2008 Scenario 1a	2008 Scenario 1b	2008 Scenario 2a	2008 Scenario 2b	2008 Scenario 3a	2008 Scenario 3b	2008 Scenario 4a	2008 Scenario 4b
TSP	1	1.65	2.01	1.23	1.48	2.67	3.30	1.84	2.26
PM_{10}	1	4.00	4.64	3.67	4.19	2.50	3.28	1.75	2.27
SO_2	1	1.41	1.76	0.99	1.23	2.46	3.30	1.73	2.30
NO_X	1	1.45	2.28	1.20	1.78	1.97	3.62	1.48	2.61
NMOC	1	4.90	6.52	3.36	4.44	2.48	3.66	1.74	2.54
CO	1	6.04	8.21	4.31	5.79	2.27	3.42	1.63	2.42

Note: Emissions of 1999 = 1, relative values.

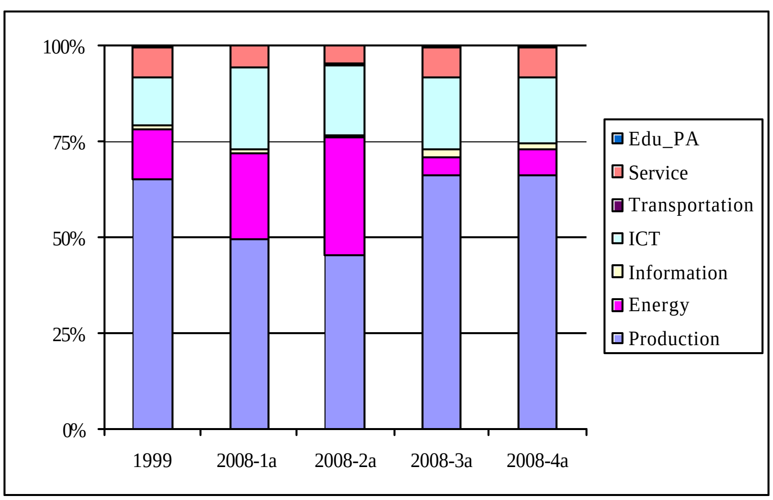

Figure 7.44. Segment contribution to TSP emission, 2008.

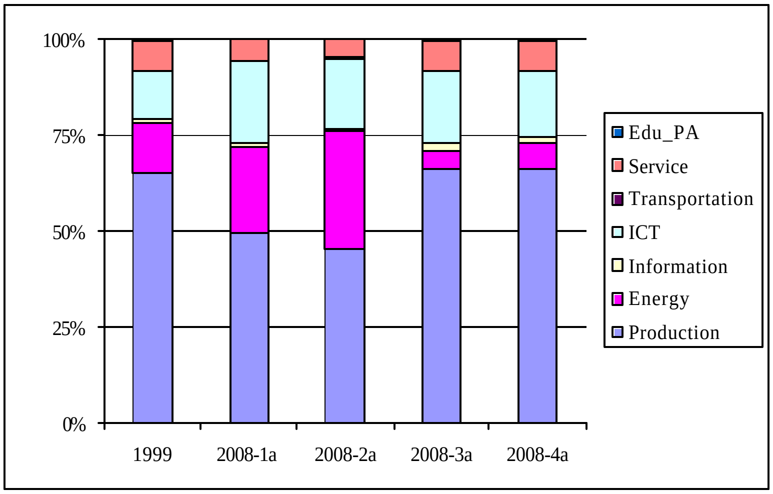

Figure 7.45. Segment contribution to PM_{10} emission, 2008.

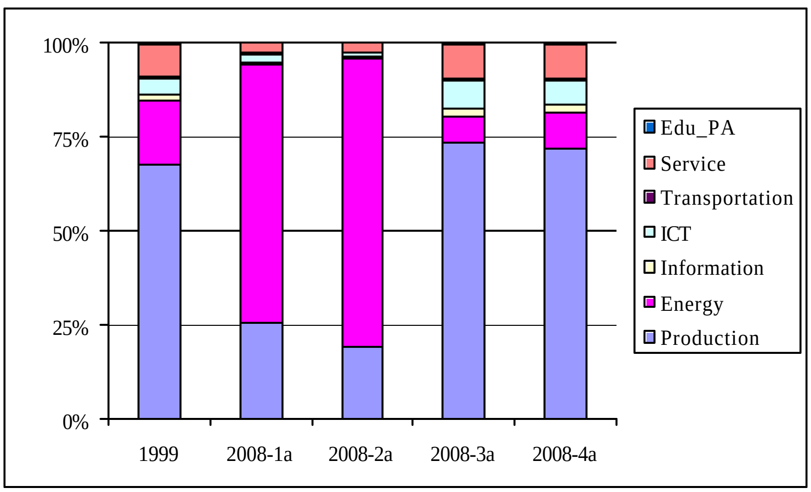

Figure 7.46. Segment contribution to SO_2 emission, 2008.

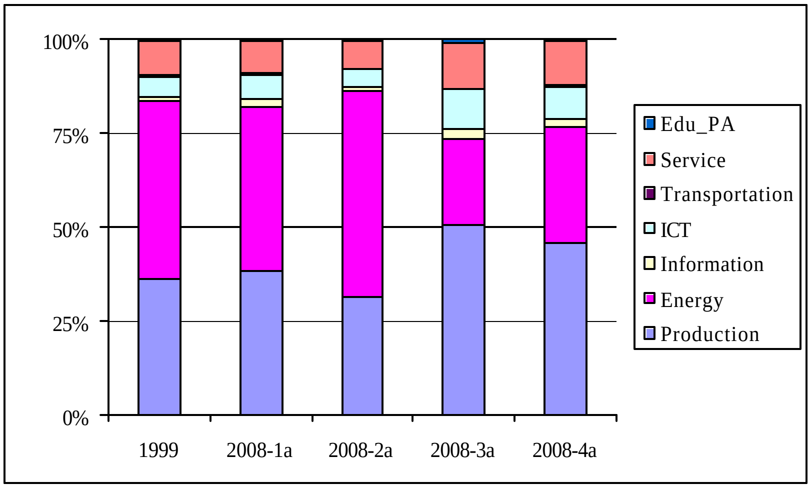

Figure 7.47. Segment contribution to NO_X emission, 2008.

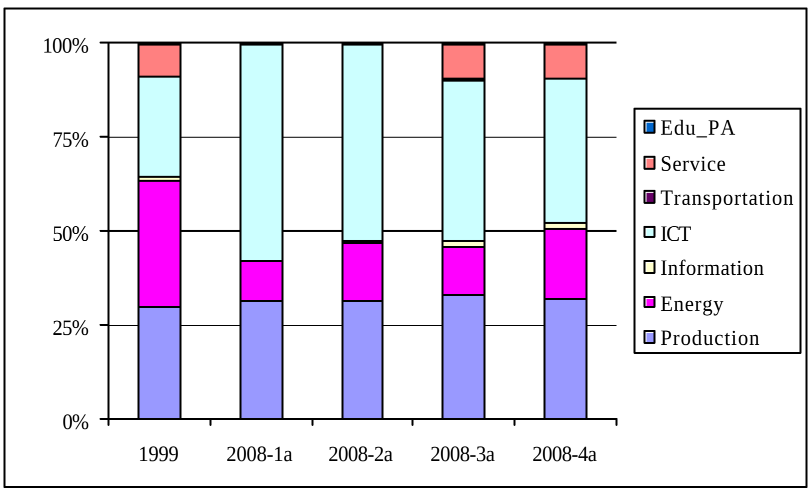

Figure 7.48. Segment contribution to NMOC emission, 2008.

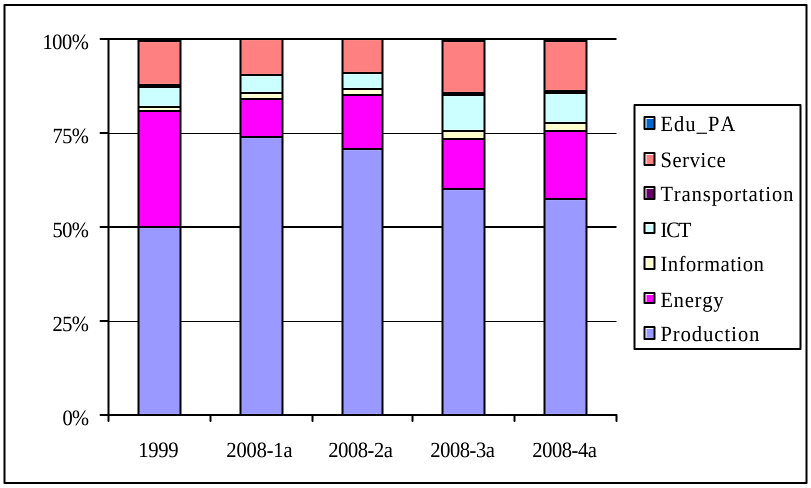

Figure 7.49. Segment contribution to CO emission, 2008.

Notes

1 Elasticity is calculated according to the following formula

$$E_i = (\Delta P^i / P^i_{1990}) / (\Delta Y / Y_{1990}) = ((P^i{}_{1999} - P^i{}_{1990}) / P^i{}_{1990}) / ((Y_{1999} - Y_{1990}) / Y_{1990})$$ Where

E_i : elasticity for pollutant *i*

P^i : emission of pollutant *i*

Y : final demand

2 The missing of emission data in the database can more likely to be interpreted by the fact that no source exceeds the reporting applicability levels required by TCEQ, rather than by the situation that no pollutants are discharged by the sources in the two segments.

3 A usual IO table generally records economic variables from 528 industries (each industry is equivalent to one three-four digit SIC-level segment).

4 All data are original except indicated otherwise.

5 The National Bureau of Economic Research defines "growth recession" as "a recurring period of slow growth in total output, income, employment, and trade, usually lasting a year or more." (NBER 2003).

6 Letters a and b are used to differentiate the scenarios using 1999 and 1990 Leontief inverse matrices respectively. For example, Scenario 1a uses the 1999 Leontief inverse matrix; Scenario 1b uses the 1990 Leontief inverse matrix, and so on.

7 The descriptions of Scenarios 2, 3, and 4 are focused on the unique situations. Similar information was skipped to keep the text tight and concise.

8 The author has asked the staff of TCEQ why there was a sudden decline of emissions in the Austin MSA but not in the entire state (of Texas) in 2001. No affirmative answer was obtained. One guess is that Austin was hit more heavily by the economic recession but rebounded more quickly than Texas on average. Further checking on relevant social and economic data is necessary to provide more convincing. (personal communication with Jim Parks, 16 May 2003).

9 " . . . Energy data at the county level by SIC does not exist . . ., in fact, even state by SIC does not exist in any government surveys . . ." (Personal communication with Robert Adler, Energy Information Agency, Department of Energy. June 2003).

CHAPTER VIII

DISCUSSION AND CONCLUSION

If I have not seen as far as others, it is because giants were standing on my shoulders.

- H. Abelson

8.1 Introduction

This study addresses the long-term environmental concerns in the context of the emerging digital economy and information age using well-developed IO analysis techniques on the regional scale. The dissertation contributes to the literature in two important ways. First, it strengthens the thin factual bases of debates concerning the environmental consequences and correspondent policy prescriptions of the digital economy. Second, it demonstrates how geographical knowledge can be combined with economic theories and methods to provide new insights into one of the principal questions of geography, human-environment interactions that have both puzzled and inspired geographers in the past one and half centuries (Marsh 1864; Thomas 1956; Pattison 1964; Wilbanks 1994; Turner 2002).

This chapter recaps methodological, theoretical, and policy-related issues of the study. It also makes final conclusions and briefly discusses the limitations of the study. This chapter and thus the dissertation end with some thoughts on the agenda of future study.

8.2 Discussion

8.2.1 Methodological implications

Methodologically, this dissertation centered on the IO analysis to examine the linkage between urban economic structure change and consequent environmental impacts. Major analytical tools include time series descriptive IO models, direct and total pollution coefficient matrices, hypothetical extraction measurement, and structural decomposition analysis. This dissertation has demonstrated that IO analysis is effective in investigating the complex environment-economy interactions among major segments of an economy in four aspects:

1) On the investigation of the trend of economic structure change, IO analysis provided macroeconomic accounts, technical coefficient matrices, and Leontief inverse matrices, and formed the basis of hypothetical extraction measurement. This analysis supplied solid evidence to explain the changing nature of the economic structure in the Austin MSA during the 1990s.

2) On the calculation of the pollution coefficients, IO analysis not only bridges the economy (sectoral outputs) and the environment (sectoral pollutant emissions), but also connects the direct and indirect effects of the economy to the environment. Patterns of pollutant emissions from major economic segments are clearly delineated with the help of IO analysis.

3) Static IO models were extended to examine the dynamics of the relative importance of three major contributors to the total pollutant emissions using structural decomposition analysis. SDA also made it possible to investigate the environmental

impacts of final demand, which is a long-overlooked but important factor influencing the environmental quality.

4) Four development scenarios have been simulated by taking the 1999 IO model as benchmark to forecast the quantities and patterns of pollutant emissions in the first decade of the 21st century (2000 to 2008). The linear nature of the IO model simplified the computational process, and provided an approachable method in examining the environmental consequences under various possible developing scenarios in the years to come.

IO analysis is, of course, just one of the gadgets in the magic toolbox of geographers, and the results from the linear model in most cases provide a somehow distorted image of the non-linear real world. However, IO analysis is a well-established and straightforward methodology that can be used to systematically model the perplexing economic and environmental interactions in an economic system with a large number of variables. In the light of the findings of the dissertation, IO analysis again distinguishes neoclassical economists' stylized, utilitarian methodologies in its bold simplification to highlight important variables and relationships in an economic system (Duchin 1998). In short, this dissertation has demonstrated that IO analysis is a valuable tool in quantifying complex economic-environment interactions from a macroeconomic perspective.

8.2.2 Theoretical implications

The theoretical implications of this dissertation are twofold: 1) to the substitutability between information and energy/material, and 2) to the emerging information ecology in the digital economy.

1 The substitutability between information and energy/material

The discussion about the substitutability between information and energy begins with the problem of Maxwell's Demon in physics in the late 19th century (Leff and Rex 1990). Maxwell's Demon challenged the second law of thermodynamics by claiming that information is able to generate free energy starting from a state of maximum entropy. The problem has been touched upon primarily with three approaches, in physics (e.g., of idealized models of our physical environment); in engineering (e.g., of descriptions of machines dedicated to particular tasks); and in economics (e.g., of national accounts and models of production and consumption (Spreng 1993). This dissertation explored the substitutability problem using the third approach.

Spreng (1993) argues that the substitutability between energy, time, and information can be observed in many instances, in parts of physics, engineering, and economics. He also argues that new information technology (NIT) can be used to substitute time and energy to improve the quality of life without adding stress to the environment (Spreng 1993, 23). Chen (1994, 26) contends that information could substitute for traditional production factors, such as capital, material, and energy, via its incorporation in the production factors and its combinations. He asserts that "the incorporation of information into the factors of production and their combinations is the major force behind the current tendency towards the dematerialization of the productive system." However, neoclassical economic theory is not capable of modeling information in its traditional framework. According to the neoclassical theory, a production factor has four intrinsic properties: divisibility, substitutability by other factors, complementarity with other factors, and independence vis-à-vis the others. Non-material information, on the other hand, is independent of any of the four factors.. It is neither additive; nor divisible, nor is it easily quantifiable, nor exhaustible. These characteristics of information make it difficult for scholars to analyze the substitutability between information and other production factors using traditional neoclassical economic theory.

Both Chen (1994) and Spreng (1993) suggest that one feasible way to examine the substitutability between information and energy without measuring information in its physical terms was to study the economic activities of a society. In fact, since the early 1960s, scholars have started to investigate the information activities by analyzing the national accounts of economy of the U.S. Machlup (1962, 1984) and Porat (1977) conclude that information activity was playing increasingly significant role in the U.S. economy. They argue that the U.S. has entered an information society. Machado (1994) demonstrate not only the trend of informatization, but also the possible substitutability between energy (output of energy segment) and information (output of information segment) using IO analysis in the U.S. economy between 1963 and 1987 (see also Machado and Miller 1997). These efforts indicate that IO analysis (national economic account analysis in general) is a approachable way to study the economic structure change and substitutability effects between segments in an economic system despite the difficulty in reaching a consensus on standard classification scheme of the economy.

In the context of Austin, the results from both the trends of input-output accounts and hypothetical extraction measurement support two conclusions: (1) there was a trend of informatization in the Austin MSA during the 1990s, (2) there existed substitution effects among input factors (e.g., information and energy/production) to produce per unit of output in economic segments, and increasing importance of information sector in the economy has demonstrated not only by the growth in the share of total output, but also by its share in the total input (both direct and indirect) to generate one unit of output for all the segments. In addition, decreasing requirements to inputs (both direct and indirect) from energy and production sectors to generate one unit of output for all the segments indicates the declining significance of the two segments in Austin's economy during the 1990s. In both three-and seven-segment models, the above arguments are valid except that inputs from production to energy segment increased.

The implication of the above discussion is that, even though information is not a direct (tangible) factor of production, and its abundance does not automatically cause the growth of production, the mastery of information may help transform abundant information into productivity. In the digital economy, the argument of substituting information for energy/materials (dematerialization) is not only possible, but also expected to slow down entropy degradation, although how to turn the idea into practice remains an open question. On the other hand, the interpretation of the implication has to be confined to the Austin MSA, additional analysis on various geographical scales is necessary before the implication should be generalized.

2 From industrial ecology to information ecology: A paradigm shift?

At the end of the 1980s, Frosch and Gallopoulos (1989) coined the term “industrial ecology” in order to treat the side effects of the “end of pipe” syndrome which became increasingly evident and acute after about two decades of the practice of the first generation of environmental policy. The ecological analogy of industrial process makes it possible not only to trace the flows and transformations of materials in all industrial processes, but also to integrate the waste fully into the web of industrial relationships. The accomplishments of industrial ecology have expanded the focus of the waste control from a manufacturing process into the entire life cycle of products.

In the past fifteen years or so, the methodological development of industrial ecology has been dominated by the functional approach, which focuses on the potential environmental effects that a product generates over its entire life cycle from cradle to grave. It is usually practiced via life-cycle analyses, total quality management, and design for environment of certain products or services. The functional approach measures all significant environmental flows and impacts by means of providing services, largely independent of the location of linked processes and any predefined temporal boundary. The primary objective of the approach is to compare alternative options (products and services) in terms of their environmental impacts by detailed documentation on the material and energy flows related to its suppliers, customers, stakeholders, and corporate partners (Sui 2003).

The regional approach was inspired by the analogy of food webs of ecological systems. Local-regional industrial ecosystems are collections of industrial actors in a geographically defined area. In an ideal situation, the actors form an ecosystem through co-operation and inter-dependency and use each other's waste material (recycling of matter) and waste energy (cascading of energy) for the inputs of raw materials and energy. In practice, the "eco-industrial parks" have been launched in the 1970s with a limited success (Erkman 1997; Sui 2003).

From its origin to the latest development, industrial ecology has always focused on the functional approach, aiming at optimizing material flows to minimize the resource input and waste generation. Compared to the rich empirical case studies using the functional approach, the regional approach is much less frequently adopted.

The emerging digital economy, however, is very likely to rely more on the flow of information than on the tangible goods and services, as demonstrated in this study as well as in some previous ones. The creation, transformation, and dissemination of information, the interactions and substitutability between information and energy/material flows are exerting great impacts on the environment of the physical world, although little is known about the cause-and-effect relationships among these complex relations.

The unbalanced use of the two approaches of the industrial ecology becomes more of a problem due to the fundamental difference between the digital and industrial economy in terms of the material and information flow. If we confine our conceptualization solely to the metabolism of the physical part of the economy, we may not be able to capture the whole picture of the environmental impacts of the digital economy. The reconceptualization of the foundations of the industrial ecology is expected to provide a new analytic framework to better understand the interactions between flows of information, material, and energy and the consequent environmental impacts in the emerging digital economy and information age. There are two promising trends toward the evolution of the industrial ecology: 1) to integrate regional and functional approaches, that is, to set a clear spatial and temporal specification in units for functional approach; and 2) to pay more attention to information flows of the economy.

Information ecology is proposed to be an equivalent concept of industrial ecology in the digital economy to model complex information flows and their environmental impacts in the emerging digital economy (Sui 1998; Sui and Rejeski 2002). The term "information ecology" is first seen in the discussion of social and linguistic dimensions of information by social scientists who are interested in the social consequences of the information explosion (Harris 1989; Davenport and Prusak 1997; Nardi and O'Day 1999). The term is borrowed for the study of industrial ecology, referring to a new analytic framework extending from industrial ecology to explore the environmental impacts of not only material flows, but more importantly, information flows in the digital economy.

In the traditional industrial economy, our understanding of the environmental impacts of the economic development is dominated by the tyranny of a mechanistic scheme in a Cartesian framework, in which almost everything can be explained by a simple linear law taking the form of a statement with a single cause and consequent effect. The defining characteristics of the emerging digital economy challenge the conventional thinking on the environment and the economy for its deterministic, predictable, and mechanistic view. The latest research results from the theories of nonlinear dynamics and complexity may be more helpful in illuminating the convoluted relationship between the digital economy and the environment. The information ecology is expected to go beyond the traditional wisdom to understand the interactions among information flows, industrial metabolism, and the environment with a nonlinear, complex, process-dependent, organic, and dynamic view.

The main instruments in the toolbox of industrial ecology are life cycle analysis (LCA), total quality control (TQC), and design for environment (DE). It may be premature to discuss the toolkit of information ecology because the subject is still in the stage of conceptualization. However, some insights can be drawn from the examination on the major approaches of industrial ecology, and LCA and IO analysis are two potential methods that can be inherited. LCA is proposed because it can act as an important analytical tool to investigate the complex interactions among information, energy, and material flows at the company/industry (microeconomic) level. IO analysis excels as another feasible choice because it is not only a well-developed method to model the interactions among information activities, material flows, and environmental inputs (and residuals) on various geographic and temporal scales, but it is also able to avoid the conceptual conflicts between primary properties of information and traditional production factors.

The benefits of the integration of the functional and regional approaches seem to be more obvious in the emerging digital economy. For the functional approach, a clear spatial and temporal specification in units will be beneficial because it assigns geographic meaning to LCA, which is important to compare the commonalities and differences of the results of LCA spatially. For the regional approach, the target of the analysis has to be disaggregated into certain material flow(s) between economic system components either in an entire regional economy or on specific segments within an economy. Systematic studies on how to synergistically integrate the two approaches to address challenging environmental problems in the digital economy is essential to the methodological frameworks of the information ecology.

Information ecology is yet a virgin field to be explored as a logical extension of industrial ecology. Expanding the concepts, theories, and methodological framework of industrial ecology to information ecology is a ground-breaking project. Erkman (1997) believed that a strong motive to ensure a lasting success for industrial ecology is aesthetic and elegant, quoting Ausubel's word "The goal of industrial ecology is a more elegant, less wasteful network of industrial processes" (Erkman 1997, 7). The goal of information ecology, then, can also be set to pursue more elegant, less wasteful networked industrial and information processes.

8.2.3 Policy implications

This dissertation provides insights for the new generation of environmental policies for the Austin MSA in particular and the U.S. in general in two major aspects: 1) goals and targets, 2) environment monitoring and regulatory instruments.

1 Goals and targets

The first generation of environmental policies was centered on the regulation of residuals from manufacturing processes featured by fragmented thoughts and practices. To a large extent, these laws and policies worked out. In the emerging digital economy, as targets of the policy shift from the production and consumption behavior of a few larger smokestack industries to millions of small enterprises and individuals, environmental problems generally become less painfully obvious, but are harder to quantify and more unpredictable, and more difficult to enforce. In addition, these problems are by no means fewer in quantity. As Socolow (1994) states, the environmental future “will be no less restless than our own.” The next generation of environmental policies has to address not only the effects of production processes, whether they are big smokestacks or atomized sources, but also ourselves, thousands of millions of consumers whose decisions about what to buy, where to live, how much to drive, and what to throw away are profoundly shaping the quality of our environment (Esty and Chertow 1997).

The new rising industrial ecology successfully extended the material/energy analysis from a manufacturing process into the whole life cycle of products, but it falls short in capturing the environmental consequences of information flows, which are closely related to the information generation, transformation, distribution, and interaction with other economic activities. Industrial ecology is still expected to play a critical role in dealing with the optimization of material flows in a product lifecycle, but it has to be complemented by the emerging information ecology to adapt the changing nature of the economy and the society in the digital economy and information age.

It is probably more appealing, morally logical, and relatively easier to require major pollution sources to pay for the cost of environmental damages as the first generation of environmental policy has done. However, it is essential but especially challenging to fashion a coalition to carry out a new generation of environmental policy when the target of regulation is millions of individual consumers and small businesses. On the one hand, a law is not only far less effective in changing the cultural values underlying the consumption of goods than the technology to produce these goods, but also less effective in influencing individual rather than cooperative behaviors. On the other hand, the expected high enforcement costs may prevent the effective implementation of laws and regulations. Thus the new generation of environmental policy must regulate the impacts of both production and consumption processes. The primary goal, minimizing the resource input and pollution generation and preventing resource depletion, must be supplemented by a second goal; that is, effectively influencing the consumption behavior of government, cooperations, and individuals to achieve sustainability.

2. Environment monitoring and regulatory instruments

There are two common problems in the current pollution monitoring systems, such as TCEQ's STARS and EPA's TRI. First, they are generally limited to manufacturing segments (i.e. TRI contains only the information of releases and other waste management activities of the facilities in manufacturing segments with SIC codes

20 - 39). Second, these environmental monitoring systems were designed to collect data from major industrial point sources (Both STARS and TRI have reporting applicability levels). High costs make it practically infeasible to monitor every single point source. One possible solution is to use social-economic data as a proxy for pollution estimation because they are usually more likely than environmental data to be collected systematically and extensively. For example, energy consumption and fuel mixtures data can be combined to estimate non-point air pollutant emissions.

Even the currently available environmental-related statistical data are not without any problems. First, these data tends to be available only at high levels of aggregation (both geographically and sectorally). Second, if disaggregated data are available in some unusual cases, they might not be organized by standard industrial classification schemes (e.g., SIC and NAICS). The direct consequence of these problems is the serious data mismatch and asymmetry between economic and environmental data, which becomes one of the major impediments to over-aggregate certain environmentally sensitive segments in particular and to quantify the economic-environment interactions in a more detailed manner in general. The problem can be partially addressed through more coordination, communication, and information exchange among various governmental agencies at the federal, state, and local levels, non-governmental environmental groups, private parties, and research institutes. In many cases, the data is not unavailable; it may simply not have been systematically organized, carefully edited, and properly stored in the right place and/or in an appropriate format. One bold solution to the problem is to create a new independent scientific agency to collect and disseminate data regarding to environmental and public health[1] (Esty and Chertow 1997).

In the digital economy, the top-down regulatory approach will continue to play an important role in the processes of environmental policymaking and implementation, but the bottom-up participatory policy needs to be strongly encouraged and strengthened to become an indispensable part of the next generation of environmental policies.

It is true that environmental protection should remain one of the major businesses of all levels of government, from federal, to state, to local. But it should also be the business of everybody, environmental groups, industries, businesses, community associations, and the general public. The CTSIP introduced in Chapter III is a promising initiative to encourage the general public to play their stewardship roles in the management of local environment.

New Environmental Protection Instruments (NEPIs) and Environmental Management Systems (EMSs) are suggested to be deployed and practiced in wider domains with a faster pace. Actually, not only have they been employed in many EU countries and Japan for quite a while, but they have caused "fundamental transition" in environmental policies in these countries (Golub 1998; Zito et al., 2003). NEPIs and EMSs are expected not only to be the supplemental instruments for environmental management, but more importantly, to help the conceptual transition from the traditional environmental government to environmental governance.

8.3 Conclusion

This dissertation has achieved three major objectives. The primary objective is to investigate the dynamics of economic structure change and consequent environmental impacts in the emerging digital economy and information age using the Austin MSA – a new rising high-tech hub in central Texas – as a case study. The relationship between economic structure change and point air pollutant emission has been analyzed, and four future development scenarios simulated. The second objective is to investigate the possibility and feasibility of using environmentally extended IO analysis in exploring complex environment-economic interactions in a very dynamic economic environment. This dissertation has not only demonstrated the applications and limitations of IO analysis, but also highlighted the values of SDA and HEM in investigating the regional environment-economic interactions. The third objective is to suggest guidelines for the new generation of environmental policies in the context of the emerging digital economy. This has been achieved by critically reviewing the advantages and disadvantages of the current generation of environmental policy and by the analysis of the defining characteristics of the emerging digital economy. These achievements are accomplished through three major steps. IMPLAN software has been used to construct IO models, and all the data analysis has been finished using Microsoft EXCEL.

Step one is the construction of the IO models. Both three-and seven-segment IO models for the years of 1990, 1994, and 1997 are constructed using IMPLAN after the IO tables have been collected and segmental classification schemes determined. These models form the basis for the following analysis and simulations.

Step two is IO-based analysis and modeling. Analysis based on input-output accounts, direct effects (technical coefficient matrices), and total effects (Leontief inverse matrices) have been performed to examine the trend of economic structure change during the 1990s. Hypothetical extraction measurement is implemented to compare the change of the relative importance of economic segments. Both direct and total pollutant coefficients have been calculated to examine how the quantity and patterns of pollutant emissions change with the transformation of the economic structures. SDA is used to identify the major sources of pollutant emissions during the 1990s.

Step three is EIO-based simulation and forecast. Four development scenarios have been designed and simulated by the year of 2008 using a 1999 IO model as the benchmark. Future pollution emission patterns along various development trajectories are further forecasted and compared.

The dissertation has led to the following conclusions at the methodological, theoretical, and policy levels:

1) At the methodological level, this dissertation has demonstrated the utility of the (E)IO analysis for exploring the complex economic-environmental interactions. The integration of IO analysis, hypothetical extraction measurement, and SDA not only provide analytic handles for investigating the environmental impacts of the digital economy, but also enrich the collections of tools for geographers to launch studies on the problems of social, economic, and environmental interactions on various temporal and spatial scales. In practice, the environmental data is found to be less available as

geographical scale goes down to the state or county level, limiting the application of IO analysis.

2) At the theoretical level, three hypotheses about the environmental consequences of the digital economy: dematerialization, decarbonization, and the substitutability between information and energy/material, have been inexplicitly tested. The argument about the dematerialization and the substitutability between information and energy/material in manufacturing process in the emerging digital economy have been generally supported by two facts: the input of the information segment to all the segments increased, the input of the production segments [2] for all the segments decreased. Decarbonization has been substantiated by the fact that both direct and total pollutant coefficients declined during the 1990s in general.

This study concludes that the overall environmental impacts of the emerging digital economy at the Austin MSA were benign during the 1990s from the perspective of macroeconomics. In the first decade of the 21st century (by the year 2008), assuming a moderate final demand growth rate and repeating the changing rate of direct pollutant emission coefficients of the 1990s, SO2, NO, NMOC, and TSP are expected to have moderate growth, PM_{10} and CO, the other two pollutants with the highest emission elasticity in the 1990s, are expected to have relatively high growth rates.

While the manufacturing processes tends to be more environmentally friendly, the rapid growth of final demands has been proven to contribute increasingly to the pollutant emissions in the Austin economy, offsetting the environmental gains from the technological advancement and economic structure changes. Thus environmental impacts from the demand side deserve more theoretical and practical studies of scholars and more policy considerations of regulators.

3) At the policy level, the dissertation argues that the first generation of environmental policies has to be reformed in order to adapt the changing nature of environmental problems in the dynamic digital economy. Information ecology is proposed to be the equivalent of industrial ecology in industrial economy to direct the continuous explorations on the environmental impacts of the digital economy featured by the rising significance of information flows.

In the case of Austin MSA, environmental impacts of the ICT segment are worth more intimate attentions from policymakers. First, the ICT segment is playing an increasingly important role in the local economy. Second, many negative environmental impacts of the ICT segment tend to be indirect, subtle, and potentially last longer.

Policymakers in Austin can learn a great deal from the experience of the Silicon Valley, an area dominated by the ICT segment and established its high-tech image a decade earlier than the Austin MSA. In the Silicon Valley, the leaking of toxic chemicals from underground storage tanks of those high-tech companies has caused substantial regional groundwater contamination. The establishment of the Silicon Valley Toxics Coalition (SVTC) was the direct response to the rising social, environmental, and public health concerns of the general public in the Silicon Valley region. SVTC has been playing an important role in four aspects, (1) advance environmental sustainability and clean production, (2) improve community health, (3) promote environmental and social justice, and (4) ensure democratic decision-making for communities and workers affected by the high-tech revolution in Silicon Valley and other high-tech areas of the US and the world.

As the new rising Silicon Hills, the potentially negative impacts of the ICT segment have neither been fully understood, nor received enough attention from the local government. These problems may simply have been overwhelmed by unprecedented economic achievements in the past 10 to 15 years. The annual reports of CTTSIP, the first initiative to promote the sustainability of the region, have not emphasized the significant social, economic and environmental impacts of ICT either (CTSIP 2003). In addition, some negative consequences of the development of ICT (high-tech industries in general) have already been reported. One study accuses the fast high-tech development of the direct cause of the increasing social inequity and spatial segregation in the region during the 1990s (Lee 2002).

8.4 Limitation

Input-output analysis offers a practical approach to explore the trend of economic structure change and to evaluate the possible environmental consequences of the emerging digital economy. The method, however, suffers the same drawbacks as other published researches using the same approach. The study itself, just like any other great or mediocre study, has its limitations. I'd like to call attention to at least the following four limitations:

First, the assumption of linearity between sectoral output and emissions has been maintained in the study. The linearity nature of IO models posed limitations on the results of the study because the assumption is more likely not hold in the mostly non-linear real world. The author is fully aware that the results and conclusions of the study are only imperfect representation of what are happening in the real world.

Second, the environmental data in empirical parts of the dissertation are based on the point industrial air pollutant emissions, which represent only a portion of, rather than the total set of the air pollutant emissions of the region. Point sources not exceeding the report criteria, non-point sources emissions (e.g., emissions from transportation vehicles), and emissions related to direct household energy consumptions (e.g., energy consumed for household cooling and heating) have not been considered in the analysis due to the difficulties in data collection. Thus the conclusions must be interpreted carefully, and further generalization of the conclusions may not be applicable and appropriate.

Third, although highly aggregated IO models are able to provide valuable insights on the general trends of the economic structure change and the correspondent environmental consequences, they are not able to supply more detailed economic and environmental information at much less disaggregated segmental level, especially on those environmentally sensitive segments. The asymmetry of the economic and the environmental data is the cause of the limitation. Anther major disadvantage of the lack of less aggregated models is that it is impossible to apply sensitivity analysis. And sensitivity analysis is important in examining the stability of the results of IO analysis, which are sensible to level of aggregation in many cases.

Fourth, it would be ideal if longer time series data were available (e.g., starting from 1980). Economic data (IO tables) are more accessible, time-series data of the 1980s or even earlier are usually not difficult to obtain. The problem is the general dearth of related environmental data. To this study, the industrial point emissions data earlier than the year of 1990 (and almost all the other environmental data set at the MSA level at least in Texas) are unfortunately not available and/or inaccessible. The ten-year span is the longest time series that can be possible to achieve in this study, and the reliability and applicability of the results are unfortunately diminished due to this limitation.

8.5 Future research agenda

The study has sketched only the outline, rather than painted the full picture of the environmental impacts of the emerging digital economy. The future study will be continued along the following directions:

1) The similar study will be extended on both higher or lower geographic scales (e.g., on county, state, multi-state, and country levels).

2) The methodologies will be applied on other types of ecological inputs (e.g., water use) and ecological outputs (e.g., toxic chemicals released).

3) SDA will be implemented at a more disaggregated level; e.g., including energy mix and level to supply more detailed evidences on the interactions among economic structure change, energy use, and environmental consequences if relevant environmental and economic data are available.

4) Household lifestyle options and their impacts on the environment will be further investigated. This is actually one of the major themes of Duchin's structure economics (Duchin 1998), which eagerly calls for more detailed study on household consumption behavior. Comprehensive understandings on the environmental implications of lifestyles will offer an opportunity to identify the environmental consequences of the economic structure change from the demand, rather than the supply side, which forms one of the major themes of the next generation of environmental policy.

The ultimate solutions to the environmental problems, however, have to touch the very heart of societal norms such as lifestyles, equity, cultural identities, social values (e.g., publicly recognized expectations), and social motivations (e.g., moral beliefs and values systems). These issues can not be easily solved by either harsh regulations, or by advanced science and technology, and ethical and philosophical considerations then surface as essential to answer these normative questions. At the very end of the study, I suddenly sensed that I have the answer for a question that has puzzled me since the first day as a Ph.D. student; that is, why the dissertation is the partial requirement for the degree of Doctorate of Philosophy, not of Geography, Environment, Economics, or any other discipline.

Notes

[1] The name of the new agency has been suggested to be Bureau of Environmental Indicators and Statistics.

[2] Production segments include production and energy segments in three segments models. In seven-segment model, production segments includes to all the segments except for information, service, and Edu_PA.

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APPENDIX A

DESCRIPTIONS OF ECONOMIC SEGMENTS

Three Austin I-O tables, 1990, 1994, and 1999 are used as original data sources. Each of the three tables is actually a 528 by 528 matrix. The sectors in the tables are grouped into more aggregated segments to capture the major feature of Austin economy. Detailed description about seven segments economy is provided, for the three-segment aggregation, only IO table record number is provided since the sectors are the same as in the seven-segment aggregation.

1 Seven-segment aggregation

Table A.1 Education and public administration (10 sectors)

IO table record No.	Description	87 SIC code
495	ELEMENTARY AND SECONDARY SCHOO	8210
496	COLLEGES, UNIVERSITIES, SCHOOL	8220
498	JOB TRAININGS & RELATED SERVIC	8330
499	CHILD DAY CARE SERVICES	8350
512	OTHER STATE AND LOCAL GOVT ENT	--
515	OTHER FEDERAL GOVERNMENT ENTER	--
519	FEDERAL GOVERNMENT - MILITARY	--
520	FEDERAL GOVERNMENT - NON-MILIT	--
522	STATE & LOCAL GOVERNMENT - EDU	--
523	STATE & LOCAL GOVERNMENT - NON	--

Table A.2 Energy (8 sectors)

IO table Record No.	Description	87 SIC code	Note
37	COAL MINING	1200	
38	NATURAL GAS & CRUDE PETROLEUM	1310	
39	NATURAL GAS LIQUIDS	1320	
213	LUBRICATING OILS AND GREASES	2992	
443	ELECTRIC SERVICES	4910	Also part of 4930
444	GAS PRODUCTION AND DISTRIBUTIO	4920	Also part of 4930
511	STATE AND LOCAL ELECTRIC UTILI		Part of 4910
512	OTHER STATE AND LOCAL GOVT ENT	--	

Table A.3 ICT (17 sectors)

IO table Record	Description	87 SIC code
267	NONFERROUS WIRE DRAWING AND IN	3357
339	ELECTRONIC COMPUTERS	3571
340	COMPUTER STORAGE DEVICES	3572
341	COMPUTER TERMINALS	3575
342	COMPUTER PERIPHERAL EQUIPMENT,	3577
343	CALCULATING AND ACCOUNTING MAC	3578
370	RADIO AND TV RECEIVING SETS	3651
372	TELEPHONE AND TELEGRAPH APPARA	3661
373	RADIO AND TV COMMUNICATION EQU	3663
374	COMMUNICATIONS EQUIPMENT NEC	3669
375	ELECTRON TUBES	3671
376	PRINTED CIRCUIT BOARDS	3672
377	SEMICONDUCTORS AND RELATED DEV	3674
378	ELECTRONIC COMPONENTS, N.E.C.	3675 3676 367
400	SEARCH & NAVIGATION EQUIPMENT	3812
402	AUTOMATIC TEMPERATURE CONTROLS	3822
473	EQUIPMENT RENTAL AND LEASING	7350

Table A.4 Information (13 sectors)

IO table Record	Description	87 SIC code
174	NEWSPAPERS	2710
175	PERIODICALS	2720
176	BOOK PUBLISHING	2731
178	MISCELLANEOUS PUBLISHING	2740
181	GREETING CARD PUBLISHING	2770
371	PHONOGRAPH RECORDS AND TAPE	3652
441	COMMUNICATIONS, EXCEPT RADIO A	4810 4820 4840
442	RADIO AND TV BROADCASTING	4830
470	OTHER BUSINESS SERVICES	7320 7331 733
475	COMPUTER AND DATA PROCESSING S	7370
483	MOTION PICTURES	7800
484	THEATRICAL PRODUCERS, BANDS ET	7920
497	OTHER EDUCATIONAL SERVICES	8230 8240 8290

Table A.5 Transportation (13 sectors)

IO table Record	Description	87 SIC code	Note
392	SHIP BUILDING AND REPAIRING	3731	
393	BOAT BUILDING AND REPAIRING	3732	
433	RAILROADS AND RELATED SERVICES	4010, 4740	Also part of 4789
434	LOCAL, INTERURBAN PASSENGER TR	4100	
435	MOTOR FREIGHT TRANSPORT AND WA	4200	Also part of 4789
436	WATER TRANSPORTATION	4400	
437	AIR TRANSPORTATION	4500	
438	PIPE LINES, EXCEPT NATURAL GAS	4600	
439	ARRANGEMENT OF PASSENGER TRANS	4720	
440	TRANSPORTATION SERVICES	4730 4783, 47	Also part of 4789
482	MISCELLANEOUS REPAIR SHOPS	7690	
510	LOCAL GOVERNMENT PASSENGER TRA		Part of 4100
513	U.S. POSTAL SERVICE	4311	

Table A.6 Service (58 sectors)

IO table Record	Description	87 SIC code	Note
446	SANITARY SERVICES AND STEAM SU	4953 4959 496	
447	WHOLESALE TRADE	5000 5100	
448	BUILDING MATERIALS & GARDENING	5200	
449	GENERAL MERCHANDISE STORES	5300	
450	FOOD STORES	5400	
451	AUTOMOTIVE DEALERS & SERVICE S	5500	
452	APPAREL & ACCESSORY STORES	5600	
453	FURNITURE & HOME FURNISHINGS S	5700	
454	EATING & DRINKING	5800	
455	MISCELLANEOUS RETAIL	5900	
456	BANKING	6000	
457	CREDIT AGENCIES	6100 6710 672	
458	SECURITY AND COMMODITY BROKERS	6200	
459	INSURANCE CARRIERS	6300	
460	INSURANCE AGENTS AND BROKERS	6400	
461	OWNER-OCCUPIED DWELLINGS		
462	REAL ESTATE	6500	
463	HOTELS AND LODGING PLACES	7000	
464	LAUNDRY, CLEANING AND SHOE REP	7210 7250	
465	PORTRAIT AND PHOTOGRAPHIC STUD	7220	
466	BEAUTY AND BARBER SHOPS	7230 7240	
467	FUNERAL SERVICE AND CREMATORIE	7260	
468	MISCELLANEOUS PERSONAL SERVICE	7290	
469	ADVERTISING	7310	
471	PHOTOFINISHING, COMMERCIAL PHO	7334 7335 733	
472	SERVICES TO BUILDINGS	7340	
474	PERSONNEL SUPPLY SERVICES	7360	
476	DETECTIVE AND PROTECTIVE SERVI	7381 7382	
477	AUTOMOBILE RENTAL AND LEASING	7510	
478	AUTOMOBILE PARKING AND CAR WAS	7520 7542	
479	AUTOMOBILE REPAIR AND SERVICES	7530 7549	
480	ELECTRICAL REPAIR SERVICES	7620	
481	WATCH, CLOCK, JEWELRY AND FURN	7630 7640	
485	BOWLING ALLEYS AND POOL HALLS	7930	
486	COMMERCIAL SPORTS EXCEPT RACIN	7941	
487	RACING AND TRACK OPERATION	7948	
488	AMUSEMENT AND RECREATION SERVI	7910 7991 799	
489	MEMBERSHIP SPORTS AND RECREATI	7997	
490	DOCTORS AND DENTISTS	8010, 8020, 8	
491	NURSING AND PROTECTIVE CARE	8050	

Table A.6 (Continued)

IO table Record	Description	87 SIC code	Note
492	HOSPITALS	8060	
493	OTHER MEDICAL AND HEALTH SERVI	0740, 8070, 8	
494	LEGAL SERVICES	8110	
500	SOCIAL SERVICES, N.E.C.	8320 8390	
501	RESIDENTIAL CARE	8360	
502	OTHER NONPROFIT ORGANIZATIONS	8400 8650 869	
503	BUSINESS ASSOCIATIONS	8610 8620	
504	LABOR AND CIVIC ORGANIZATIONS	8630 8640	
505	RELIGIOUS ORGANIZATIONS	8660	
506	ENGINEERING, ARCHITECTURAL SER	8710	
507	ACCOUNTING, AUDITING AND BOOKK	8720, 8990	
508	MANAGEMENT AND CONSULTING SERV	8740	
509	RESEARCH, DEVELOPMENT & TESTIN	8730	
518	USED AND SECONDHAND GOODS	--	
521	COMMODITY CREDIT CORPORATION		
525	HOUSEHOLD INDUSTRY-LOW INCOME	8800	
526	HOUSEHOLD INDUSTRY-MED INCOME	8800	
527	HOUSEHOLD INDUSTRY-HIGH INCOME	8800	

Table A.7 Production (409 sectors)

IO table Record	Description	87 SIC code	Note
1	DAIRY FARM PRODUCTS	241	Also : part of 0191, 02
2	POULTRY AND EGGS	0251 0252 025	Also : part of 0191, 02
3	RANCH FED CATTLE		Part of 0191, 0212, 021
4	RANGE FED CATTLE		Part of 0191, 0212, 021
5	CATTLE FEEDLOTS	211	Also : part of 0191, 02
6	SHEEP, LAMBS AND GOATS	214	Also : part of 0191, 02
7	HOGS, PIGS AND SWINE	213	Also : part of 0191, 02
8	OTHER MEAT ANIMAL PRODUCTS		Part of 0191, 0212, 021
9	MISCELLANEOUS LIVESTOCK	0271 0272	Also : part of 0191 021
10	COTTON	131	Also : part of 0191, 02
11	FOOD GRAINS	0111 0112	Also : part of 0191, 02
12	FEED GRAINS	115	Also : part of 0139, 01
13	HAY AND PASTURE		Part of 0139, 0191, 021
14	GRASS SEEDS		Part of 0139, 0191, 021
15	TOBACCO	132	Also : part of 0191, 02
16	FRUITS	0171 0172 017	Also : part of 0179, 01
17	TREE NUTS		Part of 0173, 0179, 019

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
18	VEGETABLES	0134 0161	Also : part of 0119, 01
19	SUGAR CROPS	133	Also : part of 0191, 02
20	MISCELLANEOUS CROPS		Part of 0119, 0139, 019
21	OIL BEARING CROPS	116	Also : part of 0119, 01
22	FOREST PRODUCTS		Part of 0181, 0191, 021
23	GREENHOUSE AND NURSERY PRODUCT	182	Also : part of 0181, 01
24	FORESTRY PRODUCTS	0810 0830 0	
25	COMMERCIAL FISHING	910	
26	AGRICULTURAL, FORESTRY, FISHER	0710 0720 075	Also : part of 0279
27	LANDSCAPE AND HORTICULTURAL SE	780	
28	IRON ORES	1010	
29	COPPER ORES	1020	
30	LEAD AND ZINC ORES	1030	
31	GOLD ORES	1041	
32	SILVER ORES	1044	
33	FERROALLOY ORES, EXCEPT VANADI	1060	
34	METAL MINING SERVICES	1080	
35	URANIUM-RADIUM-VANADIUM ORES	1094	
36	METAL ORES, NOT ELSWHERE CLASS	1099	
40	DIMENSION STONE	1410 1420	
41	SAND AND GRAVEL	1440	
42	CLAY, CERAMIC, REFRACTORY MINE	1450	
43	POTASH, SODA, AND BORATE MINER	1474	
44	PHOSPHATE ROCK	1475	
45	CHEMICAL, FERTILIZER MINERAL M	1479	
46	NONMETALLIC MINERALS (EXCEPT F	1480	
47	MISC. NONMETALLIC MINERALS, N.	1490	
48	NEW RESIDENTIAL STRUCTURES		Part 15, 16, 17
49	NEW INDUSTRIAL AND COMMERCIAL		Part 15, 16, 17
50	NEW UTILITY STRUCTURES		Part 15, 16, 17
51	NEW HIGHWAYS AND STREETS		Part 15, 16, 17
52	NEW FARM STRUCTURES		Part 15, 16, 17
53	NEW MINERAL EXTRACTION FACILIT		Part 15, 16, 17
54	NEW GOVERNMENT FACILITIES		Part 15, 16, 17
55	MAINTENANCE AND REPAIR, RESIDE		Part 15, 16, 17
56	MAINTENANCE AND REPAIR OTHER F		Part 15, 16, 17
57	MAINTENANCE AND REPAIR OIL AND	1380	
58	MEAT PACKING PLANTS	2011	
59	SAUSAGES AND OTHER PREPARED ME	2013	
60	POULTRY PROCESSING	2015	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
61	CREAMERY BUTTER	2021	
62	CHEESE, NATURAL AND PROCESSED	2022	
63	CONDENSED AND EVAPORATED MILK	2023	
64	ICE CREAM AND FROZEN DESSERTS	2024	
65	FLUID MILK	2026	
66	CANNED SPECIALTIES	2032	
67	CANNED FRUITS AND VEGETABLES	2033	
68	DEHYDRATED FOOD PRODUCTS	2034	
69	PICKLES, SAUCES, AND SALAD DRE	2035	
70	FROZEN FRUITS, JUICES AND VEGE	2037	
71	FROZEN SPECIALTIES	2038	
72	FLOUR AND OTHER GRAIN MILL PRO	2041	
73	CEREAL PREPARATIONS	2043	
74	RICE MILLING	2044	
75	BLENDED AND PREPARED FLOUR	2045	
76	WET CORN MILLING	2046	
77	DOG, CAT, AND OTHER PET FOOD	2047	
78	PREPARED FEEDS, N.E.C	2048	
79	BREAD, CAKE, AND RELATED PRODU	2051, 2053	
80	COOKIES AND CRACKERS	2052	
81	SUGAR	2061 2062 206	
82	CONFECTIONERY PRODUCTS	2064	
83	CHOCOLATE AND COCOA PRODUCTS	2066	
84	CHEWING GUM	2067	
85	SALTED AND ROASTED NUTS & SEED	2068	
86	COTTONSEED OIL MILLS	2074	
87	SOYBEAN OIL MILLS	2075	
88	VEGETABLE OIL MILLS, N.E.C	2076	
89	ANIMAL AND MARINE FATS AND OIL	2077	
90	SHORTENING AND COOKING OILS	2079	
91	MALT BEVERAGES	2082	
92	MALT	2083	
93	WINES, BRANDY, AND BRANDY SPIR	2084	
94	DISTILLED LIQUOR, EXCEPT BRAND	2085	
95	BOTTLED AND CANNED SOFT DRINKS	2086	
96	FLAVORING EXTRACTS AND SYRUPS,	2087	
97	CANNED AND CURED SEA FOODS	2091	
98	PREPARED FRESH OR FROZEN FISH	2092	
99	ROASTED COFFEE	2095	
100	POTATO CHIPS & SIMILAR SNACKS	2096	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
101	MANUFACTURED ICE	2097	
102	MACARONI AND SPAGHETTI	2098	
103	FOOD PREPARATIONS, N.E.C	2099	
104	CIGARETTES	2110	
105	CIGARS	2120	
106	CHEWING AND SMOKING TOBACCO	2130	
107	TOBACCO STEMMING AND REDRYING	2140	
108	BROADWOVEN FABRIC MILLS AND FI	2210 2220 223	
109	NARROW FABRIC MILLS	2240	
110	WOMENS HOSIERY, EXCEPT SOCKS	2251	
111	HOSIERY, N.E.C	2252	
112	KNIT OUTERWEAR MILLS	2253	
113	KNIT UNDERWEAR MILLS	2254	
114	KNIT FABRIC MILLS	2257 2258	
115	KNITTING MILLS, N.E.C	2259	
116	YARN MILLS AND FINISHING OF TE	2269 2281 228	
117	CARPETS AND RUGS	2270	
118	THREAD MILLS	2284	
119	COATED FABRICS, NOT RUBBERIZED	2295	
120	TIRE CORD AND FABRIC	2296	
121	NONWOVEN FABRICS	2297	
122	CORDAGE AND TWINE	2298	
123	TEXTILE GOODS, N.E.C	2299	
124	APPAREL MADE FROM PURCHASED MA		
125	CURTAINS AND DRAPERIES	2391	
126	HOUSEFURNISHINGS, N.E.C	2392	
127	TEXTILE BAGS	2393	
128	CANVAS PRODUCTS	2394	
129	PLEATING AND STITCHING	2395	
130	AUTOMOTIVE AND APPAREL TRIMMIN	2396	
131	SCHIFFI MACHINE EMBROIDERIES	2397	
132	FABRICATED TEXTILE PRODUCTS, N	2399	
133	LOGGING CAMPS AND LOGGING CONT	2410	
134	SAWMILLS AND PLANING MILLS, GE	2421	
135	HARDWOOD DIMENSION AND FLOORIN	2426	
136	SPECIAL PRODUCT SAWMILLS, N.E.	2429	
137	MILLWORK	2431	
138	WOOD KITCHEN CABINETS	2434	
139	VENEER AND PLYWOOD	2435 2436	
140	STRUCTURAL WOOD MEMBERS, N.E.C	2439	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
141	WOOD CONTAINERS	2441 2449	
142	WOOD PALLETS AND SKIDS	2448	
143	MOBILE HOMES	2451	
144	PREFABRICATED WOOD BUILDINGS	2452	
145	WOOD PRESERVING	2491	
146	RECONSTITUTED WOOD PRODUCTS	2493	
147	WOOD PRODUCTS, N.E.C	2499	
148	WOOD HOUSEHOLD FURNITURE	2511	
149	UPHOLSTERED HOUSEHOLD FURNITUR	2512	
150	METAL HOUSEHOLD FURNITURE	2514	
151	MATTRESSES AND BEDSPRINGS	2515	
152	WOOD TV AND RADIO CABINETS	2517	
153	HOUSEHOLD FURNITURE, N.E.C	2519	
154	WOOD OFFICE FURNITURE	2521	
155	METAL OFFICE FURNITURE	2522	
156	PUBLIC BUILDING FURNITURE	2530	
157	WOOD PARTITIONS AND FIXTURES	2541	
158	METAL PARTITIONS AND FIXTURES	2542	
159	BLINDS, SHADES, AND DRAPERY HA	2591	
160	FURNITURE AND FIXTURES, N.E.C	2599	
161	PULP MILLS	2610	
162	PAPER MILLS, EXCEPT BUILDING P	2620	
163	PAPERBOARD MILLS	2630	
164	PAPERBOARD CONTAINERS AND BOXE	2650	
165	PAPER COATED & LAMINATED PACKA	2671	
166	PAPER COATED & LAMINATED NEC	2672	
167	BAGS, PLASTIC	2673	
168	BAGS, PAPER	2674	
169	DIE-CUT PAPER AND BOARD	2675	
170	SANITARY PAPER PRODUCTS	2676	
171	ENVELOPES	2677	
172	STATIONERY PRODUCTS	2678	
173	CONVERTED PAPER PRODUCTS, N.E.	2679	
177	BOOK PRINTING	2732	
179	COMMERCIAL PRINTING	2750	
180	MANIFOLD BUSINESS FORMS	2760	
182	BLANKBOOKS AND LOOSELEAF BINDE	2782	
183	BOOKBINDING & RELATED	2789	
184	TYPESETTING	2791	
185	PLATE MAKING	2796	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
186	ALKALIES & CHLORINE	2812	
187	INDUSTRIAL GASES	2813	
188	INORGANIC PIGMENTS	2816	
189	INORGANIC CHEMICALS NEC.	2819	
190	CYCLIC CRUDES, INTERM. & INDUS	2865 2869	
191	PLASTICS MATERIALS AND RESINS	2821	
192	SYNTHETIC RUBBER	2822	
193	CELLULOSIC MAN-MADE FIBERS	2823	
194	ORGANIC FIBERS, NONCELLULOSIC	2824	
195	DRUGS	2830	
196	SOAP AND OTHER DETERGENTS	2841	
197	POLISHES AND SANITATION GOODS	2842	
198	SURFACE ACTIVE AGENTS	2843	
199	TOILET PREPARATIONS	2844	
200	PAINTS AND ALLIED PRODUCTS	2850	
201	GUM AND WOOD CHEMICALS	2861	
202	NITROGENOUS AND PHOSPHATIC FER	2873 2874	
203	FERTILIZERS, MIXING ONLY	2875	
204	AGRICULTURAL CHEMICALS, N.E.C	2879	
205	ADHESIVES AND SEALANTS	2891	
206	EXPLOSIVES	2892	
207	PRINTING INK	2893	
208	CARBON BLACK	2895	
209	CHEMICAL PREPARATIONS, N.E.C	2899	
210	PETROLEUM REFINING	2910	
211	PAVING MIXTURES AND BLOCKS	2951	
212	ASPHALT FELTS AND COATINGS	2952	
214	PETROLEUM AND COAL PRODUCTS, N	2999	
215	TIRES AND INNER TUBES	3010	
216	RUBBER AND PLASTICS FOOTWEAR	3020	
217	RUBBER AND PLASTICS HOSE AND B	3052	
218	GASKETS, PACKING AND SEALING D	3053	
219	FABRICATED RUBBER PRODUCTS, N.	3060	
220	MISCELLANEOUS PLASTICS PRODUCT	3080	
221	LEATHER TANNING AND FINISHING	3110	
222	FOOTWEAR CUT STOCK	3130	
223	HOUSE SLIPPERS	3142	
224	SHOES, EXCEPT RUBBER	3143 3144 314	
225	LEATHER GLOVES AND MITTENS	3150	
226	LUGGAGE	3160	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
227	WOMENS HANDBAGS AND PURSES	3171	
228	PERSONAL LEATHER GOODS	3172	
229	LEATHER GOODS, N.E.C	3190	
230	GLASS AND GLASS PRODUCTS, EXC	3210 3229 323	
231	GLASS CONTAINERS	3221	
232	CEMENT, HYDRAULIC	3240	
233	BRICK AND STRUCTURAL CLAY TILE	3251	
234	CERAMIC WALL AND FLOOR TILE	3253	
235	CLAY REFRACTORIES	3255	
236	STRUCTURAL CLAY PRODUCTS, N.E.	3259	
237	VITREOUS PLUMBING FIXTURES	3261	
238	VITREOUS CHINA FOOD UTENSILS	3262	
239	FINE EARTHENWARE FOOD UTENSILS	3263	
240	PORCELAIN ELECTRICAL SUPPLIES	3264	
241	POTTERY PRODUCTS, N.E.C	3269	
242	CONCRETE BLOCK AND BRICK	3271	
243	CONCRETE PRODUCTS, N.E.C	3272	
244	READY-MIXED CONCRETE	3273	
245	LIME	3274	
246	GYPSUM PRODUCTS	3275	
247	CUT STONE AND STONE PRODUCTS	3280	
248	ABRASIVE PRODUCTS	3291	
249	ASBESTOS PRODUCTS	3292	
250	MINERALS, GROUND OR TREATED	3295	
251	MINERAL WOOL	3296	
252	NONCLAY REFRACTORIES	3297	
253	NONMETALLIC MINERAL PRODUCTS,	3299	
254	BLAST FURNACES AND STEEL MILLS	3312	
255	ELECTROMETALLURGICAL PRODUCTS	3313	
256	STEEL WIRE AND RELATED PRODUCT	3315	
257	COLD FINISHING OF STEEL SHAPES	3316	
258	STEEL PIPE AND TUBES	3317	
259	IRON AND STEEL FOUNDRIES	3320	
260	PRIMARY COPPER	3331	
261	PRIMARY ALUMINUM	3334	Also part of 2819
262	PRIMARY NONFERROUS METALS, N.E	3339	
263	SECONDARY NONFERROUS METALS	3340	
264	COPPER ROLLING AND DRAWING	3351	
265	ALUMINUM ROLLING AND DRAWING	3353 3354 335	
266	NONFERROUS ROLLING AND DRAWING	3356	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
268	ALUMINUM FOUNDRIES	3363, 3365	
269	BRASS, BRONZE, AND COPPER FOUN	3364, 3366	
270	NONFERROUS CASTINGS, N.E.C.	3369	
271	METAL HEAT TREATING	3398	
272	PRIMARY METAL PRODUCTS, N.E.C	3399	
273	METAL CANS	3411	
274	METAL BARRELS, DRUMS AND PAILS	3412	
275	CUTLERY	3421	
276	HAND AND EDGE TOOLS, N.E.C.	3423	
277	HAND SAWS AND SAW BLADES	3425	
278	HARDWARE, N.E.C.	3429	
279	METAL SANITARY WARE	3431	
280	PLUMBING FIXTURE FITTINGS AND	3432	
281	HEATING EQUIPMENT, EXCEPT ELEC	3433	
282	FABRICATED STRUCTURAL METAL	3441	
283	METAL DOORS, SASH, AND TRIM	3442	
284	FABRICATED PLATE WORK (BOILER	3443	
285	SHEET METAL WORK	3444	
286	ARCHITECTURAL METAL WORK	3446	
287	PREFABRICATED METAL BUILDINGS	3448	
288	MISCELLANEOUS METAL WORK	3449	
289	SCREW MACHINE PRODUCTS AND BOL	3450	
290	IRON AND STEEL FORGINGS	3462	
291	NONFERROUS FORGINGS	3463	
292	AUTOMOTIVE STAMPINGS	3465	
293	CROWNS AND CLOSURES	3466	
294	METAL STAMPINGS, N.E.C.	3469	
295	PLATING AND POLISHING	3471	
296	METAL COATING AND ALLIED SERVI	3479	
297	SMALL ARMS AMMUNITION	3482	
298	AMMUNITION, EXCEPT FOR SMALL A	3483	
299	SMALL ARMS	3484	
300	OTHER ORDNANCE AND ACCESSORIES	3489	
301	INDUSTRIAL AND FLUID VALVES	3491, 3492	
302	STEEL SPRINGS, EXCEPT WIRE	3493	
303	PIPE, VALVES, AND PIPE FITTING	3494 3498	
304	MISCELLANEOUS FABRICATED WIRE	3495 3496	
305	METAL FOIL AND LEAF	3497	
306	FABRICATED METAL PRODUCTS, N.E	3499	
307	STEAM ENGINES AND TURBINES	3511	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
308	INTERNAL COMBUSTION ENGINES, N	3519	
309	FARM MACHINERY AND EQUIPMENT	3523	
310	LAWN AND GARDEN EQUIPMENT	3524	
311	CONSTRUCTION MACHINERY AND EQU	3531	
312	MINING MACHINERY, EXCEPT OIL F	3532	
313	OIL FIELD MACHINERY	3533	
314	ELEVATORS AND MOVING STAIRWAYS	3534	
315	CONVEYORS AND CONVEYING EQUIPM	3535	
316	HOISTS, CRANES, AND MONORAILS	3536	
317	INDUSTRIAL TRUCKS AND TRACTORS	3537	
318	MACHINE TOOLS, METAL CUTTING T	3541	
319	MACHINE TOOLS, METAL FORMING T	3542	
320	INDUSTRIAL PATTERNS	3543	
321	SPECIAL DIES AND TOOLS AND ACC	3544 3545	
322	POWER DRIVEN HAND TOOLS	3546	
323	ROLLING MILL MACHINERY	3547	
324	WELDING APPARATUS	3548	
325	METALWORKING MACHINERY, N.E.C.	3549	
326	TEXTILE MACHINERY	3552	
327	WOODWORKING MACHINERY	3553	
328	PAPER INDUSTRIES MACHINERY	3554	
329	PRINTING TRADES MACHINERY	3555	
330	FOOD PRODUCTS MACHINERY	3556	
331	SPECIAL INDUSTRY MACHINERY NEC	3559	
332	PUMPS AND COMPRESSORS	3561 3563	
333	BALL AND ROLLER BEARINGS	3562	
334	BLOWERS AND FANS	3564	
335	PACKAGING MACHINERY	3565	
336	POWER TRANSMISSION EQUIPMENT	3566 3568	
337	INDUSTRIAL FURNACES AND OVENS	3567	
338	GENERAL INDUSTRIAL MACHINERY,	3569	
344	TYPEWRITERS AND OFFICE MACHINE	3579	
345	AUTOMATIC MERCHANDISING MACHIN	3581	
346	COMMERCIAL LAUNDRY EQUIPMENT	3582	
347	REFRIGERATION AND HEATING EQUI	3585	
348	MEASURING AND DISPENSING PUMPS	3586	
349	SERVICE INDUSTRY MACHINES, N.E	3589	
350	CARBURETORS, PISTONS, RINGS, V	3592	
351	FLUID POWER CYLINDERS & ACTUAT	3593	
352	FLUID POWER PUMPS & MOTORS	3594	

Table A.7 (Continued)

IO table Record	Description	87 SIC code	Note
353	SCALES AND BALANCES	3596	
354	INDUSTRIAL MACHINES NEC.	3599	
355	TRANSFORMERS	3612	
356	SWITCHGEAR AND SWITCHBOARD APP	3613	
357	MOTORS AND GENERATORS	3621	
358	CARBON AND GRAPHITE PRODUCTS	3624	
359	RELAYS & INDUSTRIAL CONTROLS	3625	
360	ELECTRICAL INDUSTRIAL APPARATU	3629	
361	HOUSEHOLD COOKING EQUIPMENT	3631	
362	HOUSEHOLD REFRIGERATORS AND FR	3632	
363	HOUSEHOLD LAUNDRY EQUIPMENT	3633	
364	ELECTRIC HOUSEWARES AND FANS	3634	
365	HOUSEHOLD VACUUM CLEANERS	3635	
366	HOUSEHOLD APPLIANCES, N.E.C.	3639	
367	ELECTRIC LAMPS	3641	
368	WIRING DEVICES	3643 3644	
369	LIGHTING FIXTURES AND EQUIPMEN	3645 3646 364	
379	STORAGE BATTERIES	3691	
380	PRIMARY BATTERIES, DRY AND WET	3692	
381	ENGINE ELECTRICAL EQUIPMENT	3694	
382	MAGNETIC & OPTICAL RECORDING M	3695	
383	ELECTRICAL EQUIPMENT, N.E.C.	3699	
384	MOTOR VEHICLES	3711	
385	TRUCK AND BUS BODIES	3713	
386	MOTOR VEHICLE PARTS AND ACCESS	3714	
387	TRUCK TRAILERS	3715	
388	MOTOR HOMES	3716	
389	AIRCRAFT	3721	
390	AIRCRAFT AND MISSILE ENGINES A	3724 3764	
391	AIRCRAFT AND MISSILE EQUIPMENT	3728 3769	
394	RAILROAD EQUIPMENT	3740	
395	MOTORCYCLES, BICYCLES, AND PAR	3750	
396	COMPLETE GUIDED MISSILES	3761	
397	TRAVEL TRAILERS AND CAMPERS	3792	
398	TANKS AND TANK COMPONENTS	3795	
399	TRANSPORTATION EQUIPMENT, N.E.	3799	
401	LABORATORY APPARATUS & FURNITU	3821	
403	MECHANICAL MEASURING DEVICES	3823 3824 382	
404	INSTRUMENTS TO MEASURE ELECTRI	3825	
405	ANALYTICAL INSTRUMENTS	3826	

Table A.7 (Continued)

406	OPTICAL INSTRUMENTS & LENSES	3827	
407	SURGICAL AND MEDICAL INSTRUMEN	3841	
408	SURGICAL APPLIANCES AND SUPPLI	3842	
409	DENTAL EQUIPMENT AND SUPPLIES	3843	
410	X-RAY APPARATUS	3844	
411	ELECTROMEDICAL APPARATUS	3845	
412	OPHTHALMIC GOODS	3850	
413	PHOTOGRAPHIC EQUIPMENT AND SUP	3860	
414	WATCHES, CLOCKS, AND PARTS	3870	
415	JEWELRY, PRECIOUS METAL	3911	
416	SILVERWARE AND PLATED WARE	3914	
417	JEWELERS MATERIALS AND LAPIDAR	3915	
418	MUSICAL INSTRUMENTS	3930	
419	DOLLS	3942	
420	GAMES, TOYS, AND CHILDRENS VEH	3944	
421	SPORTING AND ATHLETIC GOODS, N	3949	
422	PENS AND MECHANICAL PENCILS	3951	
423	LEAD PENCILS AND ART GOODS	3952	
424	MARKING DEVICES	3953	
425	CARBON PAPER AND INKED RIBBONS	3955	
426	COSTUME JEWELERY	3961	
427	FASTENERS, BUTTONS, NEEDLES, P	3965	
428	BROOMS AND BRUSHES	3991	
429	SIGNS AND ADVERTISING DISPLAYS	3993	
430	BURIAL CASKETS AND VAULTS	3995	
431	HARD SURFACE FLOOR COVERINGS	3996	
432	MANUFACTURING INDUSTRIES, N.E.	3999	
445	WATER SUPPLY AND SEWERAGE SYST	4940 4952	
516	NONCOMPARABLE IMPORTS	--	
517	SCRAP	--	
524	REST OF THE WORLD INDUSTRY	--	
528	INVENTORY VALUATION ADJUSTMENT	--	

2 Three-segment aggregation

Table A.8 Sectors in three-segment model (IO table record number only)

	Production	Information	Energy
	1-36	174	37
	40-173	175	38
	177	176	39
	179-180	178	213
	182-212	181	443
	214-370	371	444
	372-440	441	511
	445-469	442	512
	471-474	470	
	476-482	475	
	485-496	483	
	498-510	484	
	513-528	497	
Total sectors	507	13	8

APPENDIX B

TRANSACTIONS TABLES, TECHNICAL COEFFICIENT (A) MATRICES, LEONTIEF INVERSE (L) MATRICES, AND TOTAL FLOW MATRICES

1 Transaction tables

Table B.1 Transaction table for three-segment model, 1990[1]

	Production	Energy	Information
Production	5490.784	217.7269	272.7158
Energy	611.9492	475.1256	9.120269
Information	326.6767	9.522698	102.949

Unit: Million USD

Table B.2 Transaction table for three-segment model, 1994

	Production	Energy	Information
Production	8529.244	247.0717	498.1949
Energy	444.2162	212.0256	8.363102
Information	590.3829	12.51627	364.6236

Unit: Million USD

Table B.3 Transaction table for three-segment, 1999

	Production	Energy	Information
Production	15665.6	250.75	1231.882
Energy	614.7477	273.0956	12.9411
Information	1660.208	24.15755	936.2507

Unit: Million USD

Table B.4 Transaction table for seven-segment model, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	693.6526	67.81512	58.94626	243.2903	42.92732	447.5141	75.30449
Energy	238.5659	465.6898	9.319453	37.70871	10.95924	120.7538	70.43439
Information	37.19566	9.224582	103.0266	49.70657	11.23789	302.1134	17.77172
ICT	11.35443	1.057451	1.439261	11.06688	0.718805	7.525975	1.180877
Transportation	94.56107	25.98052	24.80291	32.10782	72.15302	132.8362	9.454644
Service	444.1108	93.51057	148.7884	277.3111	60.4398	1754.695	97.08534
Edu_PA	38.02051	17.68975	8.854	19.75255	4.581165	63.6587	7.08215

Unit: Million USD

Table B.5 Transaction table for seven-segment model, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	1025.47	102.9154	127.0583	395.8375	77.12373	675.7272	60.33334
Energy	156.8361	207.5495	8.81445	44.61739	10.41268	113.0491	14.65576
Information	36.41557	11.36292	349.2338	102.7408	23.42233	513.4836	10.95395
ICT	28.54267	3.262376	24.05692	29.58076	3.881162	44.35342	2.114182
Transportation	136.7921	32.88946	37.52957	87.83578	187.9904	273.1377	8.271019
Service	548.2	97.07066	287.5818	559.1962	174.1268	3384.901	65.5164
Edu_PA	24.43852	5.344159	5.480265	13.88937	3.941589	44.43758	3.333004

Unit: Million USD

Table B.6 Transaction table for seven-segment model, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	1886.349	90.34397	210.1691	515.5885	86.75134	1005.603	83.40553
Energy	280.1724	282.8552	14.12115	46.54461	5.693902	130.2237	12.90906
Information	197.5636	23.3571	932.6451	359.1739	46.81147	1305.902	39.56973
ICT	30.40879	1.487898	16.28185	48.96712	1.740552	29.54766	1.59394
Transportation	236.0254	19.2746	62.0988	88.43571	120.8378	257.4419	6.579576
Service	1663.588	116.9553	851.1007	1301.151	187.5562	5326.386	103.7133
Edu_PA	68.53129	8.518977	20.6637	29.68792	7.488888	88.64522	9.111575

Unit: Million USD

2 Technical coefficient (A) matrices

Table B.7 A coefficients, three-segment model, 1990

	Production	Energy	Information
Production	0.217851	0.110298	0.149596
Energy	0.024280	0.240694	0.005003
Information	0.012961	0.004824	0.056472

Table B.8 A coefficients, three-segment model, 1994

	Production	Energy	Information
Production	0.210082	0.162500	0.143990
Energy	0.010941	0.139450	0.002417
Information	0.014542	0.008232	0.105385

Table B.9 A coefficients, three-segment model, 1999

	Production	Energy	Information
Production	0.203998	0.137767	0.142269
Energy	0.008005	0.150044	0.001495
Information	0.021619	0.013273	0.108126

Table B.10 A coefficients, seven-segment model, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.135539	0.034354	0.032334	0.075613	0.054286	0.034223	0.025085
Energy	0.046616	0.235914	0.005112	0.011720	0.013859	0.009235	0.023463
Information	0.007268	0.004673	0.056514	0.015448	0.014211	0.023104	0.005920
ICT	0.002219	0.000536	0.000789	0.003440	0.000909	0.000576	0.000393
Transportation	0.018477	0.013161	0.013605	0.009979	0.091245	0.010159	0.003149
Service	0.086779	0.047371	0.081617	0.086186	0.076432	0.134189	0.032341
Edu_PA	0.007429	0.008961	0.004857	0.006139	0.005793	0.004868	0.002359

Table B.11 A coefficients, seven-segment model, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.134314	0.067688	0.036723	0.057392	0.060091	0.032754	0.014525
Energy	0.020542	0.136506	0.002548	0.006469	0.008113	0.005480	0.003528
Information	0.004770	0.007473	0.100937	0.014896	0.018249	0.024890	0.002637
ICT	0.003738	0.002146	0.006953	0.004289	0.003024	0.002150	0.000509
Transportation	0.017917	0.021632	0.010847	0.012735	0.146472	0.013240	0.001991
Service	0.071802	0.063844	0.083118	0.081077	0.135670	0.164073	0.015773
Edu_PA	0.003201	0.003515	0.001584	0.002014	0.003071	0.002154	0.000802

Table B.12 A coefficients, seven-segment model, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.133329	0.049637	0.024272	0.037280	0.052812	0.025513	0.010752
Energy	0.019803	0.155406	0.001631	0.003365	0.003466	0.003304	0.001664
Information	0.013964	0.012833	0.107710	0.025971	0.028498	0.033132	0.005101
ICT	0.002149	0.000817	0.001880	0.003541	0.001060	0.000750	0.000205
Transportation	0.016683	0.010590	0.007172	0.006394	0.073563	0.006532	0.000848
Service	0.117584	0.064257	0.098293	0.094081	0.114180	0.135136	0.013370
Edu_PA	0.004844	0.004680	0.002386	0.002147	0.004559	0.002249	0.001175

3 Leontief inverse (L) matrices

Table B.13 Leontief inverse coefficients, three-segment model, 1990

	Production	Energy	Information
Production	1.287776	0.188368	0.205175
Energy	0.041296	1.323076	0.013563
Information	0.017901	0.009352	1.062740

Table B.14 Leontief inverse coefficients, three-segment model, 1994

	Production	Energy	Information
Production	1.27309502	0.242369	0.2055625
Energy	0.01624519	1.165171	0.00576285
Information	0.02084308	0.014661	1.12119363

Table B.15 Leontief inverse coefficients, three-segment model, 1999

	Production	Energy	Information
Production	1.263855	0.208008	0.201954
Energy	0.011958	1.178530	0.003882
Information	0.030814	0.022581	1.126188

Table B.16 Leontief inverse coefficients, seven-segment model, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.135539	0.034354	0.032334	0.075613	0.054286	0.034223	0.025085
Energy	0.046616	0.235914	0.005112	0.011720	0.013859	0.009235	0.023463
Information	0.007268	0.004673	0.056514	0.015448	0.014211	0.023104	0.005920
ICT	0.002219	0.000536	0.000789	0.003440	0.000909	0.000576	0.000393
Transportation	0.018477	0.013161	0.013605	0.009979	0.091245	0.010159	0.003149
Service	0.086779	0.047371	0.081617	0.086186	0.076432	0.134189	0.032341
Edu_PA	0.007429	0.008961	0.004857	0.006139	0.005793	0.004868	0.002359

Table B.17 Leontief inverse coefficients, seven-segment model, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.134314	0.067688	0.036723	0.057392	0.060091	0.032754	0.014525
Energy	0.020542	0.136506	0.002548	0.006469	0.008113	0.005480	0.003528
Information	0.004770	0.007473	0.100937	0.014896	0.018249	0.024890	0.002637
ICT	0.003738	0.002146	0.006953	0.004289	0.003024	0.002150	0.000509
Transportation	0.017917	0.021632	0.010847	0.012735	0.146472	0.013240	0.001991
Service	0.071802	0.063844	0.083118	0.081077	0.135670	0.164073	0.015773
Edu_PA	0.003201	0.003515	0.001584	0.002014	0.003071	0.002154	0.000802

Table B.18 Leontief inverse coefficients, seven-segment model, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	0.133329	0.049637	0.024272	0.037280	0.052812	0.025513	0.010752
Energy	0.019803	0.155406	0.001631	0.003365	0.003466	0.003304	0.001664
Information	0.013964	0.012833	0.107710	0.025971	0.028498	0.033132	0.005101
ICT	0.002149	0.000817	0.001880	0.003541	0.001060	0.000750	0.000205
Transportation	0.016683	0.010590	0.007172	0.006394	0.073563	0.006532	0.000848
Service	0.117584	0.064257	0.098293	0.094081	0.114180	0.135136	0.013370
Edu_PA	0.004844	0.004680	0.002386	0.002147	0.004559	0.002249	0.001175

4 Total flow matrices

Table B.19 Total flow coefficients, three-segment model, 1990

	Production	Energy	Information
Production	1.000000	0.142371	0.193063
Energy	0.032068	1.000000	0.012762
Information	0.013901	0.007069	1.000000

Table B.20 Total flow coefficients, three-segment model, 1994

	Production	Energy	Information
Production	1.000000	0.208012	0.183343
Energy	0.012760	1.000000	0.005140
Information	0.016372	0.012583	1.000000

Table B.21 Total flow coefficients, three-segment model, 1999

	Production	Energy	Information
Production	1.000000	0.176498	0.179325
Energy	0.009461	1.000000	0.003447
Information	0.024381	0.019160	1.000000

Table B.22 Total flow coefficients, seven-segment model, 1990

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	1.000000	0.043809	0.043177	0.094812	0.068636	0.042152	0.032743
Energy	0.063095	1.000000	0.011053	0.023143	0.023874	0.015236	0.033388
Information	0.011078	0.007117	1.000000	0.020279	0.018187	0.025125	0.007850
ICT	0.002355	0.000695	0.000971	1.000000	0.001152	0.000713	0.000522
Transportation	0.022668	0.016211	0.017170	0.014847	1.000000	0.012659	0.005227
Service	0.107287	0.061639	0.101031	0.113827	0.098559	1.000000	0.043715
Edu_PA	0.008737	0.009743	0.005888	0.007808	0.007109	0.005531	1.000000

Table B.23 Total flow coefficients, seven-segment model, 1994

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	1.000000	0.084342	0.048484	0.073432	0.078347	0.049521	0.018398
Energy	0.024668	1.000000	0.004996	0.010178	0.012478	0.007594	0.004708
Information	0.008632	0.011888	1.000000	0.020452	0.025683	0.028359	0.003749
ICT	0.004141	0.002838	0.007456	1.000000	0.003913	0.00258	0.000673
Transportation	0.023237	0.02871	0.015633	0.01868	1.000000	0.01697	0.003234
Service	0.092878	0.089814	0.107277	0.10919	0.172986	1.000000	0.021771
Edu_PA	0.003584	0.004094	0.002052	0.002612	0.00379	0.002416	1.000000

Table B.24 Total flow coefficients, seven-segment model, 1999

	Production	Energy	Information	ICT	Transportation	Service	Edu_PA
Production	1.000000	0.061282	0.032403	0.048457	0.066810	0.036549	0.013367
Energy	0.024149	1.000000	0.003211	0.005703	0.006333	0.004761	0.002375
Information	0.022035	0.019048	1.000000	0.034740	0.038574	0.037986	0.006696
ICT	0.002348	0.001069	0.002060	1.000000	0.001397	0.000904	0.000265
Transportation	0.019484	0.013306	0.009223	0.008964	1.000000	0.007971	0.001367
Service	0.143167	0.086749	0.119781	0.120969	0.146193	1.000000	0.018423
Edu_PA	0.005432	0.005287	0.002878	0.002807	0.005342	0.002555	1.000000

[1] All the data are original except indicated otherwise.

APPENDIX C

RESULTS OF THE STRUCTURE DECOMPOSITION ANALYSIS OF THE SIX POLLUTANTS AT SEGMENTAL LEVEL, 1990 - 1999[i]

Table C.1 SDA of TSP at segmental level, 1990 - 1994

Segment	Technology		Final demand						Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	import	
1	-6.36	-157.31	302.17	13.75	19.80	14.50	43.95	-46.49	92.01
2	1.94	14.73	-1.87	-0.46	-1.59	1.71	20.37	5.24	20.04
3	2.36	-3.56	6.87	1.61	0.19	0.13	5.73	1.99	7.66
4	-18.23	14.65	41.54	0.68	0.34	0.32	54.62	18.00	55.95
5	0.74	-0.93	0.27	0.72	-0.02	0.15	0.37	1.15	1.24
6	-2.14	-20.15	41.17	8.92	0.39	1.41	9.94	1.78	20.66
7	-13.28	-2.42	8.36	-1.46	-8.28	-0.01	1.36	-1.06	-8.39
Total	-482.60	-1031.98	654.11	-168.29	-200.75	-155.17	-872.83	-536.57	-1397.04

Table C.2 SDA of PM_{10} at segmental level, 1990 - 1994

Segment	Technology		Final demand						Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	import	
1	-1.43	-231.72	181.36	-21.69	-31.23	-22.87	-69.33	-93.35	-145.13
2	2.78	8.81	-0.32	-0.36	-1.26	1.36	16.15	4.62	15.89
3	1.60	-5.55	4.01	0.04	0.00	0.00	0.15	0.14	0.20
4	-10.16	-17.81	24.30	-0.09	-0.04	-0.04	-6.98	-3.48	-7.15
5	0.50	-1.45	0.16	-0.48	0.01	-0.10	-0.25	-0.02	-0.82
6	0.47	-35.79	23.70	-6.26	-0.27	-0.99	-6.97	-2.86	-14.49
7	-6.28	-3.88	4.42	-1.11	-6.27	-0.01	1.03	-0.61	-6.35
Total	-1292.42	899.60	1529.92	20.39	-256.80	91.63	1344.76	62.88	1199.98

Table C.3 SDA of SO_2 at segmental level, 1990 - 1994

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	import	
1	-13.84	274.57	11.94	59.85	86.18	63.12	191.30	127.79	400.46
2	-8.14	24.31	-4.31	-0.33	-1.14	1.23	14.67	2.57	14.43
3	-0.52	4.36	2.34	1.72	0.20	0.14	6.14	2.02	8.20
4	-5.01	107.72	9.36	2.09	1.04	0.97	168.06	60.09	172.16
5	0.22	1.63	0.08	2.23	-0.05	0.47	1.15	1.88	3.80
6	0.99	-173.04	100.20	-37.94	-1.67	-5.98	-42.28	-16.02	-87.88
7	-10.82	4.32	4.35	-0.46	-2.62	0.00	0.43	-0.50	-2.65
Total	-37.12	243.85	123.96	27.15	81.95	59.95	339.46	177.82	508.52

Table C.4 SDA of NOx at segmental level, 1990-1994

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	import	
1	-353.50	-436.59	997.10	-10.11	-14.56	-10.66	-32.32	-274.68	-67.66
2	-217.48	1110.29	-117.21	-23.85	-82.42	88.92	1056.54	263.60	1039.20
3	-18.44	1.21	37.98	5.96	0.69	0.50	21.28	7.68	28.43
4	-169.31	80.52	224.16	2.36	1.18	1.10	190.24	59.52	194.89
5	-5.30	2.40	1.78	2.95	-0.06	0.62	1.52	6.15	5.03
6	-250.11	125.39	275.64	72.14	3.17	11.37	80.39	16.15	167.07
7	-278.29	16.38	110.47	-29.06	-164.80	-0.23	27.10	-15.54	-166.98
Total	-1292.42	899.60	1529.92	20.39	-256.80	91.63	1344.76	62.88	1199.98

Table C.5 SDA of NMOC of at segmental level, 1990 - 1994.

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	import	
1	-13.84	274.57	11.94	59.85	86.18	63.12	191.30	127.79	400.46
2	-8.14	24.31	-4.31	-0.33	-1.14	1.23	14.67	2.57	14.43
3	-0.52	4.36	2.34	1.72	0.20	0.14	6.14	2.02	8.20
4	-5.01	107.72	9.36	2.09	1.04	0.97	168.06	60.09	172.16
5	0.22	1.63	0.08	2.23	-0.05	0.47	1.15	1.88	3.80
6	0.99	-173.04	100.20	-37.94	-1.67	-5.98	-42.28	-16.02	-87.88
7	-10.82	4.32	4.35	-0.46	-2.62	0.00	0.43	-0.50	-2.65
Total	-37.12	243.85	123.96	27.15	81.95	59.95	339.46	177.82	508.52

Table C.6 SDA of CO at segmental level, 1990 - 1994

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-60.55	1259.04	76.11	41.03	140.27	65.95	-8.47	589.74	1864.34
2	-39.20	285.94	-20.16	707.50	1063.90	-22.53	-1744.52	85.15	311.73
3	-4.05	35.15	4.45	3.21	1.76	0.70	13.43	11.33	46.87
4	-23.94	144.08	25.90	0.18	0.43	0.52	75.58	77.46	223.50
5	-1.19	9.82	0.23	1.12	1.32	0.17	0.90	8.11	16.97
6	-43.63	359.04	35.15	62.24	13.62	13.47	48.53	59.30	409.87
7	-44.91	28.82	16.80	6.69	56.76	0.37	-0.84	-1.68	-0.97
Total	-217.47	2121.90	138.47	821.97	1278.07	58.65	-1615.39	829.41	2872.32

Table C.7 SDA of TSP at segmental level, 1994 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-1.63	-552.68	500.71	89.57	352.92	157.02	-98.80	12.39	-41.21
2	-1.63	56.79	3.47	10.12	15.07	-0.03	-21.69	26.84	85.46
3	-11.55	-11.08	20.90	3.23	2.39	0.90	14.38	-1.06	-2.78
4	-33.45	-16.01	77.68	-0.20	0.42	0.57	76.89	12.48	40.70
5	-1.79	-2.76	3.78	0.87	1.92	0.09	0.91	-1.59	-2.37
6	-52.33	-63.64	98.29	45.07	12.50	10.64	30.09	-6.23	-23.91
7	-5.98	-6.05	9.46	0.79	8.26	0.07	0.34	-0.12	-2.68
Total	-108.37	-595.43	714.29	149.44	393.48	169.25	2.12	42.71	53.21

Table C.8 SDA of PM_{10} at segmental level, 1994-1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-0.58	3.54	180.88	32.36	127.49	56.72	-35.69	118.32	302.16
2	-0.60	88.57	1.22	3.57	5.31	-0.01	-7.65	39.89	129.08
3	-4.12	1.40	7.48	1.16	0.86	0.32	5.15	1.09	5.85
4	-12.05	4.54	18.05	-0.05	0.10	0.13	17.86	4.94	15.48
5	-0.64	0.32	1.36	0.31	0.69	0.03	0.33	0.09	1.13
6	-18.68	15.66	34.39	15.77	4.37	3.72	10.53	2.85	34.22
7	-2.14	1.61	3.40	0.28	2.97	0.03	0.12	0.05	2.92
Total	-38.81	115.64	246.78	53.40	141.79	60.94	-9.35	167.24	490.84

Table C.9 SDA of SO_2 at segmental level, 1994 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-3.00	625.42	231.09	41.34	162.88	72.47	-45.60	497.77	1351.28
2	10.52	-191.65	35.91	104.88	156.14	-0.35	-224.76	-56.04	-201.26
3	-9.45	10.51	16.67	2.58	1.91	0.72	11.47	4.39	22.12
4	-36.88	25.26	48.12	-0.13	0.26	0.35	47.64	17.51	54.01
5	-3.38	2.67	3.89	0.89	1.97	0.09	0.94	0.36	3.54
6	-77.54	43.15	115.02	52.74	14.62	12.45	35.21	6.28	86.91
7	-12.71	4.57	13.26	1.11	11.58	0.10	0.48	0.04	5.16
Total	-132.44	519.92	463.97	203.41	349.36	85.83	-174.63	470.32	1321.76

Table C.10 SDA of NO_X at segmental level, 1994 - 1999.

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-17.62	-880.95	1430.55	255.90	1008.32	448.62	-282.29	419.24	951.23
2	59.85	-151.04	206.25	602.37	896.74	-2.00	-1290.87	99.54	214.60
3	-56.87	-22.12	100.19	15.49	11.46	4.32	68.92	2.99	24.18
4	-218.38	-139.60	345.64	-0.91	1.87	2.52	342.16	-15.31	-27.65
5	-19.76	-5.35	23.11	5.29	11.71	0.53	5.56	-8.36	-10.37
6	-455.81	-182.44	682.33	312.85	86.75	73.86	208.87	-20.91	23.17
7	-74.05	-14.09	77.98	6.52	68.06	0.58	2.82	-0.70	-10.86
Total	-782.64	-1395.58	2866.04	1197.51	2084.92	528.43	-944.82	476.48	1164.31

Table C.11 SDA of NMOC at segmental level, 1994 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	0.10	-442.48	256.75	45.93	180.97	80.52	-50.66	-82.26	-267.89
2	0.63	29.95	6.40	18.69	27.83	-0.06	-40.06	17.92	54.91
3	-6.70	-11.46	13.33	2.06	1.52	0.57	9.17	-1.70	-6.53
4	-19.83	-131.30	127.12	-0.34	0.69	0.93	125.84	-15.63	-39.64
5	-1.47	-3.49	2.95	0.68	1.50	0.07	0.71	-1.95	-3.96
6	-39.42	-167.63	122.98	56.38	15.64	13.31	37.64	-16.10	-100.17
7	-4.55	-5.60	6.37	0.53	5.56	0.05	0.23	-0.13	-3.91
Total	-71.24	-731.99	535.89	123.94	233.70	95.38	82.87	-99.84	-367.19

Table C.12 SDA of CO at segmental level, 1994 - 1999

Segment	Technology			Final demand					
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	Sum
1	-3.53	-1432.75	1225.58	219.23	863.85	384.34	-241.84	-14.23	-224.93
2	7.06	130.25	42.12	123.02	183.14	-0.41	-263.63	89.55	268.98
3	-31.65	-31.02	59.97	9.27	6.86	2.59	41.26	-2.43	-5.12
4	-101.98	-113.56	178.02	-0.47	0.96	1.30	176.23	-23.89	-61.41
5	-7.05	-7.50	11.72	2.68	5.94	0.27	2.82	-5.16	-7.99
6	-186.96	-271.69	413.99	189.81	52.63	44.82	126.73	-22.26	-66.91
7	-24.50	-16.40	32.32	2.70	28.21	0.24	1.17	-0.39	-8.97
Total	-348.60	-1742.68	1963.72	546.25	1141.59	433.14	-157.27	21.19	-106.36

Table C.13 SDA of TSP at segmental level, 1990 - 1999

Segment	Technology			Final demand					
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	Sum
1	-13.22	-781.25	875.42	162.90	556.92	261.84	-33.63	-30.15	50.80
2	-0.63	75.35	-1.49	65.71	98.81	-2.09	-162.02	32.27	105.50
3	-8.12	-15.55	27.58	4.96	2.72	1.09	20.75	0.96	4.87
4	-75.05	26.14	114.82	0.29	0.69	0.83	121.20	30.74	96.65
5	-0.62	-3.90	3.81	1.35	1.59	0.21	1.09	-0.42	-1.13
6	-64.04	-84.12	149.17	72.90	15.95	15.78	56.83	-4.26	-3.25
7	-30.17	-8.60	28.86	3.33	28.26	0.19	-0.42	-1.16	-11.07
Total	-191.85	-791.93	1198.16	311.43	704.95	277.84	3.80	27.98	242.36

Table C.14 SDA of PM_{10} at segmental level, 1990 - 1999

Segment	Technology			Final demand					
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	Sum
1	-3.59	-392.13	525.42	97.77	334.26	157.16	-20.18	27.34	157.03
2	0.98	99.70	-0.26	11.40	17.14	-0.36	-28.11	44.54	144.97
3	-4.38	-6.93	16.11	2.90	1.59	0.63	12.12	1.25	6.06
4	-43.13	-17.35	67.18	0.17	0.41	0.48	70.91	1.62	8.33
5	-0.22	-1.75	2.20	0.78	0.92	0.12	0.63	0.08	0.32
6	-34.06	-32.19	85.88	41.97	9.18	9.08	32.72	0.10	19.73
7	-14.91	-3.23	15.26	1.76	14.95	0.10	-0.22	-0.56	-3.43
Total	-99.30	-353.88	711.80	156.75	378.44	167.21	67.87	74.38	333.00

Table C.15 SDA of SO_2 at segmental level, 1990 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-240.58	-529.65	1263.58	235.13	803.86	377.95	-48.54	167.43	660.78
2	-70.36	-325.28	-34.68	1525.79	2294.39	-48.60	-3762.21	-196.62	-626.95
3	-37.03	-15.91	62.40	11.23	6.16	2.46	46.94	2.34	11.80
4	-206.32	-44.80	254.13	0.63	1.53	1.83	268.24	-5.35	-2.35
5	-9.02	-3.90	10.04	3.56	4.20	0.54	2.86	-1.61	-4.49
6	-315.61	-106.13	401.27	196.10	42.90	42.44	152.89	-14.57	-35.04
7	-206.85	-12.44	146.66	16.92	143.61	0.95	-2.11	-6.40	-79.04
Total	-1085.77	-1038.10	2103.39	1989.35	3296.65	377.57	-3341.93	-54.80	-75.28

Table C.16 SDA of NO_X at segmental level, 1990-1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-646.93	-1515.83	2888.74	482.17	1734.66	807.79	-135.88	157.58	883.56
2	-191.26	1163.50	-93.53	392.25	617.99	-14.58	-1089.19	375.09	1253.80
3	-95.74	-15.03	152.54	25.42	14.05	5.67	107.40	10.84	52.62
4	-514.57	16.50	619.66	1.40	3.52	4.18	610.55	45.65	167.24
5	-24.17	-4.06	24.94	7.51	9.62	1.26	6.55	-2.05	-5.34
6	-819.19	14.18	998.76	446.23	100.19	100.10	352.24	-3.49	190.25
7	-544.37	1.30	381.24	40.05	345.27	2.28	-6.37	-16.02	-177.84
Total	-646.93	-1515.83	2888.74	482.17	1734.66	807.79	-135.88	157.58	2364.28

Table C.17 SDA of NMOC at segmental level, 1990 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-18.59	70.87	34.59	6.44	22.01	10.35	-1.33	45.69	132.57
2	-6.91	58.75	-3.44	151.45	227.75	-4.82	-373.44	20.94	69.34
3	-0.72	-7.35	9.41	1.69	0.93	0.37	7.08	0.33	1.67
4	-11.15	73.27	25.88	0.06	0.16	0.19	27.32	44.51	132.52
5	-0.38	-0.82	1.10	0.39	0.46	0.06	0.31	-0.06	-0.16
6	-23.59	-495.86	363.05	177.42	38.82	38.40	138.33	-31.66	-188.05
7	-20.89	-0.07	15.02	1.73	14.71	0.10	-0.22	-0.62	-6.56
Total	-82.22	-301.20	445.62	339.20	304.83	44.64	-201.95	79.13	141.33

Table C.18 SDA of CO at segmental level, 1990 - 1999

Segment	Technology			Final demand					Sum
	Technical Coefficient	Pollution Intensity	Final demand subtotal	Household Consumption	Government consumption	Investment	Exports	Import	
1	-110.28	952.69	220.49	41.03	140.27	65.95	-8.47	576.50	1639.41
2	-33.70	453.73	-16.08	707.50	1063.90	-22.53	-1744.52	176.76	580.71
3	-14.27	29.24	17.85	3.21	1.76	0.70	13.43	8.92	41.75
4	-66.22	102.98	71.60	0.18	0.43	0.52	75.58	53.73	162.09
5	-4.08	6.93	3.15	1.12	1.32	0.17	0.90	2.98	8.98
6	-123.89	302.27	127.36	62.24	13.62	13.47	48.53	37.21	342.95
7	-86.45	20.58	57.97	6.69	56.76	0.37	-0.84	-2.04	-9.94
Total	-438.89	1868.43	482.35	821.97	1278.07	58.65	-1615.39	854.06	2765.95

Note

[i] All the data are original except indicated otherwise. Unit: Ton.

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