CHINA'S ENERGY-USE CHANGES FROM 1981 TO 1987:
A STRUCTURAL DECOMPOSITION ANALYSIS

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ABSTRACT

Energy consumption normally grows faster than economic output in developing countries because several major changes associated with development--industrialization, substitution of commercial energy for traditional energy, the construction of modern infrastructure, urbanization, and motorization--point towards an increased energy intensity. China's economic development in the 1980s, however, did not follow this pattern. Between 1981 and 1987, the growth rate of total primary energy consumption in China was only about half that of the real gross domestic product (GDP). Energy intensity, in grams of standard coal equivalent per renminbi (gsce/RMB) of GDP (in 1980 constant prices), decreased by almost 22 percent from 1,273 in 1981 to 996 in 1987.

The purpose of this dissertation is to explore how this drop in China's energy intensity occurred and to determine major sources of energy savings. I combine a quantitative modeling approach with a qualitative policy analysis and study China's energy-use changes from both macro- and micro-perspectives. The result of my structural decomposition analysis indicates that China's energy savings from 1981 to 1987 came primarily from production-technology changes rather than final-demand shifts. The driving force of energy-intensity decline is energy-efficiency improvements--reductions in energy inputs per unit of gross output--in many production sectors, which is multiplied across the entire economy through interindustry input-output linkages. I identify three macroeconomic factors that are primarily responsible for the energy-efficiency improvements: (1) energy-conservation programs, (2) improvements in macroeconomic performance, and (3) increases in energy prices. I find that very often the improvements in energy management and the introduction of energy-saving technologies are not the result of direct efforts to reduce energy consumption or costs, but of indirectly pursuing other economic goals, such as capacity expansion, improved product quality and variety, and increased productivity.

A key lesson from this study of China's energy-use changes between 1981 and 1987 is that energy problems are closely connected to broader issues of social and economic development. The energy intensity of an economy is not just a function of energy prices or a result of energy-cost minimization calculus. Rather, it is the cumulative product of millions of decisions made by consumers on how much and where to spend their money and by producers on how to combine energy and other inputs to provide the goods and services that consumers demand. Those decisions affect the level and mix of different types of economic activities, which ultimately determine the energy requirement of the economy and the nation's aggregate demand for energy.

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CHAPTER 1

INTRODUCTION

Energy consumption normally grows faster than final economic output in developing countries.[1] Economic development in the People's Republic of China (China) in the 1980s, however, did not follow this pattern. Between 1981 and 1987, the growth rate of total primary energy consumption in China was only about half that of the gross domestic product (GDP) and energy intensity, in grams of standard coal equivalent per renminbi (gsce/RMB) of GDP (in 1980 constant prices), decreased by almost 22 percent from 1,273 in 1981 to 996 in 1987 (Polenske and Lin, 1993). The purpose of this research is to explore how this drop in China's energy intensity occurred and to identify factors that were primarily responsible for the energy savings.

BACKGROUND

Because of rapidly growing energy consumption, energy intensity, measured in terms of an energy-to-final output ratio, typically increases during the early stage of economic development (Dunkerley et al., 1981; Leach, et al., 1986; Ang, 1987; OTA, 1991; Wu and Dong, 1991). Eden and Posner et al. (1981) calculate energy-GDP ratios for many countries and find that such ratios rise at the early stage of economic development, decline slightly with industrial maturity, and

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[1] This relationship holds regardless of whether final output is measured in terms of gross domestic product (GDP) or gross national product (GNP). Also, throughout this research, we will use the term "energy" to refer to commercial energy, thus excluding traditional (mostly biomass) fuels. If biomass is included, we will note this explicitly.

then are maintained at a fairly high level. Levine et al. (1991) indicate that between 1972 and 1988, energy consumption for the developing countries as a whole grew about 20 percent more than GDP. Schipper and Meyers (1992) similarly report that for most of the past 20-30 years, commercial energy consumption increased more rapidly than GDP in developing countries. Researchers, for example, have documented rising energy intensity in Brazil, Greece, Mexico, and Pakistan (Samouilidis and Mitropoulos, 1984; Sterner, 1985; Riaz, 1987; Schipper and Meyers, 1992). Imran and Barnes (1990) show that despite sharp increases in energy prices, the average energy intensity of developing countries continued to rise in the late 1970s and 1980s. Gibbons et al. (1989) reach a similar conclusion in examining energy-intensity changes in Japan, developing countries, the former Soviet Union, and the United States from 1960 to 1986. Using both cross-section and time-series data, Zilberfarb and Adams (1981) estimate that the elasticity of energy consumption with respect to gross national product (GNP) in developing countries is significantly above one, being in the neighborhood of 1.35.

Analysts cite five major factors that underlie the observed increase in energy intensity as final output grows in developing countries.[2] First, development theorists posit that economic development is a transformation process from the agricultural to

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[2] Some analysts have questioned the usefulness of the concept of energy intensity because it is determined by many factors and will change as those factors change (Berndt and Wood, 1974; 1975; Percebois, 1979). We will discuss some of those issues in Chapter 2. We believe that energy intensity is a useful summary indicator for tracing energy-use changes in a given economy over time. Like any summary indicator, energy intensity suppresses the details and complexities that are of significance in understanding the relationship between energy and the economy. That is one reason why studies like this one are important.

manufacturing sectors and finally to the service sector (Clark, 1940; Kuznets, 1956; Chenery and Syrquin, 1975). In the industrialization stage, an increase of the more energy-intensive manufacturing industries and a decline of the less energy-intensive agricultural industries will lead to a more rapid rise in total energy use than in final output (Dunkerley et al., 1981; Moroney, 1988). Second, the use of traditional energy is widespread in many developing countries. Higher incomes resulting from economic development enhance the convenience and cost advantages of commercial over traditional energy and stimulate substitution (Ang, 1987). Thus, the share of commercial energy in total energy consumption increases sharply as development proceeds. Because energy-intensity calculations usually include only commercial energy, this tends to increase energy intensity. Third, infrastructure development is often a precondition for economic development. This requires large quantities of energy-intensive materials, such as steel and cement (Goldemberg, 1991). Fourth, developing countries typically experience rapid urbanization, which is a powerful force driving up energy intensity because it shifts production activities formerly undertaken in the home with little or no energy to outside producers who do use energy and because it increases the demand for transportation, which needs modern, commercial fuels (Jones, 1989; Imran and Barnes, 1990). Fifth, economic development is usually accompanied by increasing mobility and an expanding motorized transportation system, which augment even more the fuel requirements (Imran and Barnes, 1990).

China's economic development during the 1980s, however, did not follow this pattern (Lin, 1991; Polenske and Lin, 1993). China is still a low-income country at an early stage of economic development. Its GDP per capita was only $465 in 1985 (Wu et al., n.d.).[3] There is a large potential for substitution of commercial for traditional energy in China because the use of traditional fuels is widespread, accounting for about 80 percent of daily energy consumption in rural areas (Deng and Wu, 1984; Smil, 1988; B. Wang, 1990), China experienced a rapid economic growth, motorization, and urbanization in the 1980s. Between 1981 and 1987, the growth rate of GDP (in 1980 constant prices) averaged about 10 percent per year. Industrial output grew at an even higher rate--12 percent annually. The number of nonmilitary motor vehicles doubled, from 20 million in 1981 to 41 million in 1987 (SSB, 1992, p. 348). The percentage of population living in urban areas increased from 20 percent in 1981 to 25 percent in 1987. The country was also undertaking major infrastructure construction. Total investment in capital projects grew by approximately 15 percent annually during 1981-1987. Meanwhile, the annual growth rate of energy consumption was only 5 percent, or just half that of GDP, and energy intensity, in grams of standard coal equivalent per RMB (gsce/RMB) of GDP (in 1980 constant prices), decreased by almost 22 percent, from 1,273 in 1981 to 996 in 1987 (see Chapter 2 of this study).[4]

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[3] Based on the official exchange rate.

[4] As we will discuss in the next section, this phenomenon of declining energy intensity also occurs in some developing countries and in several newly industrialized countries. The trend towards declining energy intensity is expected to continue in China. The official plan of the Chinese government is to limit the growth rate of primary energy consumption to about half that of GDP between 1990 and 2000 (CCPC, 1991; Polenske and Lin, 1993).

Unlike what happened in many oil-importing countries during the two oil crises, the drop in energy intensity in China was not caused by a reduction in energy supply. In fact, energy production in China exhibited the greatest growth in the world between 1980 and 1990 (EIA, 1992, p. 253). In 1980, China produced about 18 quadrillion British thermal units (Btu) of primary energy. By 1990, the production had reached 30 quadrillion Btu and China displaced Saudi Arabia as the world's third largest energy producer, after the United States and the former Soviet Union. In addition, the reduction in energy intensity was achieved at the same time as China's energy mix shifted away from more convenient oil and natural gas to coal, which was inherently more difficult to use and had lower end-use efficiency. Between 1981 and 1987, the share of coal in total primary energy consumption increased from 73 percent to 76 percent while that of oil and natural gas fell from 23 percent to 19 percent (see Chapter 2 of this study).

RESEARCH PURPOSE

The purpose of this research is to explore how this drop in China's energy intensity occurred between 1981 and 1987, the years for which we have reasonable data, and to identify factors that were primarily responsible for the energy savings. We illuminate the complex relationship between energy use and economic activity: how energy use is linked to what final goods and services people consume and how those goods and services are produced. Using a structural decomposition analysis as a basic framework, we will investigate the following three questions:

1. How did energy consumption in China's economy change from 1981 to 1987?

2. How much of this change can be attributed to final-demand shifts (changes in what is consumed) and/or to production-technology changes (changes in how to produce)? and

3. What components of final-demand shifts and/or production-technology changes were primarily responsible for the energy savings that led to the reduction in China's energy intensity?

The separation of final-demand shifts from production-technology changes is important because they reflect two different aspects of the economy, namely, the consumption and production of final goods and services versus intermediate goods and services, and because the factors and policy levers that affect them are often very different (OTA, 1990). In addition, confusion abounds over how China was able to reduce its energy intensity significantly in the 1980s while its economy grew rapidly. Some analysts believe that the decline in energy intensity was, to a large degree, caused by a structural shift from heavy industry to light industry (Cheng, 1984; Tomitate, 1989; Smil, 1990; Kambara, 1992). Others, on the other hand, attribute 40-60 percent of the energy savings to increases in energy efficiency, either through better management or by upgrading equipment and production processes (B. Wang, 1990; Qiu and He, 1991). Our earlier studies on China's material production sectors show that overall, energy-efficiency improvement was the dominant force behind China's energy-intensity reduction in the

1980s, although structural changes did play the dominant role between 1978 and 1981 (Lin, 1991; Polenske and Lin, 1993).[5]

Some of this confusion on the role of energy efficiency and structural change may stem from definitional and measurement differences. Energy efficiency, for example, may be defined economically as the amount of energy required per unit of economic output (economic energy efficiency) or technically as the ratio between raw energy input to useful energy output (technical or thermal efficiency). Schurr and Netschert (1975) point out the paradoxical relationship between the two. On the one hand, the overall thermal efficiency of an economy tends to be inversely associated with the degree of mechanization because the efficiency of transforming raw energy into heat is much higher than that of converting heat into mechanical work. On the other hand, an economy with a high level of mechanization often has a high overall productivity and economic efficiency of energy use.

> One is tempted to summarize this aspect of the relation between thermal and economic efficiency of energy in the form of a paradox. The greater the share of the total energy input converted into mechanical work (directly or via generation of electricity) and, thus, the greater the contribution of energy in raising over-all productivity by replacing and multiplying human labor, the lower the over-all thermal efficiency. On the other hand, the greater the share of energy inputs going into heat, the lower the over-all productivity of the economy but the higher the thermal efficiency of its energy system (Schurr and Netschert, 1975, p. 173).

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[5] Sinton and Levine (1993) analyze three different sets of data with differing levels of industrial disaggregation and reach a similar conclusion.

It also makes a big difference whether researchers measure economic output in physical quantities or in terms of its monetary value. This can be illustrated using steel as an example. It usually requires more energy to produce one tonne of special steel than to produce the same amount of ordinary steel.[6] If we measure steel output in tonnes, the economic energy efficiency of producing special steel is lower than that of producing ordinary steel. Yet, if we measure steel output in terms of its monetary value in the market, the economic energy efficiency of producing special steel is often higher because special steel commands a much higher sales value than ordinary steel in China. Thus, depending on how the output is measured, the changes in the mix of special- and ordinary-steel production will have a completely opposite effect on economic energy efficiency.

It is extremely difficult, however, to clarify the confusion by comparing different studies, because most major studies on China's energy-use changes are conducted by government agencies and the full reports are seldom available to the general public. For those related articles appearing in professional journals, researchers often just state the conclusions and do not provide detailed, if any, information about their methodologies (Sinton and Levine, 1993). From our literature review and discussions with Chinese colleagues, we find that many researchers in China do not use a formal model, but they rely instead on what may be characterized as a "back-of-envelope" approach. Some of the often-cited figures about the relative contribution of

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[6] Most of the measures are given in metric units, tonnes, rather than short tons or long tons.

structural adjustment and energy efficiency to energy savings are, in fact, an extrapolation from some engineering case studies and from research on several energy-intensive industries, most of which were conducted in the middle of the 1980s.

In this research, we examine energy-use changes in China's economy from 1981 to 1987 within the general framework of input-output economics. For input-output economists, the amount of energy required in the economy is the cumulative product of millions of decisions--the consumer deciding what to consume, the government making budget decisions, the investor evaluating where to invest, the trade representative negotiating tariff structures, the manager choosing a production technology, and so on. Those decisions affect what to consume (final demand) and how to produce (production technology), which ultimately determine the nation's aggregate demand for energy. We focus on energy-use changes, rather than changes in the aggregate energy-to-GDP ratio, because it allows us to examine divergent paths of different sectors and to quantify energy effects of various factors directly. It also provides us the flexibility of using other yardsticks besides GDP, such as gross output, to assess energy intensity. We cover only the changes from 1981 to 1987 because those are the only two years for which we have reasonably detailed data. Given the rapid changes in economic and institutional conditions in China in the 1980s, we will be very careful in generalizing our research findings beyond the study period.

This study differs from most previous research on China's energy-intensity reduction in four important aspects. First, we study energy-use changes within a unified and clearly specified framework of the structural decomposition analysis, with a consistent set of concepts, definitions, assumptions, and computations. Second, unlike most previous studies which focus exclusively on the industrial sector, our analysis covers all sectors of the economy, including both material-production sectors and service-producing sectors. Third, we explicitly trace intersectoral input-output linkages and account for both direct and indirect energy use; for example, energy consumption in a radio-assembly line would be a direct use of energy, while the use of plastics in making a radio is an indirect use of energy because energy is required to produce plastics. This enables us to capture not only the direct impacts of an energy conservation measure, but also its indirect impacts through intersectoral linkages. Fourth, we place the structural decomposition analysis into a broad context of changing economic and institutional conditions in China and link energy-use changes with the economic-reform program and changes in government policies in the 1980s.

CONTEXT OF THE STUDY

This study may be viewed within the context of two recent developments in energy research, which have been generating a large number of studies. The first is the notion of decoupling energy use and economic growth and the second is discussion on conserving energy to reduce greenhouse-gas emissions.

Decoupling of Energy and Economic Growth

Historically, economic growth, as measured by an increase in real GDP, and an increase in energy consumption are tightly linked. Hall et al. (1986) review statistical evidence and previous studies from various countries and find that both time-series and cross-section analyses support a strong relationship between economic activity and fuel use. A high correlation between energy consumption and economic output is also found by Cleveland et al. (1984), who adopt a biophysical approach to analyzing the energy-economy relationship, and by Costanza (1980, 1981) who conducts an input-output analysis for the United States. Hafele (1981) examines the relationship between fuel uses and GDP in 25 countries. His result indicates that the change in fuel use relative to the change in GDP over time was 0.99. Hall et al. (1986) and Zucchetto and Walker (1981) reach a similar conclusion in their analyses. Thus, conventional wisdom is that energy consumption is proportionally (almost 1:1) linked to economic growth (Hall et al., 1986); in other words, for economic activity to increase, there has to be a proportional increase in energy consumption. Related to this conventional wisdom is the notion, sometimes called a "development effect" (Ang, 1985; 1987), that as a country moves through various stages of economic development, its energy intensity first increases, then falls, and finally levels off at a certain point, i.e., the income elasticity of energy tends towards unity in the long term (Brooks, 1972; Nguyen, 1984).

In the early 1970s, this iron link between economic growth and rising energy use seemed to be broken. In the United States, for example, real GDP grew by about 2.5 percent per year between 1972 and 1985, but energy use increased at an annual rate of only 0.3 percent, resulting in about a 25 percent reduction in overall energy-intensity

(OTA, 1990).[7] The same phenomenon also occurred in other industrialized countries, such as Austria, France, Germany, Japan, Sweden, and the United Kingdom during the same period (Dunkerley, 1980; Ostblom, 1982; Jenne and Cattell, 1983; Morovic et al., 1989; U.S. DOE, 1989), in several newly industrialized countries, such as South Korea and Taiwan (Chen and Rose, 1990; Chung, 1991), and even in some developing countries (Leach et al., 1986). Analysts term this phenomenon as the "decoupling of energy and GDP" and question the validity of the conventional wisdom about the iron link between energy use and economic growth. Some analysts, such as Goldemberg (1991) and Weinberg (1988), point out that decoupling of economic growth and energy use is not a new phenomenon; it has taken place for decades. Goldemberg (1991) also reviews empirical evidence on the evolution of energy intensity in different countries or country groups since 1840, finding a general pattern, namely, as a country develops, its energy intensity first increases, then peaks, and finally declines at a certain stage of development. The peak values of energy intensity a country has to reach in the development process, however, decline and become much less accentuated over time, primarily because of modern methods of production and advancements in energy technologies.

We believe that there is a close, but flexible, link between energy use and economic development, which may change as economic, institutional, technological, and resource conditions change. In the United States, for example, energy and GNP seem to be recoupled from

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[7] This trend ended in the late 1980s. Some analysts, such as Cleveland et al. (1984) and Kaufmann (1992), argue that the iron link has never been broken.

1986 to 1988, with energy use increasing at a 3.9 percent annual rate and GNP growing at 4.1 percent (OTA, 1990). To understand the energy-development link, we must, therefore, dig below the surface of energy intensity to see who uses energy, for what purposes, and how energy consumption changes in relation to changes in economic activities. In this study, we show that intimate connections exist between energy consumption, final demand, and production technology, and that with certain changes in final demand and/or production technology, energy intensity can decline even at an early stage of economic development. The study should improve our understanding of the relationship between economic development and energy use in China, the world's third largest commercial energy consumer. It also provides an opportunity to compare the declining energy-intensity in China with the decoupling of energy-use and GDP in several other countries to see whether there are common or divergent forces at work.

Conserving Energy to Reduce Greenhouse-Gas Emissions

Energy consumption in China has become a matter of international concern because of its contribution to increased emissions of greenhouse gases, which many scientists believe cause global warming (IPCC, 1991a; 1991b; World Resources Institute, 1990). In 1988, carbon releases from China's combustion of fossil fuels amounted to about 550 million tonnes or about 10 percent of the total world generation, with nearly 450 million tonnes coming from coal (Smil, 1990). Driven by the requirements of the still rapidly industrializing economy and the need to accommodate roughly 15 million additional people every year, China's energy use and carbon-dioxide generation will continue to increase unless specific measures are taken to reduce the rate of increase. The World Energy Conference participants project that China may account for as much as one-third of the global increase in commercial energy consumption between 1990 and 2020 (Manne and Schrattenholzer, 1989). China's share of global carbon-dioxide emissions may exceed 15 percent in the next decade and 25 percent before the middle of the next century (Smil, 1990). Clearly, without China's cooperation there can be no effective long-term program for reducing global warming.

Reducing carbon-dioxide emissions in China, however, is a complex issue and may have a high economic cost. Energy is a fundamental input to the economy and a major source of productivity growth (Hudson and Jorgensen, 1974; Moroney, 1992). There is already an energy shortage in many parts of the country, which forces a large number of factories to produce at less than their designed capacity or even to close completely, for varying periods of time (Polenske, 1991).[8] Energy restrictions are likely to exacerbate the energy-shortage problem and cost both jobs and income. Because China's fossil-fuel resource base is dominated by coal, any constraints on carbon-dioxide emissions will be costly. Manne and Richels (1991), for example, estimate that even limiting carbon emissions to twice their 1990 level will result in over a 10 percent reduction in China's annual gross domestic product by the latter half of the next century.

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[8] This phenomenon is still occurring according to information Polenske and Lin (1992) gathered on a field trip to China in August 1992.

Many analysts believe that energy conservation[9] is a key to this development-environmental deadlock and that it provides one of the best hopes for slowing global warming (Goldemberg et al., 1987; Keepin and Kats, 1988; Kats, 1990; Geller, 1991).[10] They argue that increased energy efficiency can save a large amount of energy, reducing energy demand thus carbon-dioxide emissions from the burning of fossil fuels. This allows developing countries to shift resources from wasteful expenditures on energy to investing in more productive sectors. In addition, energy saving from efficiency improvements helps developing countries to control other energy-related pollution, reduces their dependence on energy imports, improves their imbalance of payments, and enhances national security (French, 1990). The end result is that developing countries can use less energy, emit fewer air pollutants, and enjoy more rapid and sustainable economic growth (Kats, 1990). Analysts are particularly optimistic about the energy-saving potential in China because the energy-intensity of China's economy is much higher not only than that of advanced economies but also than that of most developing countries (Gibbons, 1991; Chandler, 1988; Wei, 1991; Wang and Zhou,

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[9] As pointed out by Professor Rose (1986), the "rational and effective use" of energy is a preferable term to "energy conservation" because many people interpret the latter narrowly as curtailment or preservation; but because energy conservation has become so embedded in the field, we will use it here, with its broader implication.

[10] Not every one agrees that an improvement in energy efficiency will lead to a reduction in energy demand. Brooks (1990) and Greenhalph (1990), for example, argue that increasing energy efficiency has the effect of reducing the implicit energy price and increases, not decreases, energy demand at the macroeconomic level. A similar argument, known as the "rebound effect," has been advanced by Khazzoom (1987) at the microeconomic level, although there are heated debates on the size of the rebound effect (Lovins, 1988; Khazzoom, 1989; Henly et al., 1988).

1991). Some analysts, such as Meyers (1988), argue that the potential for energy-efficiency improvement is perhaps the most important unused energy resource in China.

These are, however, just claims for potential energy savings. There is no assurance that such savings, or even a small fraction of them, will actually be achieved. In this study, we will analyze factors behind the fall in China's energy intensity between 1981 and 1987 and identify some policy instruments or options that may be used to realize some, if not all, of the alleged large energy-saving potential in China. We will also conduct a case study of energy-efficiency improvements in China's iron and steel industry to find out what those enterprises actually did to conserve energy and what motivated them to adopt more energy-efficient production technologies. This is important because, so far, we seem to be far better at identifying potentials for energy savings in developing countries than designing effective strategies to realize those potentials and there exists an energy conservation gap (Brooks and Krugmann, 1990).

Part of the reason for the energy conservation gap, we believe, is that analysts rely too much on engineering-economics calculus and overemphasize the role of energy prices and cost-minimization in encouraging the use of energy-saving technologies. Energy costs, which rarely comprise more than 5 percent of total production costs, are just one of many factors managers consider in choosing technology and factor inputs. To make energy efficiency relevant to the average business enterprise, we need to look not only at cost impacts but also at other motivations for technological changes, such as increasing output, promoting productivity, improving product mix and quality, enhancing flexibility, and so on. Furthermore, technological adoption and use are constrained by macroeconomic and resource conditions and embedded within an institutional context, which provides both incentives and disincentives for decision-makers. It will take more than "getting energy prices right" to improve energy efficiency in developing countries. Measures must also be taken, for example, to provide a favorable economic environment for investing in more-efficient energy technologies and to strengthen institutions so that the improved technologies can be used appropriately.

ORGANIZATION OF THE STUDY

The study consists of seven chapters. Following this introduction, Chapter 2 presents an overview of energy consumption in China's economy and provides a context and background information for the structural decomposition analysis. We examine the size and structure of China's energy consumption in 1981 and 1987, assess energy intensity of China's economy, and illustrate how energy uses changed between 1981 and 1987. Chapter 3 lays the conceptual and methodological foundation for the study. We review briefly the history of structural decomposition analysis, describe our model structure and implementation, and discuss the strengths and limitations of the model. We also outline the broad results of our structural-decomposition computations, which serves as a framework for a more detailed analysis in Chapters 4 and 5.

Chapters 4 and 5 form the core of this study. In Chapter 4, we perform a set of computations to determine energy impacts of final-demand shifts. The final-demand shifts include not only the changes in direct use of energy by consumers, but also the indirect energy changes caused by changes in the demand for nonenergy goods and services, which require varying amounts of energy in their production. Our analysis indicates that economic growth, the increase in the overall level of final demand (i.e., GDP), was the engine behind China's energy-consumption growth between 1981 and 1987. In Chapter 5, we examine how changes in production technology from 1981 to 1987 affected energy consumption in China's economy. We find that most of the energy savings between 1981 and 1987 came from energy-efficiency improvement--the reduction in energy input per unit of gross output--in many production sectors, which was multiplied across the entire economy through interindustry input-output linkages. We also identify several factors that were primarily responsible for the energy-efficiency improvement.

In Chapter 6, we conduct a case study of energy-efficiency improvements in China's iron and steel industry to complement our macro-level structural decomposition analysis of energy-use changes. We review the progress made towards more efficient energy use in the industry between 1981 and 1987 and describe in some detail how this greater efficiency was achieved. We show that energy-efficiency gains in China's iron and steel industry was the result not only of direct efforts to reduce energy consumption, but more importantly, of indirectly pursuing other economic goals, such as capacity expansion, better product quality, improved product variety, and increased yield of materials, which often have side benefits on energy efficiency.

Finally, in Chapter 7, we summarize the research findings, discuss their policy implications, and recommend several areas for future research. We call for a broad approach to energy conservation, which has four basic propositions. First, energy is just one factor of production, and its rational use cannot be separated from the productivity of other factor inputs and the efficient use of other products. Energy conservation, therefore, should not be pursued in isolation from other economic objectives. Rather, it should be an integral part of greater efforts to improve overall economic efficiency. Second, in developing energy-conservation strategies, policymakers should go beyond energy products. They should explore not only conservation opportunities in direct consumption of energy products, but also indirect energy savings from more efficient use of nonenergy products. Third, not all energy-saving opportunities are equal. Energy-conservation efforts should give priority to those sectors or products whose energy-efficiency improvement, through interindustry linkages, will result in the largest energy savings. Fourth, there is no simple, standard policy formula to promote energy conservation. An effective strategy must be based on diagnosis--finding the causes of energy wastes in specific situations and then carefully designing strategies to overcome those causes. As conditions and situations change, policymakers must also shift the types of strategies used to improve energy efficiency.

CHAPTER 2

ENERGY IN CHINA'S ECONOMY, 1981 AND 1987

Energy plays a critical role in an economy. It is not only a final product that people use for such basic activities as cooking, lighting, controlling temperature, and powering appliances, but it also is a fundamental input to the economy, essential for manufacturing products, transporting output, and delivering services (OTA, 1990). In fact, the very definition of economic production implies use of energy, as pointed out by Chenery (1953):

> To the economist, production means anything that happens to an object or set of objects which increases its value. Usually this results in a change in form, but it may be merely a change in space or time. The basic physical condition necessary to effect any of these changes (except the last) is that energy must be applied to the material. Application of energy in some form is one element common to both the economist's and the engineer's concept of production.

In this chapter, we examine the energy-use pattern in China's economy to provide the context and background information for the structural decomposition analysis presented in Chapters 3 to 5. We divide the chapter into three sections. We first review the size and structure of China's energy consumption in 1981 and 1987, then assess the energy intensity of China's economy, and finally describe in some detail how energy uses changed between 1981 and 1987.

SIZE AND STRUCTURE OF ENERGY CONSUMPTION

To the seemingly simple question, "how much commercial energy is used in China's economy?" there is no simple answer. Energy is not a single material commodity. It is an abstract concept invented by physical scientists to describe quantitatively a wide variety of natural phenomena (Rose, 1986). Energy occurs in many different forms and comes from many different resources or commodities--coal, oil, natural gas, hydropower, to name a few. There is no universally agreed upon set of standards for converting different energy commodities to a common base (EIA, 1977; Slesser, 1978; Spreng, 1988). To complicate the issue further, energy is measured in many different units-- mass or weight, volume, heat, power, and work--and reported in many different terminologies and system boundaries. Energy statistics, for example, can be collected at the point of primary source (primary energy), at the location of end-use (end-use consumption), or based on the actual service energy provides (energy service) (Spreng, 1988). It can be reported in terms of gross energy requirement or process energy requirement (Slesser, 1978). Depending on the convention and system boundary in which energy consumption is calculated, different analysts may have different estimates concerning the amount of energy used in China's economy.[1]

In this study, we estimate China's energy consumption based on the energy flows in our energy input-output model of China's economy in 1981 and 1987 (see Appendices I and II). We adopt China's official energy statistical system and measure energy in terms of standard coal equivalent. We convert coal, petroleum, natural gas, and electricity

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[1] See EIA (1977) for a summary of the nature, measurement, comparison, and utilization of energy commodities and for a set of tables for converting different energy commodities into a common base. See Slesser (1978) and Spreng (1988) for discussions of national and international energy statistics.

into standard coal according to their average *net* calorific values or *lower* heating values. We estimate the standard coal equivalent of hydropower based on the amount of fossil fuel that would be required to generate the equal kilowatt hours of hydro-electricity. To avoid double counting both the fossil fuel used to generate electricity and the electricity from the thermal power stations, we include only energy from primary sources--coal, petroleum, natural gas, and hydropower--in calculating total energy consumption for the whole economy.[2]

Energy Supply and Demand

Tables 2-1 and 2-2 show the results of our estimation of China's energy balance in 1981 and 1987. As noted earlier, China is the world's third largest commercial energy user behind the United States and former Soviet Union. It consumed approximately 874 million tonnes standard coal equivalent (tsce) of primary energy in 1987, up by 43 percent over its 1981 total primary energy consumption of 611 million tsce. In comparison, total world primary energy consumption grew by only 14 percent between 1981 and 1987 (SSB, 1990a, p. 394; 1992, p. 380). As a result, China's share of global energy consumption increased from 7 percent in 1981 to 9 percent in 1987.

Domestic energy production, which amounted to 632 million tsce in 1981 and 913 million tsce in 1987, supplies almost all of China's energy consumption (Tables 2-1 and 2-2). Imports accounted for less than one percent of total primary energy consumption in both 1981 and 1987

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[2] See Chapter 3 for discussions on our method of energy accounting and incorporating energy flows into the input-output model.

TABLE 2-1

ENERGY BALANCE OF CHINA, 1981

(1000 tonnes standard coal equivalent)

	Coal	Petroleum	Natural Gas	Hydropower	Electricity	Total
<u>Primary Supply</u>						
Production	444037	144604	16944	26677	--	632263
Exports	4890	25254	0	0	--	30144
Imports	-1379	-1019	0	0	--	-2397
Inventory Change	-5794	-263	0	0	--	-6057
Total Primary Energy Supply	446320	120632	16944	26677	--	610574
<u>Energy Demand</u>						
Energy Sectors						
Electricity						
Fuel Inputs	85684	24313	80	26677	--	136754
Electricity Production	--	--	--	--	38009	38009
Self-Use and Loss	--	--	--	--	5663	5663
Coal	10089	943	0	0	2178	13210
Petroleum	561	10276	2328	0	1029	14194
Natural Gas	36	209	4668	0	37	4951
End Uses						
Agriculture	11295	11316	0	0	3461	26071
Iron and Steel	60996	7786	1045	0	3260	73087
Nonferrous Metals	4153	1038	45	0	2278	7513
Chemical Fertilizer	34687	5290	4319	0	3764	48060
Heavy Chemicals	12492	17311	1773	0	3497	35072
Cement	23106	1023	10	0	746	24885
Construction Materials	17639	2737	70	0	658	21103
Heavy Machinery	21637	3893	638	0	2845	29013
Light Industry	48231	11034	838	0	5071	65174
Construction	2710	2469	665	0	573	6417
Freight & Communication	12640	10580	80	0	304	23603
Passenger Transport	2302	1862	13	0	54	4232
Commerce	3753	503	0	0	235	4491
Services	7956	6379	80	0	907	15321
Households	86355	1670	293	0	1450	89767
Total End Uses	349950	84891	9869	0	29101	473811
Total Primary Energy Demand	446320	120632	16944	26677	--	610574

Source: Division of Operation Research and Management Sciences, Institute of Systems Science, Chinese Academy of Sciences; and State Statistical Bureau of China. 1990. <u>China Energy Statistical Yearbook, 1989</u>. Beijing: China Energy Statistical Press, p. 230.

Note: -- = Not Applicable.

TABLE 2-2

ENERGY BALANCE OF CHINA, 1987

(1000 tonnes standard coal equivalent)

	Coal	Petroleum	Natural Gas	Hydropower	Electricity	Total
Primary Supply						
Production	662845	191632	18474	39698	--	912649
Exports	10260	44641	0	0	--	54901
Imports	-1386	-4475	0	0	--	-5862
Stock Change	-11379	1360	0	0	--	-10019
Total Primary Energy Supply	665351	150106	18474	39698	--	873629
Energy Demand						
Energy Sectors						
Electricity						
Fuel Inputs	144454	18791	545	39698	--	203488
Electricity Supply						
Production	--	--	--	--	61114	61114
Exports	--	--	--	--	5	5
Imports	--	--	--	--	-159	-159
Self-Use and Loss	--	--	--	--	8726	8726
Coal	17542	1920	146	0	3257	22866
Petroleum	1003	21009	1131	0	1897	25039
Natural Gas	68	323	5546	0	82	6019
End Uses						
Agriculture	16800	12893	0	0	4419	34113
Iron and Steel	92721	6449	958	0	5704	105831
Nonferrous Metals	6496	1446	40	0	3119	11101
Chemical Fertilizers	41178	6247	3885	0	3635	54945
Heavy Chemicals	16295	20173	2200	0	4176	42844
Cement	40871	1840	36	0	2281	45028
Construction Materials	35627	4969	243	0	1867	42706
Heavy Machinery	25986	4800	549	0	4542	35877
Light Industry	70452	10992	788	0	9944	92176
Construction	3352	5638	1144	0	718	10852
Freight & Communication	13601	17984	53	0	836	32474
Passenger Transport	2457	3552	13	0	107	6129
Commerce	5981	876	0	0	603	7460
Services	12385	8067	173	0	1832	22457
Households	118081	2138	1024	0	3521	124763
Total End Uses	502284	108064	11106	0	47305	668759
Total Primary Energy Demand	665351	150106	18474	39698	--	873629

Source: Division of Operation Research and Management Sciences, Institute of Systems Science, Chinese Academy of Sciences; and State Statistical Bureau of China. 1990. China Energy Statistical Yearbook, 1989. Beijing: China Energy Statistical Press, p. 242.

Note: -- = Not Applicable.

(2 million and 6 million tsce, respectively). China exported 30 million tsce of energy (5 percent of the energy production) in 1981 and 55 million tsce (6 percent of the production) in 1987, over 80 percent of which was petroleum products, mainly crude oil. Overall, we may characterize China's energy supply and demand condition as one of self-sufficiency. This has two important implications for understanding China's energy-use changes between 1981 and 1987. First, the fluctuation in the international energy market of the 1980s had a relatively minor impact on China's energy supply-demand conditions. Second, China's energy consumption was constrained by domestic production. The consumption tended to increase or decline as the energy production increased or declined. In fact, the growth rates of energy consumption and production were similar for most years between 1980 and 1990.[3]

Table 2-3 shows the sectoral distribution of end-use energy consumption in China in 1981 and 1987. The industrial sector was by far the largest energy user, accounting for 65 percent of China's end-use energy consumption in the 1980s--about 51 percent by the heavy industry and 14 percent by the light industry. The household sector accounted for another 19 percent of energy end use. The rest of energy consumption was distributed among agriculture (5-6 percent), construction (1-2 percent), transportation and telecommunication (6 percent), and commerce and service (4 percent). One reason for the exceptionally small share of transportation energy use is that China's

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[3] This is because China experienced a severe energy shortage in the 1980s. The growth in energy demand far outpaced the expansion in energy supply.

TABLE 2-3

SECTORAL DISTRIBUTION OF END-USE ENERGY CONSUMPTION, 1981 AND 1987
(percent)

Sector	Coal	Petroleum	N. Gas	Electric	Total
1981					
Agriculture	3.2	13.3	0.0	11.9	5.5
Heavy Industry	49.9	46.0	80.1	58.6	50.4
Iron and Steel	17.4	9.2	10.6	11.2	15.4
Nonferrous Metals	1.2	1.2	0.5	7.8	1.6
Chemical Fertilizers	9.9	6.2	43.8	12.9	10.1
Heavy Chemicals	3.6	20.4	18.0	12.0	7.4
Cement	6.6	1.2	0.1	2.6	5.3
Construction Materials	5.0	3.2	0.7	2.3	4.5
Heavy Machinery	6.2	4.6	6.5	9.8	6.1
Light Industry	13.8	13.0	8.5	17.4	13.8
Construction	0.8	2.9	6.7	2.0	1.4
Transport	4.3	14.7	0.9	1.2	5.9
Freight & Communication	3.6	12.5	0.8	1.0	5.0
Passenger Transport	0.7	2.2	0.1	0.2	0.9
Services	3.3	8.1	0.8	3.9	4.2
Commerce	1.1	0.6	0.0	0.8	0.9
Services	2.3	7.5	0.8	3.1	3.2
Households	24.7	2.0	3.0	5.0	18.9
Total End Uses	100.0	100.0	100.0	100.0	100.0
1987					
Agriculture	3.3	11.9	0.0	9.3	5.1
Heavy Industry	51.6	42.5	71.2	53.5	50.6
Iron and Steel	18.5	6.0	8.6	12.1	15.8
Nonferrous Metals	1.3	1.3	0.4	6.6	1.7
Chemical Fertilizers	8.2	5.8	35.0	7.7	8.2
Heavy Chemicals	3.2	18.7	19.8	8.8	6.4
Cement	8.1	1.7	0.3	4.8	6.7
Construction Materials	7.1	4.6	2.2	3.9	6.4
Heavy Machinery	5.2	4.4	4.9	9.6	5.4
Light Industry	14.0	10.2	7.1	21.0	13.8
Construction	0.7	5.2	10.3	1.5	1.6
Transport	3.2	19.9	0.6	2.0	5.8
Freight & Communication	2.7	16.6	0.5	1.8	4.9
Passenger Transport	0.5	3.3	0.1	0.2	0.9
Services	3.7	8.3	1.6	5.1	4.5
Commerce	1.2	0.8	0.0	1.3	1.1
Services	2.5	7.5	1.6	3.9	3.4
Households	23.5	2.0	9.2	7.4	18.7
Total End Use	100.0	100.0	100.0	100.0	100.0

Source: Calculated from data in Tables 2-1 and 2-2.
Note: N. Gas = Natural Gas, Electric = Electricity.

statistics on energy consumption in transportation sector include only consumption by work units whose primary function is transportation, such as railways' companies, and omit energy consumption by vehicles belonging to work units in the industry and agriculture categories because they are considered part of the industrial and agricultural sector (Sinton et al., 1992).

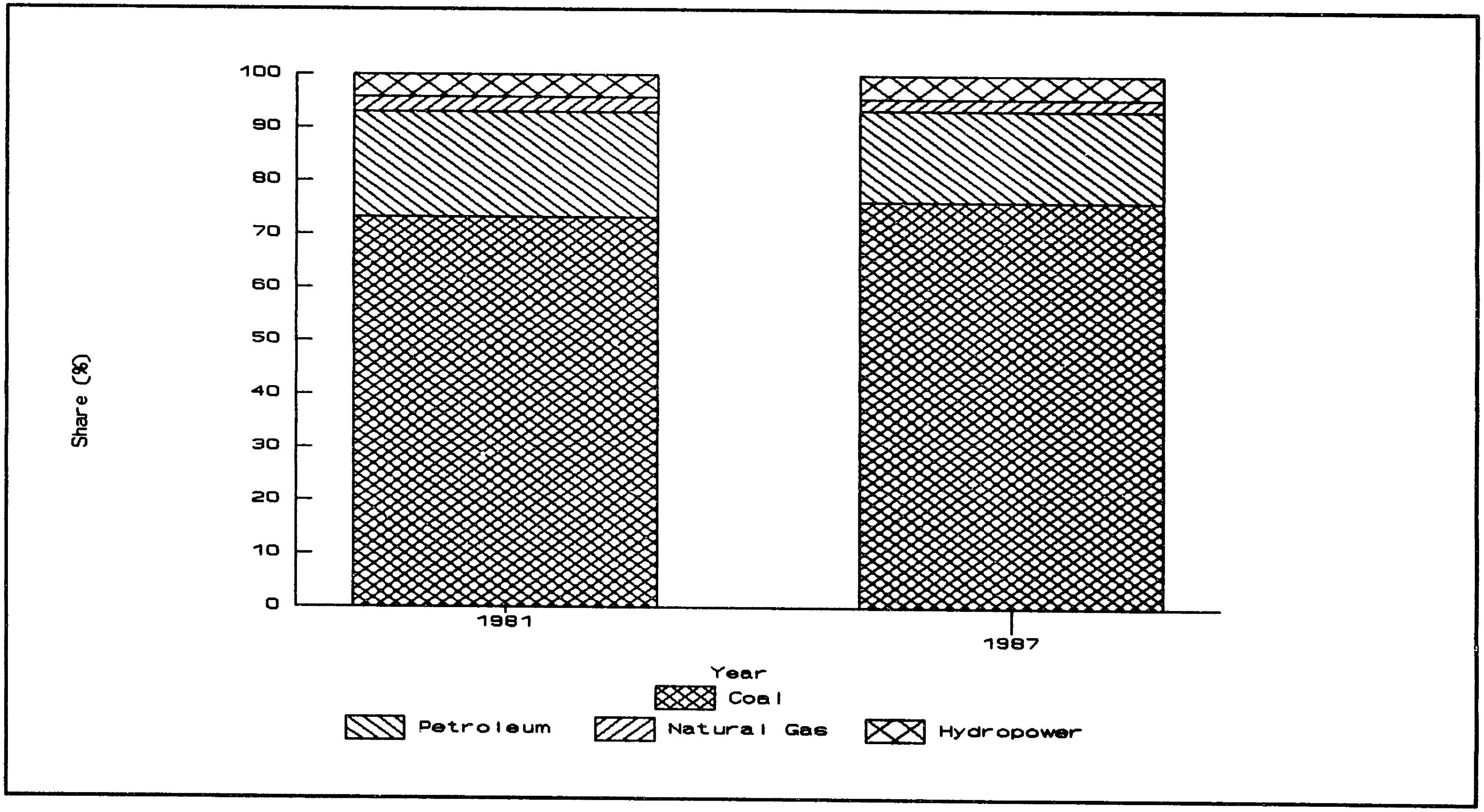
Mix of Energy Sources

Coal is the dominant source of energy in China, as shown in Figure 2-1 and Table 2-4. It accounted for 73 percent of primary commercial energy consumption in 1981 and 76 percent in 1987--the highest share of any major country (World Bank, 1985b). Even in India, where coal is also a major energy source, it accounts for only about 50 percent of primary commercial energy uses. In the United States and the former Soviet Union, the two largest coal producers and consumers of coal, coal accounts for less than 25 percent and 22 percent of total primary energy consumption, respectively. Petroleum accounted for between 17 to 20 percent of China's energy consumption in the 1980s, and natural gas and hydropower supplied the rest (about 7 percent).

Dependence on coal permeates almost every sector of China's economy, as shown in Table 2-4. Coal was the largest fuel source in all sectors except Heavy Chemicals, Construction (in 1987), Freight Transport and Communication, and Passenger Transport. In 1987, for example, coal supplied 85 percent of fuels for power generation, over 50 percent of agricultural energy consumption, and about 96 percent of household energy needs (see Table 2-6). Cheng (1984, p. 112) estimates

FIGURE 2-1

MIX OF PRIMARY ENERGY CONSUMPTION IN CHINA, 1981 AND 1987



Source: Data in Tables 2-1 and 2-2.

TABLE 2-4

ENERGY MIX OF END-USE SECTORS IN CHINA, 1981 AND 1987
(percent)

Sector	Coal	Petroleum	N. Gas	Electric	Total
1981					
Agriculture	43.3	43.4	0.0	13.3	100.0
Iron and Steel	83.5	10.7	1.4	4.5	100.0
Nonferrous Metals	55.3	13.8	0.6	30.3	100.0
Chemical Fertilizers	72.2	11.0	9.0	7.8	100.0
Heavy Chemicals	35.6	49.4	5.1	10.0	100.0
Cement	92.9	4.1	0.0	3.0	100.0
Construction Materials	83.6	13.0	0.3	3.1	100.0
Heavy Machinery	74.6	13.4	2.2	9.8	100.0
Light Industry	74.0	16.9	1.3	7.8	100.0
Construction	42.2	38.5	10.4	8.9	100.0
Freight & Communication	53.6	44.8	0.3	1.3	100.0
Commerce	83.6	11.2	0.0	5.2	100.0
Passenger Transport	54.4	44.0	0.3	1.3	100.0
Services	51.9	41.6	0.5	5.9	100.0
Households	96.2	1.9	0.3	1.6	100.0
Total End Use	73.9	17.9	2.1	6.1	100.0
1987					
Agriculture	49.2	37.8	0.0	13.0	100.0
Iron and Steel	87.6	6.1	0.9	5.4	100.0
Nonferrous Metals	58.5	13.0	0.4	28.1	100.0
Chemical Fertilizers	74.9	11.4	7.1	6.6	100.0
Heavy Chemicals	38.0	47.1	5.1	9.7	100.0
Cement	90.8	4.1	0.1	5.1	100.0
Construction Materials	83.4	11.6	0.6	4.4	100.0
Heavy Machinery	72.4	13.4	1.5	12.7	100.0
Light Industry	76.4	11.9	0.9	10.8	100.0
Construction	30.9	52.0	10.5	6.6	100.0
Freight & Communication	41.9	55.4	0.2	2.6	100.0
Commerce	80.2	11.7	0.0	8.1	100.0
Passenger Transport	40.1	57.9	0.2	1.7	100.0
Services	55.2	35.9	0.8	8.2	100.0
Households	94.6	1.7	0.8	2.8	100.0
Total End Use	75.1	16.2	1.7	7.1	100.0

Source: Calculated from data in Tables 2-1 and 2-2.

Note: N. Gas = Natural Gas, Electric = Electricity.

that almost 87 percent of China's industrial boilers and furnaces use coal as fuel (Cheng, 1984, p. 112). Even in the transportation sector where petroleum in most countries plays a key role, coal accounted for 42 percent of the total fuel in freight transport and 40 percent of the fuel in passenger transport in 1987, a decrease from 54 and 55 percent, respectively, in 1981. For nonenergy sectors as a whole, coal accounted for about three quarters of total end-use energy consumption in 1981 and 1987. The dominance of coal in the fuel mix is a major barrier to energy-efficiency improvement in China, because coal has a lower conversion efficiency and less flexibility in use than oil and natural gas.

The heavy reliance on coal is due primarily to the existence of large low-cost resources. China's proven coal reserves exceed 900 billion tonnes, behind only the Soviet Union and the United States. Total estimated resources are in the neighborhood of 2 trillion tonnes; at current production levels, it would take 2000 years to exhaust the total supply (Huang, 1991). About 70 percent of China's current mines are bituminous, 16 percent are anthracite, and 14 percent are lignite. China's oil resources, on the other hand, rank only 11th among oil-producing countries and its known natural-gas resources are small by world standards (Levine et al., 1992). Although China has the world's largest hydropower reserves--380 gigawatts (GW), about two-thirds are in southwest China, far away from the population and industrial concentrations near the coasts. Exploiting this hydropower potential would require building long-distance transmission lines, which must cross formidable terrain and would have high economic costs.

North and Northeastern China, especially Shanxi Province, contain most of China's easily accessible high-quality coal, while the major consuming centers are in the eastern and southern coastal areas. Shanxi Province alone accounted for over 20 percent of China's total raw coal production in 1981 (World Bank, 1985b, p. 207). A large amount of coal, therefore, must be shipped long distances from the north to the south and east. Coal represents about 40 percent of the total tonnage handled by railways in the 1980s (Levine et al., 1992). This puts a great strain on the rail system, much of which is single track and unelectrified. To exacerbate the situation, less than 20 percent of coal is washed, partly because of water shortages in many northern mining areas; consequently, transported coal contains large amounts of waste material (Levine et al., 1992). On the other hand, about half of the locomotives are steam-driven and their average loading capacity per train is only 3,000 tonnes--some 30 percent less than that in the Western countries. The lack of transportation capacity became a major bottleneck, limiting the expansion of energy production throughout the 1980s and causing or worsening energy shortages in many parts of the country.[4]

Another major constraint on the increased use of coal is environmental degradation. The production and combustion of coal has

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[4] Transport bottlenecks are less than they might be, in part because of the proliferation of locally owned mines, which generally meet coal needs within their immediate vicinities. Local mines, owned by provinces, counties, townships, and individuals, grew far more rapidly than their state-run counterparts, accounting for almost 70 percent of the increase in coal production in the 1980s. Currently, they contribute about 55 percent of China's annual production. One issue is the extent to which local mine production can be expanded.

many undesirable environmental impacts. In coal production, there are mining wastes, effluents from coal washing, runoff, and acid mine drainage. On the consumption side, the combustion of coal produces severe air-pollution problems in the form of sulfur oxide (SO_x), suspended particulates, and acid rain. The World Health Organization (WHO, 1986) has established guidelines of 100-150 microgram per cubic meter (ug/m^3) of air for SO_2 and 150-230 ug/m^3 of air for total suspended particulates. According to the Global Environmental Monitoring System, the mean values for five major cities in China exceed SO_2 guidelines for 66 days and exceed the particulate guidelines for 204 days per year (Perlack and Russell, 1991). There are acid-rain problems in Southern China and in the middle and lower reaches of the Yangtze river. It is estimated that the acidity of rain is below pH 5 over an area of 1.3 million square kilometers. The coal combustion in China also releases a huge amount of carbon dioxide. In 1986, China accounted for about 10 percent of global carbon emissions from all fossil fuels and 20 percent from coal (Perlack and Russell, 1991). The environmental constraints on coal production and consumption are likely to become more important in the future.

ENERGY INTENSITY OF CHINA'S ECONOMY

An international comparison of primary commercial energy consumption per U.S. dollar of GDP (Energy/$GDP) suggests that China has one of the most energy-intensive economies in the world. As shown in Table 2-5, China's energy intensity is significantly higher than that of

TABLE 2-5

INTERNATIONAL COMPARISON OF PRIMARY ENERGY INTENSITY, 1980
(primary energy per $ of GDP)

Country	kgsce/$	Index, U.S.=100
China	2.13	203
Argentina	0.44	42
Brazil	0.61	58
Mexico	0.80	76
India	1.05	100
South Korea	1.06	101
Canada	1.39	132
France	0.45	43
West Germany	0.49	47
Italy	0.53	50
Japan	0.51	49
United Kingdom	0.57	54
United States	1.05	100

Source: The World Bank. 1985. CHINA: The Energy Sector. Washington, DC: The World Bank, p. 12.

Note: kgsce = kilogram standard coal equivalent.

developed countries and major developing countries (The World Bank, 1985). In 1980, energy consumption per dollar of GDP was 2.13 kilogram standard coal equivalent (kgsce) in China, compared with 0.51 kgsce in Japan, 0.57 kgsce in United Kingdom, 0.61 in Brazil, and 1.05 kgsce in the United States and in India. Only a few centrally planned economies were in the same range in intensity of energy use as China in the 1980s (Chandler, 1988; Levine, et al., 1992). Researchers from China's Ministry of Materials, State Planning Commission, and General Fuel Corporation (CMM et al., 1991) report an even larger gap. They estimate China's energy/$GNP ratio in 1985 to be 2.37 kgsce/$, which was about four times that of the United States (0.623 kgsce/$) and over six times that of Japan (0.394 kgsce/$).

The energy/$GDP ratio, however, is not a good indicator for comparing China with other countries and may grossly overstate China's energy intensity. First, conversion of RMB into U.S. dollars using the official exchange rate undervalues the real GDP and level of economic activities in China. Analysts find that the purchasing power of currencies of developing countries is systematically greater than that suggested by their exchange rates (Summers et al., 1988). International comparisons based on exchange-rate conversions, therefore, tend to underestimate the GDP in developing countries and overstate their energy intensiveness. This is particularly problematic in China because the Chinese government had devalued the renminbi (RMB) many times in the 1980s to promote exports (Wu et al., u.d.). Summers et al.'s (1988) recalculation of China's GDP based on purchasing power parity (PPP) puts China's GDP at approximately 3-4 times its exchange-rate-derived number. In fact, using the PPP-based GDP as the output measure, OTA (1991) researchers estimate that China's energy/$GDP ratio was only about 60 percent that of the United States in 1985 (see Table 2-6). This number, however, appears to be unrealistically low, so that the real energy-intensity of China's economy is probably somewhere between that reported in Table 2-5 and in Table 2-6.

Second, the primary energy consumption in China may be slightly overstated (Smil, 1990). In calculating the standard coal equivalent of China's energy consumption, Chinese officials use a conversion ratio of 0.714 for raw coal. In other words, they assume that the typical raw Chinese coal, which accounts for about three-quarters of energy supply,

TABLE 2-6

INTERNATIONAL COMPARISON OF PRIMARY ENERGY INTENSITY, 1985
(primary energy per $ppp of GDP)

Country	GJ/$1,000	Index, U.S.=100
China	14.3	60
Brazil	10.7	45
Mexico	12.5	53
India	11.4	48
South Korea	16.1	68
Kenya	5.0	21
Egypt	20.6	87
Indonesia	6.6	28
Philippines	6.7	28
Thailand	7.0	29
Algeria	17.4	73
Japan	12.7	54
France	16.0	67
West Germany	16.9	71
United States	23.7	100

Source: OTA. 1991. Energy in Developing Countries, OTA-E-486. Washington DC: U.S. Government Printing Office, p. 32, Table 2-1.

Note: GJ = Gigajoule.
PPP = Purchasing Power Parity.
GDP = Gross Domestic Product.

has an energy content of 5 megacalorie (Mcal) or 20.7 megajoule (MJ) per kilogram (kg). This assumption is valid for state-run large-scale commercial mines whose energy content ranges between 21-31 MJ/kg. The bulk of the fuel extracted in mines run by local governments and in small rural enterprises, however, has, at least, a 5-10 percent lower heat value than suggested by the standard conversion ratio (Smil, 1990). Because small and local mines now supply nearly 55 percent of all output, it is likely that China's standard coal equivalent figure overstates its total primary energy consumption.

The energy intensity in a given economy is determined by two major factors: the industrial composition of the economy and the energy-use efficiency of individual industries. It will be high if (1) energy-intensive industries produce most of the final economic output, and/or (2) if industries use energy inefficiently. Given the measurement biases we just discussed, it may be more appropriate and meaningful to assess China's energy intensity based on comparisons of industrial structure and energy efficiency in similar processes between China and other countries.

Economic Structure

Table 2-7 shows that a large percentage of China's GDP comes from the industrial sector, which is more energy-intensive than the agriculture and service sectors. In 1985, the industrial sector accounted for 47 percent of China's GDP--a share that surpassed the level in most developing countries and the average level in industrialized market economies (World Bank, 1985b; Wu et al., n.d.). The service sector accounted for only about 20 percent of China's GDP. Within the industrial sector, heavy industry, whose energy intensity was many times that of light industry, contributed to over half of gross industrial output. The dominance of heavy industry was also reflected in the composition of consumption of the GDP. China spent about 35 percent of its GDP on gross fixed capital formation in 1985--a percentage higher than that in most developing countries, demanding a large quantity of energy-intensive investment goods, such as steel and cement (Wu et al., n.d.; Lu, 1993).

TABLE 2-7

COMPOSITION OF GROSS DOMESTIC PRODUCT IN CHINA, 1985
(percent)

Sector of Origin		Final Demand	
Agriculture	33	Gross Fixed Capital Formation	34
Manufacturing	37		
Other Industries	10	Public Expenditures	14
Services	20	Private Expenditures	52
Total	100	Total	100

Source: Wu et al. n.d. China's Energy Demand Projection into Year 2025. Beijing: Energy Expert Committee, National High Technology Development Plan, p. 3.

The dominance of heavy industry is a result of China's development strategies and sectoral policies prior to the reform era. Between 1949 and 1978, the Chinese economic development program largely followed the path of "priority growth" (Cheng, 1982; Pairault, 1988). Planners assumed that heavy industry must grow more rapidly than light industry in order to have expanded production and to have sustainable economic growth (Pairault, 1988). The Chinese government, therefore, earmarked the major share of capital investment for the development of heavy industry. Between 1953 and 1979, an average of 90 percent of the industrial investment was allocated to heavy industry (Cheng, 1982, p. 426). This caused a large disparity in the growth of agriculture, light, and heavy industries, fundamentally altering China's industrial structure. Between 1949 and 1979, the share of heavy industry in total industrial and agricultural output value increased from 8 percent to 40 percent, while that of agriculture and light industry declined from 92 percent to 60 percent (Cheng, 1982).

This unbalanced growth created serious structural problems in China's economy. Heavy industry was typically capital intensive. Its over-expansion preempted the largest share of capital investment and failed to generate enough jobs to absorb the rapidly growing labor force (Gipouloux, 1988). Furthermore, the development of heavy industry was not linked effectively to that of light industry and agriculture (Cheng, 1982). An increasing portion of heavy industrial products was used to expand heavy industry itself rather than to improve productivity of other sectors. Agriculture and light industry, which were the prime sources of state revenues, received a diminishing share of investment and only grew slowly. Thus, the whole process of heavy industry expansion became self-perpetuating and did very little, if anything, to increase consumer-goods production and to improve people's living levels.

In view of these problems, corrective measures were adopted in 1979 and a program of industrial readjustment was launched between 1979 and 1981 to change the economic structure (Klenner and Wiesegart, 1983; Gipouloux, 1988). Consumer-goods industries, the long-neglected sector, received high priority in capital construction, government loans, the supply of raw materials, energy, and the introduction of new technology. The program was highly successful, and the growth of agriculture and light industry far surpassed that of heavy industry during the readjustment period. After the 1979-1981 readjustment, China concentrated its effort on an ambitious modernization program, aiming at quadrupling its GDP by the year 2000. In order to achieve this goal, Chinese planners committed increasing amounts of resources and capital investment to build infrastructure and to assure an adequate supply of intermediate goods. Transportation and heavy industry, the two most energy-intensive sectors, again grew at a slightly higher rate than the rest of the economy and their combined output share increased slowly.

Energy Efficiencies

China's technical energy efficiencies are very low compared with modern industrial economics, mainly resulting from outdated technologies, inadequate maintenance, dependence on coal, and poor management (Smil 1988; 1990; Zhu et al., 1990). The mean efficiency of China's energy conversion is only about 33 percent, compared with 45-55 percent in most countries and almost 60 percent in Japan (Smil, 1988, 1990). Simple Chinese household coal stoves have an energy efficiency rate of about 15 percent--compared with 50-60 percent rates for ordinary oil or gas furnaces and 80-95 percent for high-efficiency natural gas units. Steam locomotives, which still dominate China's railway transportation, have typical efficiencies no higher than 6-8 percent, compared with at least 25 percent for diesels (Smil, 1990; Lu, 1993). According to data from a recent Tsinghua University study (Wu and Wei, 1991), the average industrial boiler in China operates at an efficiency of 55-60 percent. In developed countries, industrial boilers are typically operated at 75-80 percent efficiencies. Industrial ovens and furnaces in China typically operate in the 20-25 percent range, compared with 50-60 percent in industrialized countries.

China consumes more energy to provide goods and services than many other countries (Smil, 1990; B. Wang, 1990; World Bank, 1985b). Several examples illustrate the difference. The steel industry in China requires 32.8 gigajoule (GJ) (equivalent of about 1.1 tsce) per tonne of steel produced, 60 percent more than typical values in industrialized countries. The energy-intensity of synthetic ammonia production is almost twice as great in China (2.1 tsce per tonne of ammonia) as that in developed countries (1.2 tsce per tonne). Paper production is also about 40 percent more energy-intensive than in developed countries. Cement production in China requires 5.7 GJ (0.20 tsce) per tonne, compared to 3.5 GJ to 4.1 GJ (0.12-0.14 tsce) per tonne in developed countries. Similarly, for the generation of power, oil refining, and production of plate glass, the efficiencies of energy use in China are estimated to be about 70 percent of average values in developed countries. In 1985, 398 grams of standard coal were required to generate one kilowatt hour (kwh) of electricity in China, while the Japanese rate was about 340. One ton of Chinese steel and cement needed 1060 and 201 kg of standard coal, respectively, which were 1.55 and 1.88 times that of Japanese energy requirements (B. Wang, 1990; Zhang and Xue, 1990).

Agricultural production in China, which accounted for about 30 percent of the GDP in the 1980s, is highly energy intensive (Wu et al., n.d.). China has about one-fifth of the world's population, but the natural resources per capita are much less than the average level in the world. Per capita cultivated land (0.09 ha) and forest area (0.11 ha) are, respectively, only about 32 percent and 13 percent of the world average (Smil, 1990; Wu et al., n.d.). Huge pressures to increase food yield from scarce land forces China to adopt highly energy-intensive-agriculture production techniques. Smil (1988) traces direct and indirect energy use required to sustain China's farming. He estimates that total energy subsidies for China's agriculture production are about 20 GJ per hectare of cultivated land. These subsidies are about twice as large as the average U.S. intensity (10 GJ/ha), an order of magnitude above the Australian and New Zealand inputs (2-3 GJ/ha), and at the same level as in Egypt (22 GJ/ha) or in France (23 GJ/ha) (Smil, 1988).[5]

Overall, our review of the industrial structure and energy efficiencies indicates that China does have a higher energy intensity than many countries in the world, although the gap is much smaller than that suggested by energy/$GDP comparisons. The review also shows that many factors besides outdated technologies, such as industrial structure, resource conditions, energy mix, and management practice, contribute to the high energy intensity of China's economy. It is an oversimplification to assume, as some energy modelers and analysts do, that because China has a higher energy intensity than other major countries, it must have a large potential for energy-efficiency improvement, and its energy intensity must go down in the future. It is also misleading to assume that the introduction of more efficient energy equipment and process, either through domestic research and development

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[5] They are still lower, however, than the English inputs (34 GJ/ha) and are only a quarter of Dutch or Israeli farming energy intensity (over 80 GJ/ha) (Smil, 1988).

or international technology transfer, will automatically lead to a reduction in China's energy intensity. We share the view of those researchers who argue that models of energy demand should be rooted in the conditions of real-world energy use, not purely theoretical or logical structures, and that assessments of future energy-use changes should be based on the analysis of how and why energy use has changed in the past (Schipper and Meyers, 1992). In order to identify likely paths of China's energy-intensity changes, we think it is important to know, among other things, how energy-use changed in China's economy in the 1980s and what accounted for the dramatic decline in China's energy intensity since 1978.

ENERGY-USE CHANGES FROM 1981 TO 1987

Unlike assessing China's energy intensity based on an international comparison of energy/$GDP ratio, monitoring changes in energy per RMB of GDP over time can provide a meaningful measure concerning whether China's energy intensity is rising, falling, or levelling off. Table 2-8 and Figure 2-2 show that China has reduced the energy intensity of its economy significantly since 1978. Between 1978 and 1988, China's energy intensity, measured as the amount of energy used to produce a unit of GDP (in 1980 constant prices), fell by almost 30 percent from 1483 gsce/RMB to 963 gsce/RMB. The intensity climbed slightly in 1989, primarily due to a slow down in economic growth caused by political and economic instability of the Tiananmen Square turmoil, and then declined again in 1990. In 1981, China actually reduced total energy consumption by 1.4 percent, while its economy grew by 5 percent.

TABLE 2-8

PRIMARY ENERGY CONSUMPTION AND ECONOMIC GROWTH IN CHINA, 1978-1990

Year	Primary Energy Consumption		Gross Domestic Product		Energy Intensity	
	10^6 tsce	% change	10^9 RMB	% change	gsce/RMB	%change
1978	571.4	--	385.3	--	1482.9	--
1979	585.9	2.5	414.6	7.6	1413.0	-4.7
1980	602.8	2.9	447.0	7.8	1348.4	-4.6
1981	594.5	-1.4	467.0	4.5	1272.9	-5.6
1982	620.7	4.4	507.9	8.8	1222.1	-4.0
1983	660.4	6.4	560.3	10.3	1178.7	-3.6
1984	709.0	7.4	642.0	14.6	1104.5	-6.3
1985	766.8	8.2	723.7	12.7	1059.6	-4.1
1986	808.5	5.4	783.8	8.3	1031.5	-2.7
1987	866.3	7.2	870.1	11.0	995.6	-3.5
1988	930.0	7.4	965.7	11.0	963.0	-3.3
1989	969.3	4.2	1003.8	4.0	965.6	0.3
1990	987.0	1.8	1056.2	5.2	934.5	-3.2
1978-1990		72.7		174.1		-37.0
1981-1987		45.7		86.3		-21.8

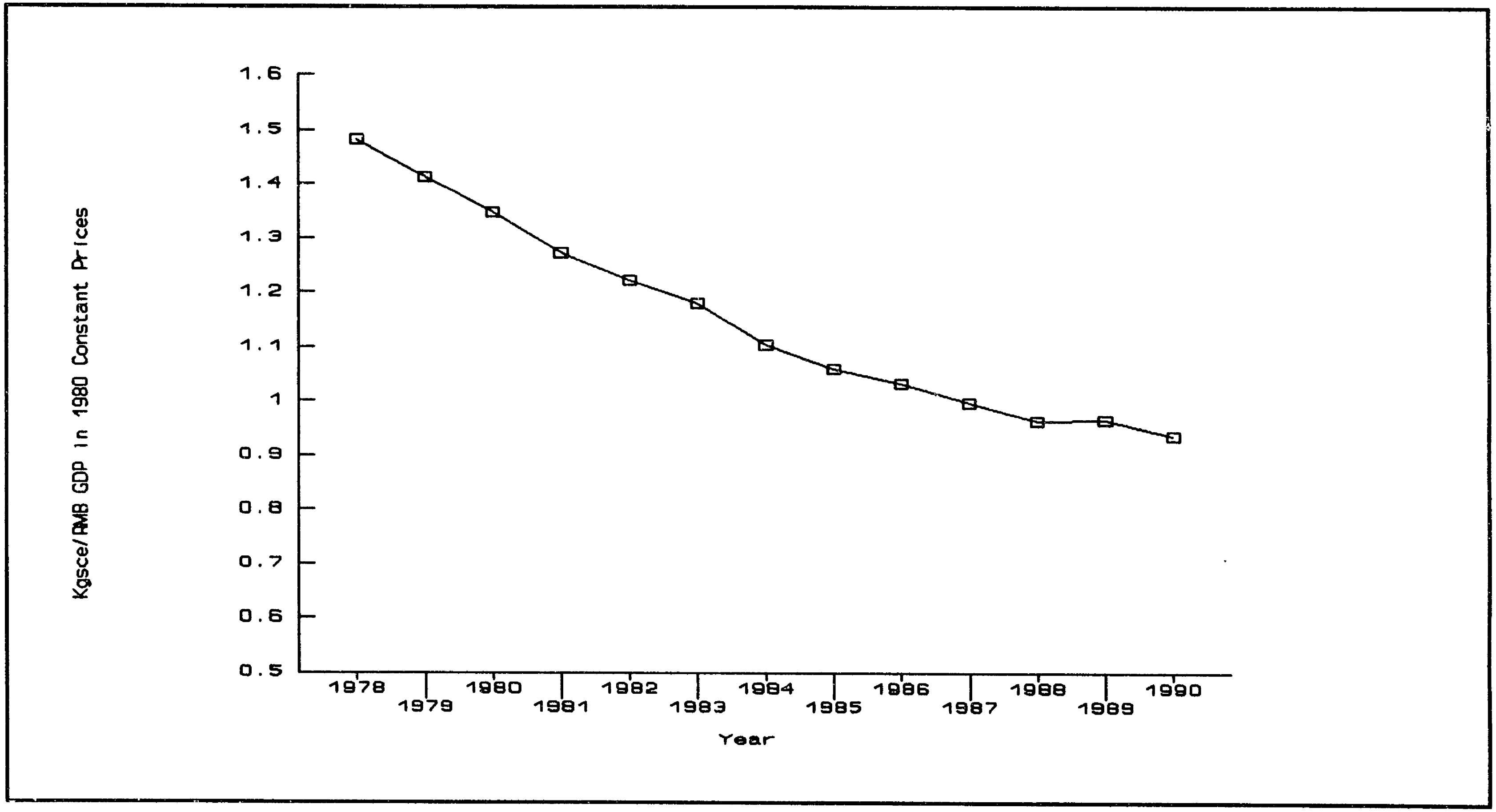
Source: State Statistical Bureau of China (SSB). 1992. China's Energy Statistical Yearbook, 1991, p. 135. and Statistical Yearbook of China, 1991, p. 31.

Note: RMB is expressed in 1980 constant prices.
tsce = tonne of standard coal equivalent.
% change = percent change over the previous year.

For the entire period between 1978 and 1990, GDP increased by 174 percent, but the primary energy consumption grew by only 73 percent, leading to a 37-percent decline in energy intensity. In this study, we will focus on energy-use changes from 1981 to 1987, the years for which we have input-output tables. During this period, the energy/GDP ratio decreased by 277 gsce/RMB, or by about 22 percent, in spite of the presence of several structural factors, such as urbanization,

FIGURE 2-2

ENERGY INTENSITY OF CHINA'S ECONOMY, 1978-1990



Source: Data in Table 2-8.

industrialization, infrastructure construction, and increased mobilization, which generate a strong upward pressure on energy intensity, as we mentioned in Chapter 1.

Table 2-9 compares 1981 and 1987 energy consumption and economic output. Note that both final demand, whose sum equals the GDP, and gross output (total of final and intermediate output) are valued at 1981 producer prices; thus, the GDP figure in Table 2-9 is slightly different from GDP data (in 1980 consumer prices) in Table 2-8. There are also some small differences in the primary energy consumption numbers because of different energy accounting used in the two tables. Between 1981 and 1987, China's gross output and GDP increased by 92 percent and 84 percent, respectively. These increases in economic output were accompanied by a far less-than-proportional increase in energy inputs. Total primary energy consumption in China increased by only 43 percent from 611 million tsce in 1981 to 874 million tsce in 1987; consequently, China's energy intensity declined by 26 percent in terms of the energy/output ratio and 22 percent if measured by the energy/GDP ratio.[6]

The decline in energy intensity is spread widely across fuels and sectors. For all four types of fuels--coal, petroleum, natural gas, and hydropower, the energy/output ratio and energy/GDP ratio were much lower in 1987 than in 1981 (see Table 2-9). The petroleum consumption per RMB

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[6] Both the GDP and gross output can be used as the denominator in the energy-output ratio and which one to use depends on the question asked and the analysis undertaken. Intuitively, we can think of the GDP as a more appropriate measure of final product or achievement of economic production and the gross output as a better measure of the overall size of the economic activity.

TABLE 2-9

GROWTH OF ENERGY CONSUMPTION AND ECONOMIC OUTPUT IN CHINA FROM 1981 TO 1987

Item	1981	1987	Change	% Change
Primary Energy Uses (1000 tsce)				
Coal	446320	665351	219031	49.1
Petroleum	120632	150106	29475	24.4
Natural Gas	16944	18474	1530	9.0
Hydropower	26677	39798	13021	48.8
Total	610574	873630	263056	43.1
Economic Output (billion RMB)				
Gross Output	1502	2887	1386	92.3
Final Output (GDP)	481	886	405	84.3
Energy/Output Ratio(gsce/RMB)				
Coal	297	230	-67	-22.5
Petroleum	80	52	-28	-35.3
Natural Gas	11	6	-5	-43.3
Hydropower	18	14	-4	-22.6
Total	407	303	-104	-25.6
Energy/GDP Ratio (gsce/RMB)				
Coal	928	751	-177	-19.1
Petroleum	251	170	-82	-32.5
Natural Gas	35	21	-14	-40.8
Hydropower	56	45	-11	-19.0
Total	1270	986	-284	-22.3

Source: Calculated from China Energy Input-Output Tables, 1981 and 1987 shown in Appendices I and II.

of GDP, for example, dropped over 30 percent from 251 gsce/RMB in 1981 to 170 gsce/RMB in 1987. In 15 out of the 18 major sectors of China's economy, energy-input uses increased at a slower rate than gross output between 1981 and 1987, as displayed in Table 2-10.[7] Four sectors--Chemical Fertilizers, Heavy Chemicals, Heavy Machinery, and Freight Transport & Telecommunications--have a gross output elasticity of energy demand of less than 0.4, indicating that the energy-consumption growth rate was less than 40 percent that of gross output in the sector. Natural Gas is the only sector with a negative elasticity due to output reduction as several major natural-gas-producing oil fields entered a mature stage and the inputs and cost of production went up in the 1980s.

Tables 2-11 and 2-12 provide detailed information on the amount (Table 2-11) and percentage rate (Table 2-12) of the energy-consumption change by sectors and fuel types. Of the total of 263 million tsce energy-consumption increase between 1981 and 1987, 219 million (83 percent) was coal and another 29 million (11 percent) was in the form of petroleum products. Of the 195 million tsce increase in end-use energy consumption, 152 million (78 percent) was coal, 23 million (12 percent) was petroleum, 18 million (9 percent) was in the form of electricity, and 1 million (1 percent) was natural gas. In terms of the sectoral distribution, most energy-use increases between 1981 and 1987 occurred in six sectors--Power, Household, Iron and Steel, Light industry, Construction Materials, and Cement--mainly because those sectors were

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[7] Analysts typically use the gross output as the denominator when they examine energy intensity in a specific sector and the GDP (final output) as the denominator when they look at energy intensity of the entire economy.

TABLE 2-10

PERCENT CHANGES IN ENERGY INPUT AND GROSS OUTPUT BY SECTORS IN CHINA, 1981 to 1987

Sector	Energy Input	Gross Output	Elasticity of Energy Use
Coal	73.1	61.0	1.20
Petroleum	76.4	63.7	1.20
Natural Gas	21.6	-25.1	-0.86
Electricity	49.0	75.5	0.65
Agriculture	30.8	56.8	0.54
Iron and Steel	44.8	74.8	0.60
Nonferrous Metals	47.8	101.9	0.47
Chemical Fertilizers	14.3	56.3	0.25
Heavy Chemicals	22.2	156.4	0.14
Cement	80.9	164.7	0.49
Construction Materials	102.4	145.1	0.71
Heavy Machinery	23.7	208.8	0.11
Light Industry	41.4	101.8	0.41
Construction	69.1	121.0	0.57
Freight & Communication	37.6	112.2	0.34
Passenger Transport	44.8	48.2	0.93
Commerce	66.1	73.3	0.90
Services	46.6	71.4	0.65

Source: Calculated from data in the Institute of Systems Sciences, Chinese Academy of Sciences. 1993. Energy Input-Output Tables of China, 1981 and 1987.

Note: Energy input is measured in tonnes of standard coal equivalent, and gross output is measured in 1981 producer prices. Elasticity of energy use is the ratio of the energy growth rate to the output growth rate.

TABLE 2-11

ENERGY-USE CHANGES IN CHINA'S ECONOMY, 1981 TO 1987

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Electricity	Total
<u>Energy Sectors</u>						
Coal	7454	977	146	--	1079	9656
Petroleum	441	10733	-1197	--	868	10845
Natural Gas	32	114	878	--	45	1068
Electricity	58770	-5522	466	13020	3063	69797
<u>End-Use Sectors</u>						
Agriculture	5505	1578	0	--	959	8042
Iron and Steel	31725	-1337	-88	--	2443	32744
Nonferrous Metals	2343	408	-5	--	842	3588
Chemical Fertilizers	6491	957	-433	--	-129	6885
Heavy Chemicals	3803	2863	427	--	680	7772
Cement	17765	816	26	--	1535	20143
Construction Materials	17988	2232	173	--	1209	21602
Heavy Machinery	4349	907	-90	--	1697	6864
Light Industry	22221	-42	-50	--	4873	27002
Construction	642	3169	479	--	145	4435
Freight & Communication	962	7404	-27	--	532	8871
Commerce	2228	372	0	--	369	2969
Passenger Transport	155	1689	0	--	53	1898
Services	4430	1688	93	--	925	7136
Households	31726	467	732	--	2071	34996
Total End Use	152334	23173	1237	--	18204	194948
Total Primary Energy Consumption	219031	29475	1530	13020	--	263056

Source: Calculated from data in Tables 2-1 and 2-2.

TABLE 2-12

PERCENT CHANGES IN ENERGY CONSUMPTION IN CHINA'S ECONOMY, 1981 TO 1987

(percent of the 1981 energy consumption)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Electricity	Total
Energy Sectors						
Coal	73.9	103.6	--	--	49.5	73.1
Petroleum	78.6	104.5	-51.4	--	84.3	76.4
Natural Gas	87.8	54.4	18.8	--	121.0	21.6
Electricity	68.6	-22.7	583.3	48.8	54.1	49.0
End-Use Sectors						
Agriculture	48.7	13.9	--	--	27.7	30.8
Iron and Steel	52.0	-17.2	-8.4	--	74.9	44.8
Nonferrous Metals	56.4	39.3	-11.8	--	37.0	47.8
Chemical Fertilizers	18.7	18.1	-10.0	--	-3.4	14.3
Heavy Chemicals	30.4	16.5	24.1	--	19.4	22.2
Cement	76.9	79.8	264.2	--	205.9	80.9
Construction Materials	102.0	81.6	248.0	--	183.8	102.4
Heavy Machinery	20.1	23.3	-14.1	--	59.7	23.7
Light Industry	46.1	-0.4	-5.9	--	96.1	41.4
Construction	23.7	128.3	72.0	--	25.3	69.1
Freight & Communication	7.6	70.0	-33.3	--	175.3	37.6
Commerce	59.4	74.0	--	--	157.1	66.1
Passenger Transport	6.8	90.7	0.0	--	97.7	44.8
Services	55.7	26.5	116.7	--	102.0	46.6
Households	36.7	28.0	250.0	--	142.8	39.0
Total End Use	43.5	27.3	12.5	--	62.6	41.1
Total Primary Energy Consumption	49.1	24.4	9.0	48.8	--	43.1

Source: Calculated from data in Tables 2-1 and 2-2.

the most important energy users in China and had the largest share of energy consumption in 1981 (see Tables 2-1 and 2-3).

There were large variations in the energy-consumption growth rates for individual energy types and in different sectors, as shown in Table 2-12. In terms of primary energy, the consumption of coal and hydropower grew by almost 50 percent, while the use of petroleum and natural gas increased by only 24 percent and 9 percent, respectively. In terms of end use, the growth rates were 44 percent for coal and 63 percent for electricity, compared with 27 percent for petroleum and 13 percent for natural gas. For individual sectors, Coal, Petroleum, Cement, Construction Materials, Construction, and Commerce experienced the strongest growth (over 70 percent) in energy consumption. Natural Gas, Chemical Fertilizers, Heavy Chemicals, and Heavy Machinery, on the other hand, had the smallest growth rates, increasing their energy use slowly by only about or less than 25 percent.

The variations in energy growth rates, however, had almost no effect on the structure of energy consumption in China. As shown in Table 2-3 and Figure 2-1, the distribution of the total energy consumption among different sectors and individual energy types was stable and remained almost unchanged between 1981 and 1987. This suggests that, overall, changing energy mix and sectoral distribution of energy consumption were not the primary cause of the energy-intensity decline between 1981 and 1987.

LINKING ENERGY-USE CHANGES WITH CHANGES IN THE ECONOMY

One of the main purposes of this study is to draw connections between the energy-use changes from 1981 to 1987 and changes in the economy. Energy is used in a large number of diverse economic activities undertaken by many different types of actors (Schipper and Meyers, 1992). We group the causes of changes in energy into two categories: (1) changes in what final goods and services people consume (final demand) and (2) changes in how those goods and services are produced (production technology). In subsequent chapters of this study, we will link energy-use changes between 1981 and 1987 to changes in final demand and production technology and identify factors that were primarily responsible for the energy-intensity reduction. Energy consumption of China's economy, for example, will increase if consumers purchase more final goods and services or if they shift their spending pattern from less energy-intensive products, such as services, to more energy-intensive ones, such as durable manufacturing goods, everything else being equal. This increase, however, may be moderated or counterbalanced by the introduction of alternative production technologies that reduce the amount of energy input used to produce final goods and services. Various elements of the final-demand shifts and production-technology changes are at work simultaneously; they may be either reinforcing or offsetting. Using a structural-decomposition analysis, we will identify those elements, quantify their individual energy impacts, and determine their combined effect on aggregate energy consumption of China's economy.

CHAPTER 3

ACCOUNTING FOR ENERGY-USE CHANGES: A STRUCTURAL-DECOMPOSITION ANALYSIS

The structural-decomposition analysis (SDA), an analysis of economic changes by means of a set of comparative static adjustments of key parameters of input-output tables (Rose and Miernyk, 1989), dates to the very origin of modern input-output economics. Leontief (1941; 1951; 1953) first developed the technique to compare input-output accounts over time. Chenery and his colleagues (Chenery and Watanabe, 1958; Chenery et al., 1962) conducted a multisector comparative static analysis to identify sources of economic growth. Carter (1970) applied the input-output framework to examine the impacts of structural change on industrial specialization and economic efficiency in the United States. She also extended the SDA to a dynamic level by linking the changes in technical-input coefficients with the allocation of investment. Stone and Armstrong (1974) performed a comparative input-output analysis to trace structural changes in the British economy from 1948 to 1968.

The SDA has been widely used in energy studies. Strout (1966), for example, analyzed how changes in technology and in the level and composition of final demand affected U.S. energy use between 1939 and 1954. Reardon (1976) conducted an input-output analysis of U.S. energy use changes from 1947 to 1958, 1958 to 1963, and 1963 to 1967. Park (1982) developed an input-output framework for measuring the direct, indirect, and income-induced energy effects of a change in final demand and for estimating the effect of technological change on energy consumption. Ostblom (1982) attributed the changes in the energy-output ratio of the Swedish economy to changes in direct energy coefficients, changes in output share of industrial sectors, and changes in the composition of final demand. Hannon (1983) compared the energy costs of providing goods and services in the United States in 1963 and 1980. Proops (1984) decomposed changes in the energy-output ratio into three factors: changes in energy intensities, changes in final demand, and changes in the structure of interindustry trading. Ploger (1985) assessed the effects of changes in output mix and energy coefficients on energy consumption in the Danish manufacturing industries. Casler and Hannon (1989) examined the readjustment potential in the industrial energy efficiency and structure in the United States. The Office of Technology Assessment (OTA, 1990) staff performed an SDA on U.S. energy-use changes between 1972 and 1988.

There are three major limitations, however, of most existing energy SDA. First, most researchers only distinguish between effects attributable to final-demand changes and an aggregated set of technical changes (Rose and Chen, 1991). They treat the Leontief coefficients as a single entity and do not separate the influence of changes in energy coefficients themselves from that of other inputs, either in terms of aggregate or subaggregates (Casler and Afrasiabi, 1990; Casler et al., 1991). Second, analysts typically specify their models in an ad hoc manner, which often does not yield a set of estimation equations or factors that are "mutually exclusive and completely exhaustive." (Rose and Chen, 1991, p. 4). Third, analysts frequently generate some interactive effects that are large, but difficult to interpret. This, to some extent, defeats the purpose of identifying individual sources of structural changes.[1]

Recently, Rose and Chen (1991) make an important contribution to advance the state-of-the-art of SDA. They extend the analysis to a two-tier KLEM (capital, labor, energy, and materials) flexible production-function framework, which produces 11 separate sources of energy-use changes and three "interactive" effects. They also formally derive a system of estimation equations that are mutually exclusive and completely exhaustive. They apply their model to study energy-demand changes in the United States between 1972-1982 (Rose and Chen, 1991) and in Taiwan between 1971 and 1984 (Chen and Rose, 1990), showing that, overall, the model can yield as much insight as more elaborate and data-intensive KLEM econometric models of production technologies. Rose and Chen, however, still generate several large interactive factors whose interpretations are ambiguous.

In this research, we develop an alternative formulation of SDA that is simpler than the Rose-Chen model but also generates a system of mutually exclusive and completely exhaustive estimation equations. Our formulation differs from the Rose-Chen model in three important aspects. First, we do not formulate the SDA with the KLEM flexible production framework. Instead, we decompose final-demand changes into level, distribution, and pattern effects and partition technological changes

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[1] Mathematically, the interactive factor emerges from the basic algebra of differential equations and measures the interactive effect of two or more factors. Different analysts handle the interactive factor differently. Some analysts treat it as a separate variable and report its value; some allocate it equally among the other factors of changes; others ignore the interaction term altogether in interpreting the results of the analysis.

into energy and nonenergy input changes. Second, Rose and Chen incorporate energy into a standard monetary input-output table by using output-to-fuel coefficients to convert energy output values from the standard input-output table into physical quantities. We, on the other hand, apply a "hybrid" method (Bullard and Herendeen, 1975; Bullard et al., 1978) and replace all energy rows in the monetary input-output table with physical energy flows. Miller and Blair (1985) demonstrate that the "hybrid" formulation is generally superior to the output-conversion approach because it always conforms with energy-conservation conditions. Third, we specify a reference point for comparing structural changes over time, which enables us to allocate energy-use changes completely among individual sources and eliminate interactive factors. We will discuss the conceptual framework of our SDA model in the next section.

CONCEPTUAL FRAMEWORK

The conceptual foundation of the SDA is input-output economics. Input-output analysis, first introduced by Leontief (1936), is specifically designed as a tool for the systematic analysis of the mutual interdependencies between different parts of an economy. The empirical basis of input-output analysis is the transactions table, which provides a detailed statistical account of the flows of goods and services among all the producing and consuming sectors of a given economy--that is, among all the various branches of business, households, and government. The table displays not only complete details of the income and product accounts, but also all intermediate transactions among producers and purchasers within a consistent accounting framework (Polenske and Fournier, 1993).

Table 3-1 shows China's 1981 input-output table, aggregated to only seven sectors for illustrative purposes. Elements in each row of the table indicate the amount of a sector's output that was sold to intermediate and final consumers in 1981. To illustrate, the first row shows that of the 64 billion RMB worth of energy output produced by the energy sector in 1981, 7 billion RMB was purchased by the final demand sectors, which included personal consumption, public expenditures, capital investment, and international trade (exports minus imports). The remaining 57 billion RMB was sold to intermediate sectors, including sales of 22 billion RMB to heavy industry, 13 billion RMB to the energy sector itself, and some smaller sales to other sectors. The sum of all purchases made by final-demand sectors is what we refer to as "gross domestic product" (GDP) or "final output," and we call the total purchases made by intermediate sectors "intermediate output." The sum of final output and intermediate output is called gross output.

Each column of Table 3-1 provides information on what inputs the industry has to purchase in order to produce its output. The inputs include intermediate inputs, that is, goods and services from other production sectors, and primary inputs--labor, capital, land, and indirect taxes. Let us use the agriculture sector (column 2) as an example. To produce its gross output of 212 billion RMB in 1981, agriculture paid out 148 billion RMB in the form of wages, profits, rent, and other payments for primary inputs. It also purchased almost 2 billion RMB worth of energy input from the energy sector, 34 billion RMB

TABLE 3-1

CHINA INPUT-OUTPUT TRANSACTIONS TABLE, 1981

(million RMB in current producer prices)

Producing Sectors	Purchasing Sectors 1	2	3	4	5	6	7	Final Demand	Gross Output
1 Energy	12532	1807	21601	8170	2718	4574	5152	7298	63850
2 Agriculture	331	33768	3841	68646	3670	10	2197	99458	211921
3 Heavy Industry	5654	17770	58392	25554	30158	2149	9246	33572	182495
4 Light Industry	2710	5794	16649	84258	12269	770	27728	146761	296939
5 Construction	0	0	0	0	0	0	0	75761	75761
6 Transport	1583	1176	5435	3816	2967	591	4201	11128	30899
7 Services	2646	3259	7341	8535	1595	2860	26151	106743	159131
8 Primary Inputs	38394	148347	69236	97960	22385	19945	84455	0	480722
9 Total Inputs	63850	211921	182495	296939	75761	30899	159131	480722	1501718

Source: Compiled by the author based on State Statistical Bureau of China. 1985. China Input-Output Table, 1981. Beijing: China Statistical Press.

input from itself, 18 billion RMB from heavy industry, plus some smaller-value amounts of other intermediate products. The total outlay of 212 billion RMB (sum of column 1) is exactly equal to the gross output of the sector (sum of row 1), conforming with the double-accounting principles employed in the input-output table.

When we divide each element in a column of Table 3-1 by the gross output for that particular industry, we obtain Table 3-2, the direct, or technical, coefficients matrix. Each coefficient in the table shows the amount that a sector purchases directly from another sector per unit of output of the purchasing sector. Each column of technical coefficients displays the formula or input mix by which a particular industry makes its product. Column 2 of Table 3-2, for example, indicates that the agriculture sector required 0.009 RMB worth of energy input, 0.159 RMB agricultural product, 0.084 RMB heavy-industry output, 0.027 RMB light-industry output, 0.006 RMB transportation output, and 0.015 RMB service output, and 0.700 RMB primary inputs in order to produce one RMB of agricultural output. Professor Leontief frequently refers to the column as a "production recipe." The recipe explicitly includes inputs used and implicitly capital equipment employed in generating output; it can be interpreted as a quantitative measure of production technology (OTA, 1990).

Throughout this research, we use the production inputs to describe production technology and define production-technology changes broadly as any changes, from whatever cause, in the production-input mixes. This way of defining production technology differs fundamentally from an engineering definition of production technology. Engineers usually

TABLE 3-2

DIRECT INPUT COEFFICIENTS MATRIX OF CHINA, 1981

(direct input per unit of output)

Producing Sectors		Purchasing Sectors						
		1	2	3	4	5	6	7
1	Energy	0.1963	0.0085	0.1184	0.0275	0.0359	0.1480	0.0324
2	Agriculture	0.0052	0.1593	0.0210	0.2312	0.0484	0.0003	0.0138
3	Heavy Industry	0.0886	0.0839	0.3200	0.0861	0.3981	0.0696	0.0581
4	Light Industry	0.0424	0.0273	0.0912	0.2838	0.1619	0.0249	0.1742
5	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	Transport	0.0248	0.0056	0.0298	0.0129	0.0392	0.0191	0.0264
7	Services	0.0414	0.0154	0.0402	0.0287	0.0210	0.0926	0.1643
8	Primary Inputs	0.6013	0.7000	0.3794	0.3299	0.2955	0.6455	0.5307
9	Total Input	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Source: Calculated from Table 3-1 as the direct input from a given sector divided by the gross output of the sector that is purchasing the input.

define the technology in terms of the operations and equipment. They see the technology as a transformation process, a way of combining inputs to obtain an output with given characteristics (Amsalem, 1983). Engineers will consider two production processes to be the same technology if the principles and methods used are basically the same. This is despite the fact that the input mixes might be different. For economists, the different input requirements will turn these two production processes into two distinct technologies.

From the direct input coefficients, we can calculate the total input requirements of each sector to produce one unit of its final demand, as shown in Table 3-3. Each element in the table describes the total amount of input that the sector requires, both directly and indirectly, to deliver one unit of its output to final users. The cell in the first row (energy input) and second column (agriculture sector), for example, indicates that to supply one RMB of agricultural product to final demand, the agricultural sector required 0.045 RMB worth of energy input--0.009 RMB of which (see Table 3-2) was direct consumption by the agriculture sector and the other 0.036 RMB was indirectly required because some inputs of agricultural production, such as chemical fertilizers and plastics, required a lot of energy to produce. This way of calculating the total energy requirement is similar to a process analysis in engineering (Miller and Blair, 1985). We first identify a target product and then list the goods and services directly required to deliver the product. These inputs to the target production process include energy (direct energy) and nonenergy inputs, as shown in Table 3-2. The nonenergy inputs are then analyzed to determine the inputs to

TABLE 3-3

TOTAL INPUT REQUIREMENTS MATRIX OF CHINA, 1981

(direct and indirect input per unit of final demand)

Producing Sectors	Purchasing Sectors						
	1	2	3	4	5	6	7
1 Energy	1.2900	0.0451	0.2553	0.1027	0.1776	0.2245	0.0970
2 Agriculture	0.0490	1.2169	0.1102	0.4132	0.1754	0.0371	0.1170
3 Heavy Industry	0.2015	0.1709	1.5637	0.2609	0.6904	0.1649	0.1790
4 Light Industry	0.1258	0.0805	0.2462	1.4718	0.3559	0.1053	0.3336
5 Construction	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
6 Transport	0.0429	0.0153	0.0606	0.0343	0.0735	1.0355	0.0460
7 Services	0.0837	0.0373	0.1051	0.0797	0.0908	0.1381	1.2288

Source: Calculated from Table 3-2 using only the seven-sector direct-input coefficients by inverting the (I-A) matrix.

their production processes, which again include some energy and nonenergy inputs. The process continues until the additional energy requirement from the next round becomes so small that it is negligible. The first round of energy inputs is the direct energy requirement, which is shown in the energy row in Table 3-2, and the subsequent rounds of energy inputs comprise the indirect energy requirements. The sum of these two is the total energy requirement and is reflected in the energy row of Table 3-3.

Mathematically, the structure of an input-output model is simple and can be expressed as:

$$AX + Y = X \qquad (1)$$

where X = vector of gross output;
Y = vector of final demand; and
A = matrix of direct input coefficients, which show the inputs required to produce one unit of gross output.

The product of A and X (i.e., AX) indicates the intermediate outputs or inputs--the amount of output that is used by production sectors to deliver final goods and services. We can rearrange Equation (1) to calculate the total amount of inputs from each sector required to provide particular sets of final goods and services:

$$X = [(I-A)^{-1}]Y \qquad (2)$$

where I = identity matrix; and
$(I-A)^{-1}$ = matrix of total input requirements, which are inputs required to deliver one unit of final demand, including final-demand itself.

Equations (1) and (2) will serve as a mathematical foundation for our SDA modeling of energy-use changes.

MODEL STRUCTURE

There are two basic approaches to incorporate energy into the conventional monetary input-output analysis: output conversion and "hybrid-units." Using the output-conversion approach, analysts first compute energy requirements in terms of output values and then convert those values into physical energy units using output-to-energy ratios. In the "hybrid-units" method, analysts replace energy rows of the standard monetary input-output table with energy flows in physical units to construct a transaction table in hybrid units--that is, energy rows in physical units and nonenergy transactions in monetary units. Miller and Blair (1985) show that the hybrid method is generally superior to the conversion approach because the latter introduces inconsistencies in accounting for energy consumption and often needs to be adjusted to satisfy energy-conservation conditions.[2]

In this study, we adopt the hybrid method to construct an energy input-output model. We express energy flows in physical units (1000 tsce) and all other transactions in value terms (million RMB, producer prices). The direct input requirements matrix (i.e., A matrix) in this hybrid-unit model represents four different relationships:

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[2] Many researchers, however, continue to use the output-conversion method, because it has smaller data requirements and is easier to implement than the hybrid method.

	Energy Sectors	Nonenergy Sectors
Energy Inputs	kgsce/kgsce 1	kgsce/RMB 2
Nonenergy Inputs	RMB/kgsce 3	RMB/RMB 4

Quadrant 1: kgsce of energy input needed per kgsce of energy sector output.

Quadrant 2: kgsce of energy input needed per RMB of nonenergy sector output.

Quadrant 3: RMB of nonenergy input needed per kgsce of energy sector output.

Quadrant 4: RMB of nonenergy inputs needed per RMB of nonenergy sector output.

The total input requirements, $(I-A)^{-1}$, have the same units as the A matrix except, of course, that they are in terms of the requirements (kgsce or RMB) per unit (kgsce or RMB) of final demand instead of per unit of gross output.

Using the energy input-output model, we can identify two parts of energy consumption: intermediate and direct. The intermediate energy consumption is the energy used by production sectors as an input to output, i.e., energy used in production activities. The direct energy consumption is the energy used or sold directly to final users, such as households and government agencies. It is not, in the period of time under consideration, used as inputs by business firms to produce output. We can obtain information about the amount of intermediate energy required in the economy by combining and rearranging Equations (1) and (2):

$$\begin{aligned} E_g = eAX &= e(X - Y) \\ &= e[(I-A)^{-1}Y - Y] \\ &= e[(I-A)^{-1}-I]Y \end{aligned} \qquad (3)$$

where E_g = vector of intermediate energy consumption;
e = matrix consisting of ones and zeros, with ones in the row locations corresponding to energy sectors and zeros in all other elements of the matrix. It selects the energy rows from the input-output table.

To calculate the direct energy consumption, we need to adjust the final energy consumption for energy exports, imports, and inventory changes. Mathematically,

$$E_d = E_y + E_u - E_v - E_w = eYn \qquad (4)$$

where E_d = vector of direct energy consumption;
E_y = vector of final energy consumption;
E_u = vector of imported energy;
E_v = vector of exported energy;
E_w = vector of net energy-inventory change, and
n = matrix consisting of ones and zeros, with ones in the diagonal locations corresponding to those columns that are not imports, exports, and inventory change and zeros in all other elements of the matrix. It excludes energy imports, exports, and inventory changes from the calculation of direct energy consumption.

Total energy consumption in the economy, E, is the sum of intermediate and direct energy consumption:

$$E = E_g + E_d = e[(I-A)^{-1}-I]Y + eYn = FY + eYn \qquad (5)$$

where $F = e[(1-A)^{-1}-I]$. The equation shows that total energy consumption in an economy is determined by total intermediate energy requirements, F, and final demand, Y. The F, in turn, is a function of production technology, measured in terms of the technical coefficients matrix, A, which includes both energy and nonenergy inputs.

Energy use in the economy, therefore, can change because of changes in final demand and/or because of changes in production technology. We apply Equation (5) to describe the changes in China's energy consumption from 1981 to 1987 as:

$$\begin{aligned}\Delta E &= E_{87} - E_{81} \\ &= (F_{87}Y_{87}+eY_{87}n) - (F_{81}Y_{81}+eY_{81}n) \\ &= (F_{87}Y_{87}-F_{81}Y_{81}) + e(Y_{87}-Y_{81})n \qquad (6)\end{aligned}$$

The first item in Equation (6), $(F_{87}Y_{87}-F_{81}Y_{81})$, represents changes in the intermediate energy use, which depends both on changes in production technology, F, and changes in final demand, Y. The second item, $e(Y_{87}-Y_{81})n$, measures changes in the direct energy consumption, which is solely a function of final-demand shifts.

To determine how much of energy-use changes is due to (1) changes in what to consume (final-demand shifts) and (2) changes in how to produce (production-technology changes), we introduce a hypothetical economy with 1981 production technology, F_{81}, and 1987 final demand, Y_{87}. The energy consumption in this hypothetical economy would be:

$$E_{F81Y87} = F_{81}Y_{87} + eY_{87}n \qquad (7)$$

where E_{F81Y87} measures the amount of energy that would be consumed in China's economy if the 1981 production technology were used to deliver 1987 final demand. Using E_{F81Y87} as a reference point, we can rewrite energy-use changes from 1981 to 1987 as

$$\begin{aligned}\Delta E &= E_{87} + E_{F81Y87} - E_{F81Y87} - E_{81} \\ &= (F_{87}Y_{87}+eY_{87}n) + (F_{81}Y_{87}+eY_{87}n) - (F_{81}Y_{87}+eY_{87}n) - (F_{81}Y_{81}+eY_{81}n) \\ &= F_{81}(Y_{87}-Y_{81})+e(Y_{87}-Y_{81})n \qquad \text{(Final-Demand Shift)} \qquad (8) \\ &\quad +(F_{87}-F_{81})Y_{87} \qquad \text{(Production-Technology Change)}\end{aligned}$$

The final-demand shift indicates the energy impact of final-demand changes while holding the production technology constant. The production-technology change quantifies the energy effect of changes in the production technology with a given final demand.

The E_{F81Y87}, however, is not the only reference point that can be used to separate energy-use changes into the final-demand shift and production-technology change component. An alternative formulation is to use E_{F87Y81} as a reference point, in which case Equation (8) becomes:

$$\begin{aligned} \Delta E &= E_{87} + E_{F87Y81} - E_{F87Y81} - E_{81} \\ &= F_{87}(Y_{87}-Y_{81})+e(Y_{87}-Y_{81})n \qquad \text{(Final-Demand Shift)} \\ &\quad +(F_{87}-F_{81})Y_{81} \qquad \text{(Production-Technology Change)} \qquad (9) \end{aligned}$$

It is obvious that except by pure chance or under some strict mathematical conditions, Equations (8) and (9) will attribute energy-use changes to final-demand shift and production-technology change differently. This ambiguity stems from the problem of indexing, that is, weights from one year usually do not give the same answer as weights from another year, and there is no single "correct" answer (Strout, 1966; Carter, 1970). In fact, the two equations are designed to answer different questions, as pointed out by Strout (1966). In Equation (8), we ask: "how much more (or less) energy would have been required in 1987 if the 1981 production technology had still been used to satisfy 1987 final demand?" In Equation (9), we try to find out "how much less (or more) energy would be used in 1981 if the 1987 production technology had been available to deliver 1981 demand." Because in this study we are mainly interested in the energy impact of using different technologies to deliver 1987, not 1981, final demand, we choose E_{F81Y87}, rather than E_{F87Y81}, as the reference point.[3]

Components of Final-Demand Shift

We can further decompose the final-demand shift component along three dimensions. First, we can identify the energy-use changes associated with changes in the level, distribution, and pattern of final demand. The level of final demand refers to the overall level of total demand (i.e., GDP), which equals the sum of all final output or expenditures. The distribution of demand refers to the distribution of the total demand among individual final-demand sectors, such as personal consumption, government expenditures, capital investment, exports, and imports. The pattern of demand refers to the mix of goods and services within the individual final-demand sector. In matrix notation, final demand is the product of its level, distribution, and pattern components.

$$Y = MDL \tag{10}$$

where M = matrix of the spending mix of individual final-demand sectors;
D = diagonal matrix with the sectoral distribution of total demand on the diagonal; and
L = diagonal matrix with the overall total demand level on the diagonal.

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[3] It is possible, of course, to combine the two formulations and use their average as a measure of the energy impact of final-demand and production-technology changes. This means using $[(F_{87}+F_{81})/2][(Y_{87}+Y_{81})/2]$ as the reference point, which is often confusing and difficult to interpret.

We can use Equation (10) to quantify the energy effects of final-demand level, distribution, and pattern changes. Mathematically,[4]

$$\Delta Y = Y_{87}-Y_{81} = M_{87}D_{87}L_{87} - M_{81}D_{81}L_{81} \tag{11}$$

$$\begin{aligned}
\Delta E_Y = {} & F_{81}(Y_{87}-Y_{81}) + e(Y_{87}-Y_{81})n \\
= {} & F_{81}[M_{87}D_{87}L_{87}-M_{81}D_{81}L_{81}] + e[M_{87}D_{87}L_{87}-M_{81}D_{81}L_{81}]n \\
= {} & F_{81}M_{81}D_{81}(L_{87}-L_{81}) + eM_{81}D_{81}(L_{87}-L_{81})n && \text{(Level Effect)} \\
& + F_{81}M_{81}(D_{87}-D_{81})L_{87} + eM_{81}(D_{87}-D_{81})L_{87}n && \text{(Distribution Effect)} \\
& + F_{81}(M_{87}-M_{81})D_{87}L_{87} + e(M_{87}-M_{81})D_{87}L_{87}n && \text{(Pattern Effect)}
\end{aligned} \tag{12}$$

Second, we can calculate the amounts of energy-use changes originating in individual final demand sectors, such as personal consumption, investment, exports, and imports. Mathematically, this is very simple because final demand in the input-output system is additive.

$$\Delta E_Y = \sum_{\iota} \Delta E_Y^{\iota} = \sum_{\iota} [F_{81}(Y_{87}^{\iota}-Y_{81}^{\iota})+e(Y_{87}^{\iota}-Y_{81}^{\iota})n] \tag{13}$$

where ΔE_Y^{ι} is the change in energy use due to changes in final-demand sector h.

Third, we can determine how changes in the purchase of an individual product or product group affect energy consumption, using the following equation:

$$\Delta E_{Y,k} = F_{81}K(Y_{87}'-Y_{81}') + eK(Y_{87}'-Y_{81}')n \tag{14}$$

where, $\Delta E_{Y,k}$ = matrix of energy-use changes associated with each product k by fuel types;

Y_{87}', Y_{81}' = diagonal matrix of total final demand vector in 1987 and 1981; and

K = matrix consisting of one(s) and zeros, with one(s) in the rows location(s) corresponding to product(s) k and zeros in all other elements of the matrix.

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[4] Similar to Equation (8), the choice of the reference point and the order in which the demand level, distribution, and pattern are varied is somewhat arbitrary.

From Equation (14), we will also be able to estimate how much of the energy-use changes due to final-demand shifts comes directly from purchases of energy products and how much comes indirectly from purchases of nonenergy products.

Components of Production-Technology Changes

The production-technology-change component in Equation (8) measures the energy-use change associated with changes in total intermediate energy requirements of final goods and services. It can be rewritten as:

$$\begin{aligned} \Delta E_T &= (F_{87} - F_{81})Y_{87} \\ &= [e(G_{87}-I) - e(G_{81}-I)]Y_{87} \\ &= (eG_{87}-eG_{81})Y_{87} \\ &= e(G_{87}-G_{81})Y_{87} \end{aligned} \tag{15}$$

where $G_{87} = (I-A_{87})^{-1}$, $G_{81} = (I-A_{81})^{-1}$.

It follows that

$$\begin{aligned} G_{87}(I-A_{87}) &= G_{81}(I-A_{81}) = I \\ G_{87}(I-A_{87}) - G_{81}(I-A_{81}) &= 0 \\ G_{87}-G_{87}A_{87}-G_{81}+G_{81}A_{81} &= 0 \end{aligned}$$

$$\begin{aligned} G_{87} - G_{81} &= G_{87}A_{87} - G_{81}A_{81} \\ &= G_{87}A_{87} - G_{87}A_{81} + G_{87}A_{81} - G_{81}A_{81} \\ &= G_{87}(A_{87}-A_{81}) + (G_{87}-G_{81})A_{81} \end{aligned}$$

$$\begin{aligned} G_{87}-G_{81} - (G_{87}-G_{81})A_{81} &= G_{87}(A_{87}-A_{81}) \\ (G_{87}-G_{81})(I-A_{81}) &= G_{87}(A_{87}-A_{81}) \\ G_{87}-G_{81} &= G_{87}(A_{87}-A_{81})(I-A_{81})^{-1} \\ &= G_{87}(A_{87}-A_{81})G_{81} \end{aligned} \tag{16}$$

Inserting Equation (16) into Equation (15) results in

$$\begin{aligned} \Delta E_T &= (F_{87} - F_{81})Y_{87} \\ &= e(G_{87}-G_{81})Y_{87} \\ &= eG_{87}(A_{87}-A_{81})G_{81}Y_{87} \end{aligned} \tag{17}$$

We split the production technology into two portions. The energy portion represents the direct use of energy inputs, like coal, oil, and electricity, by sector. It measures energy requirement per unit of output. The nonenergy portion contains all the other inputs to by production sectors, such as plastics, steel, and chemical fertilizers. We can use Equation (17) to separate the effect of changes in direct energy requirements and direct nonenergy requirements of energy use by partitioning and writing the changes in technical coefficients, $(A_{87}-A_{81})$, as

$$A_{87}-A_{81} = (A_{87,E}-A_{81,E}) + (A_{87,N}-A_{81,N}) \tag{18}$$

where A_E represents the energy rows of the technical coefficient matrix and A_N represents the nonenergy rows. Equation (13) then becomes

$$\begin{aligned} \Delta E_T &= eG_{87}(A_{87}-A_{81})G_{81}Y_{87} \\ &= eG_{87}(A_{87,E}-A_{81,E})G_{81}Y_{87} + \\ &\quad \text{(changes in energy inputs)} \\ &\quad eG_{87}(A_{87,N}-A_{81,N})G_{81}Y_{87} \\ &\quad \text{(changes in nonenergy inputs)} \end{aligned} \tag{19}$$

It tells us that the change in intermediate energy demand can be caused not only by changes in direct energy inputs, A_E, but also by changes in direct nonenergy or material inputs, A_N. Furthermore, the changes in direct input requirements will be multiplied across the economy through interindustry input-output linkages, which are quantified by the total input requirements matrix, G.

Applying the logic of Equation (19) to individual sectors or sector groups--in this case, agriculture, energy, nonenergy industrial sector, construction, transportation, and commerce, we can identify production-technology changes in individual sectors and assess their relative contribution to intermediate energy-demand changes. Mathematically,

$$\begin{aligned}\Delta E_T &= \sum_j \Delta E_T{}^j \qquad (20)\\ &= \sum_j \, [\underset{\text{(changes in energy inputs)}}{eG_{87}(A_{87,E}{}^j - A_{81,E}{}^j)G_{81}Y_{87}} + \underset{\text{(changes in nonenergy inputs)}}{eG_{87}(A_{87,N}{}^j - A_{81,N}{}^j)G_{81}Y_{87}}]\end{aligned}$$

where $\Delta E_T{}^j$ is the change in energy use due to production-technology changes in sector j.

Table 3-4 summarizes the hierarchical structure of the estimation equations for individual sources of energy-demand changes. We can use those equations to incorporate various factors that affect energy use--such as industrialization, the rise in the capital-to-labor ratio, infrastructure construction, and urbanization--into the general framework of what to consume and how to produce and to assess their likely energy consequence. Infrastructure construction projects, for example, tend to increase energy demand by increasing the gross capital formation in final demand. The rise in the capital-to-labor ratio, on the other hand, will be reflected in production-technology changes. Some factors, such as industrialization, will affect both production technology (e.g., peasants using more fertilizer in agriculture due to development of chemical fertilizer industry) and final demand (e.g., consumers spending more income on industrial products).

TABLE 3-4

STRUCTURAL DECOMPOSITION OF ENERGY-USE CHANGES

Factor	Equation
Final-Demand Shift	$F_{81}(Y_{87}-Y_{81})+e(Y_{87}-Y_{81})n$
Level Effect	$F_{81}M_{81}D_{81}(L_{87}-L_{81})+eM_{81}D_{81}(L_{87}-L_{81})n$
Distribution Effect	$F_{81}M_{81}(D_{87}-D_{81})L_{87}+eM_{81}(D_{87}-D_{81})L_{87}n$
Pattern Effect	$F_{81}(M_{87}-M_{81})D_{87}L_{87}+e(M_{87}-M_{81})D_{87}L_{87}n$
For Demand Source ℓ	$F_{81}(Y_{87}^{\ell}-Y_{81}^{\ell}) + e(Y_{87}^{\ell}-Y_{81}^{\ell})n$
For Product Group k	$F_{81}K(Y_{87}'-Y_{81}') + eK(Y_{87}'-Y_{81}')n$
Production-Technology Change	$(F_{87}-F_{81})Y_{87}$
Energy Inputs	$eG_{87}(A_{87,E}-A_{81,E})G_{81}Y_{87}$
Nonenergy Inputs	$eG_{87}(A_{87,N}-A_{81,N})G_{81}Y_{87}$
For Individual Sector j	$eG_{87}(A_{87}^{j}-A_{81}^{j})G_{81}Y_{87}$
Energy Inputs	$eG_{87}(A_{87,E}^{j}-A_{81,E}^{j})G_{81}Y_{87}$
Nonenergy inputs	$eG_{87}(A_{87,N}^{j}-A_{81,N}^{j})G_{81}Y_{87}$
Actual Energy-Use Changes	$E_{87}-E_{81}=(F_{87}Y_{87}-F_{81}Y_{81})-e(Y_{87}-Y_{81})n$

Source: the Author.

MODEL IMPLEMENTATION

To implement the model structure and conduct the SDA of energy-demand changes, we require three key data components for both 1981 and 1987: input-output tables, price indices, and energy-flow data.

Input-Output Tables

The input-output tables used in our SDA modeling are 1981 and 1987 commodity-by-commodity tables for China under the convention of the System of National Accounts (SNA). The tables are constructed by the

Institute of Systems Science (ISS), Chinese Academy of Sciences, based on the Input-Output Table of China, 1981 and 1987 (SSB, 1985; 1990b). China has two national input-output tables for 1981: one is an industry-by-industry table and the other a commodity-by-commodity table.[5] The 1981 tables are based on the material production system (MPS) of economic accounts, including only material-production sectors--agriculture, industry, construction, transportation, and commerce--and excluding service sectors.[6] China also has two sets of national input-output tables for 1987: the first is based on the SNA convention, including material-production sectors as well as service sectors, and the second is consistent with the MPS. Both of them are commodity-by-commodity tables. The ISS staff chose the commodity-by-commodity tables under the SNA as the consistent framework because these tables provide data on a commodity basis, which is best for identifying energy uses. They also extended the 1981 table to include service sectors.[7] We make some further adjustments to account for definitional and methodological changes from 1981 to 1987.[8]

In our input-output model, we identify eight final-demand sectors or sources: (1) rural personal consumption, (2) urban personal

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[5] China also compiled a physical input-output table for 1981, showing the transactions of 146 key products (Polenske and Chen, 1991).

[6] Under MPS, the energy consumed in the service sector is counted as a part of final-energy consumption.

[7] See Polenske and Chen (1991) for an excellent review of input-output work in China, including data collection procedures, account conventions, and the difference between the MPS and SNA.

[8] See Appendices I and II for the 1981 and 1987 Energy Input-Output Transactions Tables of China.

consumption, (3) social consumption, (4) capital investment, (5) inventory changes, (6) exports, (7) imports, and (8) other. Note that social consumption includes only government expenditures on public services and social welfare and thus differs from the standard definition of "government expenditures" in the national income and product account.[9] The "other" category represents all the final expenditures on goods and services that are not accounted for by the first seven final-demand sectors. It is a residual item for account-balancing purposes.

We subdivide the production activities of China's economy into 18 industrial groups and present energy-intensive sectors at a more disaggregated level than the rest of the economy, as shown in Table 3-5. Ideally, we would like to conduct the SDA at a finer industrial classification to increase the degree of homogeneity within each industrial group and to have considerable detail about changes in the production technology and spending mix, but the energy-consumption data compatible with such an industrial classification are not available nor do they have a reasonable quality. Although limited, the basic 18-sector classification is revealing and the presentation of energy-intensive sectors at a rather disaggregated level should enable us to capture most major energy-related production-technology changes and final-demand shifts.

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[9] Because the state has played such a dominant role in economic decision-making and resource allocation in China, the standard definition of "government expenditures" becomes too encompassing. In the China input-output table, most of the government administrative functions are classified as a part of the service sector.

TABLE 3-5

EIGHTEEN PRODUCTION SECTORS IN THE SDA MODEL

Code	Sector
1	Agriculture
2	Coal
3	Petroleum
4	Natural Gas
5	Electricity
6	Iron and Steel
7	Nonferrous Metals
8	Chemical Fertilizers
9	Heavy Chemicals
10	Cement
11	Construction Materials
12	Heavy Machinery
13	Light Industry
14	Construction
15	Freight Transport & Telecommunication
16	Commerce
17	Passenger Transport
18	Services

Source: the Author.

It is important to point out, however, that the results of the SDA are not invariant with respect to industrial classification. The change in industrial disaggregation will not change total levels of intermediate output and final demand, but it will affect both the production technology and spending mix. The size of the final-demand level effect, therefore, will remain about the same. The final-demand mix effect and technology-change components, on the other hand, will become greater or smaller, depending on whether the products/inputs that are growing are grouped together to reinforce each other's growth or are grouped with products/inputs that are declining, so that the changes tend to cancel each other; and on whether greater detail is devoted to static or to changing elements (Carter, 1970). A priori, there is no systematic relationship between the fineness of the industrial classification and the relative size of final-demand mix and production-technology components. Overall, the energy impact of changes in a consolidated sector will be similar to the combined effect from changes in its subsectors because "the price and output behavior of a consolidated industry tends to represent an average of the reaction pattern of its component parts (Leontief, 1941, p. 206)."

Price Indices

The analysis of change in energy-use patterns over time requires that each year's input-output tables be based on the same set of prices because a million RMB's worth of output in 1981 had a much different value or physical unit from a million RMB's worth of output in 1987.[10] We use 1981 as the base year (thus no price changes were necessary for the 1981 table) and adjust the 1987 table to 1981 prices using the price indices from the ISS. The ISS staff estimate the price indices for each of the 18 sectors based on various real output numbers and price indices reported by statistical agencies, many of which were unaccessible to researchers at large. We use the indices to convert the output in the 1987 table into 1981 constant prices for all industries within their

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[10] The constant-price model, however, does have one important drawback. It means that price, an important factor in energy use, will be held constant. This does not allow analysts to examine the impacts of price changes on energy use, indicating the need to complement the SDA with other types of analyses, such as econometric analyses or studies of energy pricing-policy changes.

respective sectors. We show the average output deflators for the 18 production sectors in Table 3-6.

How will an error in a single price deflator affect the results of the SDA? Leontief (1953) observes that errors in price indices distort output estimates only for those sectors in which the errors actually occur.

TABLE 3-6

AVERAGE OUTPUT DEFLATORS FOR 1981 AND 1987 INPUT-OUTPUT TABLES

Sector	1990 RMB=1.00		Deflator	
	1981	1987	1981	1987
1. Agriculture	1.9999	1.4209	1.0000	0.7105
2. Coal	1.8284	1.4702	1.0000	0.8041
3. Petroleum	1.7697	1.2688	1.0000	0.7170
4. Natural Gas	2.4784	1.1678	1.0000	0.4712
5. Electricity	1.7422	1.4975	1.0000	0.8595
6. Iron and Steel	1.9156	1.4079	1.0000	0.7350
7. Nonferrous Metallurgy	1.8338	1.5073	1.0000	0.8220
8. Chemical Fertilizers	1.6788	1.3432	1.0000	0.8001
9. Heavy Chemicals	1.5582	1.2739	1.0000	0.8175
10. Cement	1.7647	1.2414	1.0000	0.7035
11. Construction Materials	1.7667	1.1919	1.0000	0.6746
12. Heavy Machinery	1.3628	1.1339	1.0000	0.8320
13. Light Industry	1.3901	1.2841	1.0000	0.9237
14. Construction	1.9078	1.3140	1.0000	0.6888
15. Freight Transport and Communication	2.2876	1.6652	1.0000	0.7279
16. Commerce	2.0065	1.3344	1.0000	0.6650
17. Passenger Transport	2.2876	1.6652	1.0000	0.7279
18. Services	1.9797	1.4216	1.0000	0.7181

Source: The Institute of Systems Science, Chinese Academy of Sciences, 1993.

Carter provides an excellent illustration using the steel industry as an example.

> Suppose that the 1947-1958 price index, used for deflating the 1958 output of the steel industry to 1947 prices, is "too large." This means, in effect, that all purchases of steel and their sum, that is, total steel output, will be understated as compared with corresponding 1947 transactions. All coefficients along the steel *row* will be understated by a fixed proportion. Since their denominator will be understated, all coefficients in the steel *column* will be overstated by the same fixed proportion. It would be as if the Census of Manufactures had shifted from short to long tons between 1947 and 1958 without anyone noticing. Such dimensional "distortions" of the steel row and column are exactly compensating in their effects on other sectors: steel requirements are understated, but inputs required to produce steel are overstated. Thus, an error in the steel price does not bias estimates of requirements from mining or castings (Carter, 1970, pp. 22-23).

In other words, only errors in price deflators for energy sectors will distort the calculation for energy outputs or requirements. This is encouraging because we express energy in physical units in the SDA. This means that the errors or biases in price indices we use will have no significant effect on the estimation of aggregate energy demand. They will, however, affect the allocation of energy-use changes among different sources, which should not be overlooked. Furthermore, the price errors in different sectors may be additive and/or multiplicative. Additional work needs to be done to test the sensitivity of the findings presented in this research to changes in the deflators used.

Energy-Flow Data

The primary source for our energy-flow data is the energy-flow matrices developed by the ISS staff for their 1981 and 1987 input-output tables. The matrices show the flows of 9 different energy products being consumed by all 18 production sectors and 8 categories of final demand in our input-output model. The 9 energy products are raw coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, natural gas, and electricity, which accounted for all the primary energy consumption and about 95 percent of final energy use in the 1980s. We convert all the energy products into standard coal based on their average net calorific values or lower heating values and aggregate them into four categories--coal, petroleum, natural gas, and electricity--to be consistent with the 18-sector industrial classification of the input-output tables (see Table 3-7). We then follow the approach used by analysts at the University of Illinois (Bullard and Herendeen, 1975; Bullard et al., 1978) and the U.S. Office of Technology Assessment (OTA, 1990) and allocate energy consumption to the production and final-demand sectors that completely *used up* energy in 1981 or 1987.

TABLE 3-7

CONVERSION FACTORS OF MAJOR FUELS TO STANDARD COAL

Fuel	Average Lower Heating Value	Conversion Coefficient
Raw Coal	20,908 kJ/kg	0.7143 kgsce/kg
Coke	28,435 kJ/kg	0.9714 kgsce/kg
Crude Oil	41,816 kJ/kg	1.4286 kgsce/kg
Fuel Oil	41,816 kJ/kg	1.4286 kgsce/kg
Gasoline	43,070 kJ/kg	1.4714 kgsce/kg
Kerosene	43,070 kJ/kg	1.4714 kgsce/kg
Diesel Oil	42,652 kJ/kg	1.4571 kgsce/kg
Natural Gas	38,931 kJ/m^3	1.3300 kgsce/m^3

Source: SSB. 1991. China Energy Statistics, 1991. Beijing: China Statistical Press, p. 413.

Note: kgsce = kilogram of standard coal equivalent.

The electricity sector poses a special difficulty for our SDA modeling. At the 18-sector input-output tables, we are unable to separate primary electricity (almost all of which comes from hydropower) from secondary electricity generated in thermal-power stations. This is problematic because in order to avoid double counting both primary energy (e.g., coal) used to generate secondary energy (e.g., electricity) and the consumption of secondary energy, we should include only primary electricity in calculating total energy consumption for the whole economy. We solve this problem by introducing a hypothetical hydropower sector into the input-output model. The hydropower sector sells all its output to the electricity sector for power generation and gets all of its inputs from the earth (see the input-output transactions tables in Appendix I and II). We estimate the standard coal equivalent of hydropower based on the amount of fossil fuel that would be required to generate the equivalent amount of hydro-electricity. This way of incorporating hydropower enables us to trace both primary energy requirements and electricity end uses.

Data Limitations

Our SDA modeling relies on data from China's official statistics, which, we believe, are reasonably accurate and are of adequate quality to support the validity of our conclusions. First, most of the data come from a research group, headed by Professor Xikang Chen, at the Institute of Systems Science (ISS) of the prestigious Chinese Academy of Sciences. Professor Chen is internationally known for his input-output and systems science work in China. He and his staff have extensive experience in compiling input-output tables and are leaders in applying the input-output technique for business management and for economic and energy policy analysis.

Second, we conduct the SDA at a rather high level of sectoral aggregation, which reduces errors related to changes in industrial classification and misallocation of output among the different industries. The high sectoral aggregation may also neutralize some of the nonsystematic errors in the input-output data; for example, while some enterprises in the cement industry over-estimate their energy use, others may under-report it, cancelling some of the errors.

Third, the input-output model stems from the double-accounting principles employed in the national income and product accounts. Gross output can be accounted for either by adding the total purchases (outlays) of inputs or by tracing the flows of output from sectoral sources to destinations of intermediate and final uses. The model provides many opportunities for cross-checking data, both internally and against other economic statistics, and for detecting data inconsistencies or errors.

Finally, we supplement secondary information with field studies and complement quantitative statistics with qualitative information, such as press accounts and success stories. This helps us to know data limitations and take them into consideration in interpreting our modeling results.

We realize, however, that there are some limitations in the data. China's statistics, though improving since 1981, are still less reliable than those from the Western countries. In our own work at the MIT multiregional planning research group with some of the published and unpublished data, for example, we have found that the officials have not always taken the time to cross-check data for consistency and that statistics from different agencies sometimes contradict each other. In addition, many of the standard economic concepts, measurement instruments, and industry classification systems prevalent in the Western countries are just being adopted by the State Statistical Bureau and other agencies for use in their national, provincial, municipal, local, and enterprise statistical work.[11] We especially caution readers about the reliability of the statistics for the service sector, which accounted for about 14 percent of GDP and 3 percent of total energy consumption in 1987. For years, China collected economic statistics under the MPS convention and treated the service sector as a consumption, rather than production, activity. Since 1985, SSB shifted gradually from the MPS to the SNA and started to report GDP statistics, which included the service output. It is possible that the coverage of service industries might have changed over time in the 1980s as China's statistical staff became more familiar with the SNA.[12]

Given these data limitations, we suggest that the results of our SDA modeling be interpreted as indications of a general pattern of energy-use changes rather than as an exact estimate of different contributing components. In many cases, it is perhaps more appropriate to interpret our numerical results in terms of an ordinal scale than in

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[11] Additional details on these and other statistical issues are covered in the recent book edited by Polenske and Chen (1991).

[12] China is currently (1993) conducting a census of service industries for the first time.

terms of an interval or ratio scale.

MODEL STRENGTHS AND WEAKNESSES

The SDA model has at least three major strengths for use in energy analysis. First, it integrates energy data into an input-output account and provides a unified framework for describing the relationships between energy, other factor inputs, and other final products, and consequently, the relations between energy and the economy. The framework includes all producing sectors and all factors of production--capital, labor, energy, and material inputs. It also covers the entire energy production and consumption cycle from mining, refining, transporting, converting, distributing, to end-use. These features make SDA an invaluable tool in examining how the consumption pattern and production technology change and how those changes affect energy demand.

Second, the model describes the economy as a system of interdependent activities. It enables analysts to trace the effect of a particular final-product purchasing decision back through the product's producer, the companies that supply intermediate inputs to the producer, all the way to the raw-material processors. This is important because in today's highly complex economy, a large amount of energy is consumed indirectly through use of nonenergy inputs. For example, to produce one RMB worth of farm product in 1981 required only about 123 gsce of energy, but it required 716 gsce or almost six times as much of indirect energy use because some inputs used in farming, such as chemical fertilizers, plastics, and pesticides, required a lot of energy in their manufacturing. In other words, over 85 percent of the energy associated with farming in 1981 was not in farming, but was added a few steps before by the production links to fertilizer plants, plastics factories, and chemical factories.

Third, the SDA is a powerful tool for identifying sources of energy-demand changes and assessing the relative contribution of each individual source. Using the model, analysts can decompose changes in energy use into those due to final-demand shifts and those resulting from production-technology changes. They can then focus on different aspects of final demand and production technology. Analysts may examine, for example, how different demand sources (e.g., personal consumption and government expenditures) affect energy use. They may also determine how much of the energy-use change associated with production technology comes from energy inputs and how much from nonenergy inputs. Unlike the traditional static input-output model, which assumes fixed technical coefficients, the SDA estimation equations represent comparative static changes in input-output coefficients. Their underlying production function is more flexible than the static input-output function, allowing for input substitution and technological changes. This increases the explanatory power of the input-output model and helps in analyzing the impacts of technological changes on energy use.

The SDA method used in this analysis, however, has some important limitations, which should be taken into consideration in interpreting the results of the SDA. First, the analysis rests on the crucial assumption of a linear production function or constant returns to scale for each sector, and thus fails to account for energy-use changes caused by changes in scale of production. Many estimation equations used in decomposing energy-use changes, such as the primary energy intensity of a product and the energy associated with personal consumption, rely on this assumption. This is, however, less a problem in the SDA than in a standard static input-output analysis because the production technology in both year t and t-1 is known. We should be able to capture the impact of production-scale changes, at least partially, by examining the production-technology changes. In other words, we can consider the changes in the returns to scale as part of a broadly defined technological change.

Second, the SDA model is data-intensive and requires a large amount of internally consistent economic-transactions and energy-flow data. As a result, we can only conduct the SDA at a highly aggregated 18-sector level because of lack of data. Although we deliberately separate major energy-intensive sectors from the rest of the economy in constructing our model, this level of disaggregation is still too high to capture some important changes in specific industries and specific production processes. We are not able to tell, for example, whether a change in the direct oil coefficient in the passenger transportation sector was due to a change in modal structure or to an improvement in fuel efficiency. We, therefore, must keep the level of industrial disaggregation in mind when we interpret the changes in the production technology and final-demand mix.

Finally, the model only describes how production-technology changes and final-demand shifts affect energy consumption, but it does not explain why the technological changes and demand shifts occur. We cannot use it to answer questions such as: what caused the changes in consumer spending pattern in China between 1981 and 1987? Why was energy used more efficiently in 1987 than in 1981? To mitigate this problem, we will place final-demand and production-technology changes into a general context of changing economic, institutional, and energy conditions in China and describe how the economic-reform program and changes in government policies since 1978 led to profound changes in both what to consume and how to produce. We will also complement the SDA with a case study of energy-efficiency improvements in the iron and steel industry to see what enterprises actually did to conserve energy. There are many methods and models available for examining energy-use changes, each with strengths and weaknesses. The question, therefore, is not which method or model is the best one, but which one sheds the most light on which problem. We believe that one key to a good energy-policy analysis is to match approaches to the task at hand and to mix different methods and models as needed (Lin et al., 1992).

With the data and model limitations in mind, we will apply the SDA model to examine China's energy-use changes from 1981 and 1987 in Chapters 4 and 5. We will review the changes in final demand and production technology, decompose those changes into different elements, and determine the individual and collective energy impacts of those elements. We will, for example, describe changes in the level and mix of imports and estimate their impact on the demand for individual fuels. We will also quantify the amount of energy savings associated with the energy-efficiency improvements of a particular sector, say the cement industry. This level of detail not only increases the explanatory power of the model, but also helps us to uncover specific sources of energy savings and to identify factors that were primarily responsible for the energy-intensity reduction from 1981 to 1987.

CHAPTER 4

ENERGY EFFECTS OF FINAL-DEMAND SHIFTS

When people consume anything, they are consuming energy (Bullard and Herendeen, 1975, p. 268). Almost everything a consumer buys in the formal market nowadays requires, directly or indirectly, some energy to produce (Slesser, 1978). A change in final demand for goods and services, therefore, will have an important energy consequence.

In this chapter, we assume production technology to be that of 1981 and perform a set of computations to determine how final-demand shifts from 1981 to 1987 affect energy consumption in China's economy. We measure not only changes in direct energy use by final customers, but also changes in intermediate or indirect energy use implied by changes in the demand for both energy and nonenergy products that require varying amount of energy to make. This is important because in China, the direct energy use by final customers accounted for only about 14-15 percent of total energy consumption during the 1980s. Over 85 percent of the energy was used by production sectors as an intermediate input to provide goods and services.[1]

We view the energy impact of final-demand shifts from three different dimensions: (1) the final demand level, distribution (across final users), and pattern (i.e., spending pattern of final users), (2) the sources of final demand, such as personal consumption, social consumption, capital investment, and international trades, and (3) the

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[1] See Chapter 2 for a detailed discussion of the structure of energy consumption in China's economy.

types of final goods and services purchased. The three dimensions intercept one another and are different aspects of the same final-demand shifts from 1981 to 1987. Each of them, however, provides a unique insight into the relationship between final demand and energy consumption in China's economy.

LEVEL, DISTRIBUTION, AND PATTERN

We can split final-demand shifts into three components: level, distribution, and pattern. First, the overall level of final demand may change, that is, final users just buy more (less) of everything and keep the mix of goods and services they purchase constant. This implies that all final-demand sectors--personal consumption, social consumption, capital investment, imports, exports, and so on--increase (decrease) their expenditures on all goods and services at an uniform rate. Without any other changes, we would expect such a demand-level increase (decrease) to cause more or less the same rate of increase (decrease) in total energy consumption of an economy. In our case, this means that China's energy consumption would rise at about the same rate as its total final-demand or GDP growth between 1981 and 1987.

Second, the distribution of final demand may change. Different sectors of final demand may grow at different rates, thus changing their relative importance as buyers of final products and their share of total final demand. Because different demand sectors purchase a different mix of goods and services, which requires varying amounts of energy to produce, the change in demand distribution can have an important effect on energy consumption. As shown in Table 4-1 and Figure 4-1, energy intensity, the amount of energy consumption required to satisfy one RMB of spending, varies across individual demand sectors. For final demand as a whole, it required 1.32 kgsce energy to satisfy one RMB of final spending in 1981. The intensity for individual demand sectors ranged from a high of 1.94 kgsce/RMB for imports to a low of only 0.71 kgsce/RMB for social consumption. This may not look like a large variation, but when we consider the fact that the size of each final demand sector in China is in the magnitude of billions RMB, a one-percent redistribution of total demand among different demand sectors can have a major effect on energy requirements of the economy.

TABLE 4-1

PRIMARY ENERGY REQUIREMENTS OF FINAL-DEMAND SECTORS IN CHINA, 1981

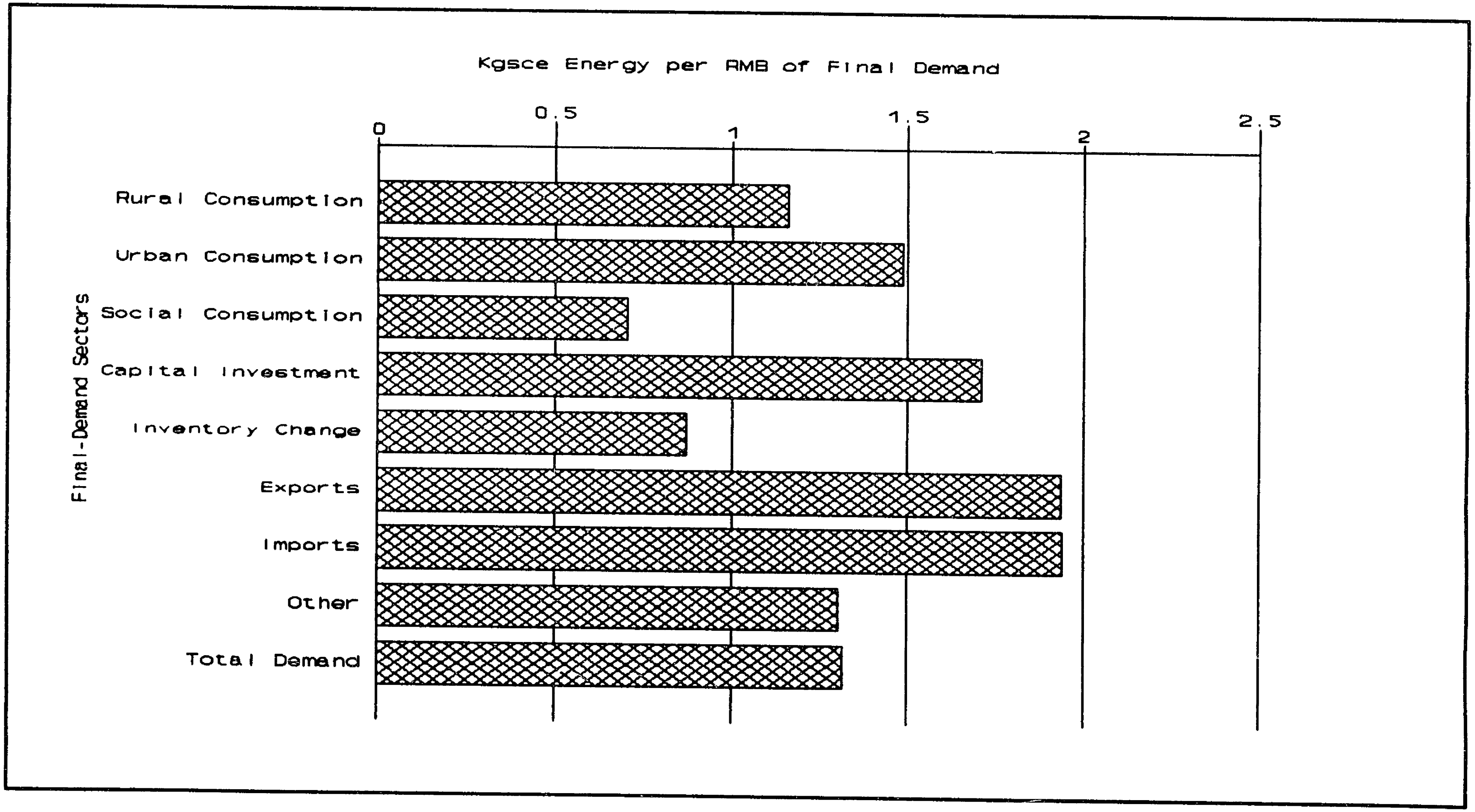
(kgsce energy per RMB of final demand)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Total
Rural Consumption	0.8340	0.2326	0.0395	0.0530	1.1590
Urban Consumption	1.1518	0.2405	0.0368	0.0576	1.4866
Social Consumption	0.4595	0.1943	0.0182	0.0337	0.7056
Capital Investment	1.2747	0.3167	0.0431	0.0761	1.7106
Inventory Change	0.5402	0.2366	0.0382	0.0569	0.8720
Exports	0.8973	0.9334	0.0479	0.0597	1.9383
Imports	1.3578	0.4063	0.0800	0.0970	1.9411
Other	0.9415	0.2564	0.0455	0.0608	1.3042
Total Demand	0.9237	0.3008	0.0352	0.0555	1.3152

Source: SDA Modeling and Computations.

FIGURE 4-1

PRIMARY ENERGY REQUIREMENTS OF FINAL-DEMAND SECTORS IN CHINA, 1981



Source: Data in Table 4-1.

Third, the pattern of final demand, that is, the mix of goods and services within the individual demand sector, may change over time. Table 4-2 and Figure 4-2 show total energy requirements for 14 nonenergy products in 1981.[2] Heavy-industry products, such as iron and steel, cement, and chemical fertilizers, had the highest energy intensities. Many of those sectors used energy both as a feedstock as well as a source of heat or power. Service and commerce sectors, on the other hand, had the lowest energy intensities.

TABLE 4-2

PRIMARY ENERGY INTENSITY OF NONENERGY PRODUCTS IN CHINA, 1981
(kgsce input per RMB of final output)

Product	Coal	Petroleum	Natural-Gas	Hydropower	Total
Agriculture	0.5389	0.2017	0.0495	0.0486	0.8387
Iron and Steel	3.7366	0.6809	0.0925	0.1707	4.6807
Nonferrous Metals	1.7680	0.5307	0.0348	0.2713	2.6048
Chemical Fertilizer	4.4603	0.9593	0.5600	0.3228	6.3023
Heavy Chemicals	1.4978	1.1916	0.1641	0.1804	3.0339
Cement	3.8161	0.4124	0.0289	0.1266	4.3840
Construction-Materials	1.7587	0.4006	0.0307	0.0716	2.2617
Heavy Machinery	1.3407	0.3382	0.0448	0.0974	1.8212
Light Industry	0.7568	0.2583	0.0372	0.0599	1.1121
Construction	1.3021	0.3122	0.0429	0.0667	1.7239
Freight and Communication	0.8100	0.5779	0.0241	0.0300	1.4419
Passenger Transport	0.6039	0.3631	0.0184	0.0274	1.0128
Commerce	0.4202	0.1319	0.0152	0.0287	0.5960
Services	0.4186	0.1860	0.0154	0.0301	0.6502

Source: SDA Modeling and Computations.

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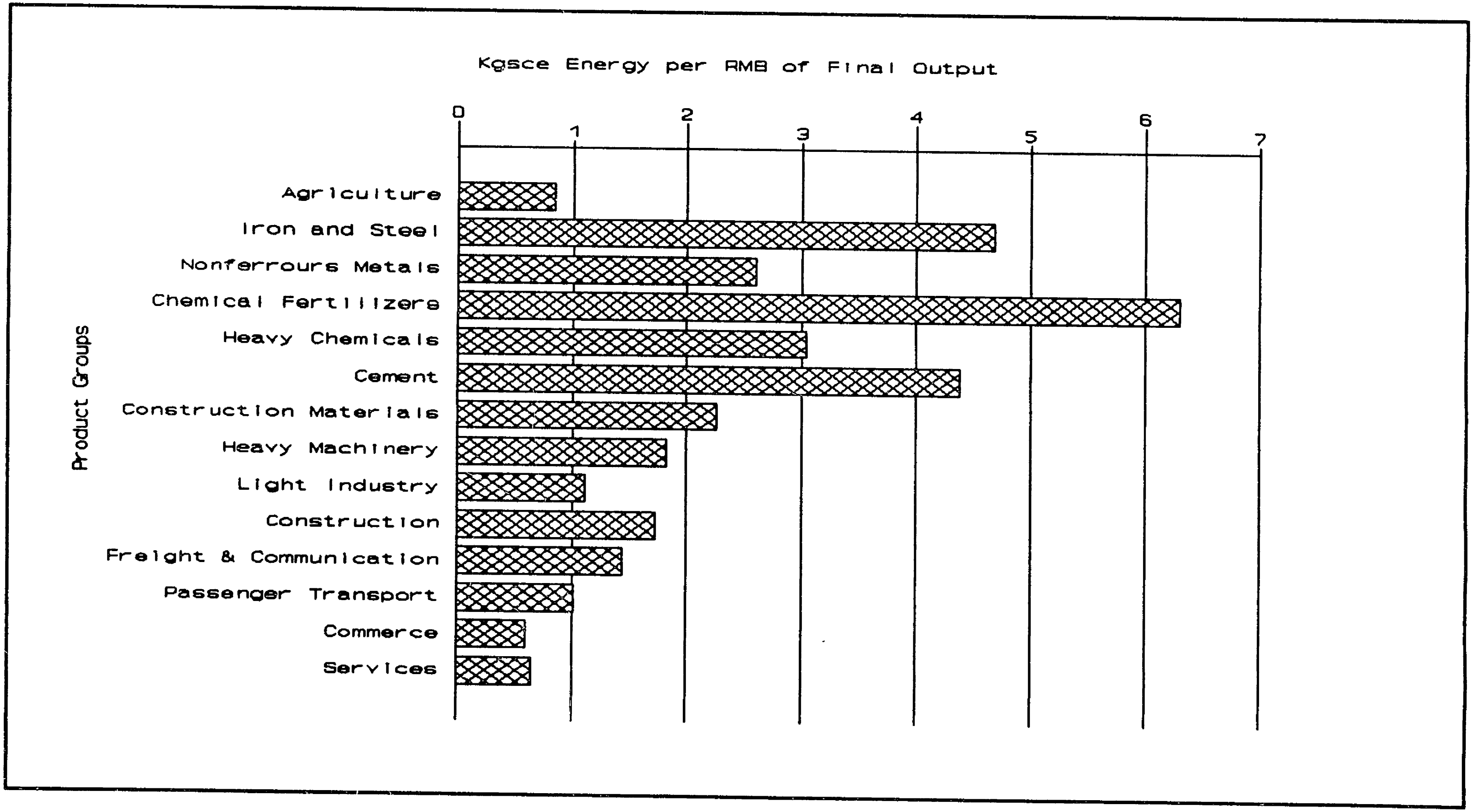
[2] We exclude energy products from the table because energy outputs are measured in physical units, which makes their energy intensities incomparable with the intensities of nonenergy products. If we measure energy output in RMB value terms, energy products have a similar level of total energy requirements to many heavy-industry products.

FIGURE 4-2

PRIMARY ENERGY INTENSITY OF NONENERGY PRODUCTS IN CHINA, 1981



Source: Data in Table 4-2.

Because of the large differences in product energy intensities, the changes in the mix of goods and services purchased by final customers can have an important impact on energy consumption of the economy. Energy consumption, for instance, will increase if there is a shift in the spending pattern from less energy-intensive commodities, such as commerce and services, to more energy-intensive ones, such as chemical fertilizers and cement.

Table 4-3 shows, in terms of the amount and percentage, energy effects of final-demand level, distribution, and pattern changes. Between 1981 and 1987, total final demand expenditures (GDP) at 1981 constant prices increased by 84 percent from 481 billion RMB to 886 billion RMB. The level effect indicates that if there were no changes in production technology and in the distribution and pattern of final demand, China's energy consumption would increase at exactly the same rate, 84 percent, for all types of fuels. This was equivalent to 515 million tsce increase in primary energy consumption--376 million tsce in coal, 102 million tsce in petroleum, 14 million tsce in natural gas, and 23 million tsce in hydropower.

The distribution of final demand, however, did not remain constant. As Table 4-4 indicates, different final-demand sectors grew at very different rates between 1981 and 1987: for example, imports rose by 324 percent; capital investment increased by 124; and rural personal consumption went up by 62 percent. The difference in growth rates led to a change in the distribution of final demand, as shown in Table 4-5. The share of rural personal consumption, inventory change, and other-demand declined while that of urban personal consumption, social consumption, capital investment, exports, and imports rose. This distributional change cut the growth rate of China's total energy consumption from 1981 to 1987 by 6 percent, saving 36 million tsce of energy, most of which came from a 10-percent increase in the GDP share of imports (Table 4-3). For individual fuels, the distributional change reduced the natural-gas growth rate by 20 percent, hydropower growth by 10 percent, coal growth by 6 percent, and petroleum growth by 2 percent (Table 4-3).

TABLE 4-3

PRIMARY ENERGY-USE CHANGES FROM 1981 TO 1987 DUE TO FINAL-DEMAND LEVEL, DISTRIBUTION, AND PATTERN CHANGES

Source	Coal	Petroleum	Natural-Gas	Hydropower	Total
Amount	(million tonnes standard coal equivalent)				
Final Demand Shift	347.5	101.9	15.0	23.3	487.7
Level Effect	376.1	101.6	14.3	22.5	514.5
Distribution Effect	-27.0	-2.5	-3.3	-2.7	-35.5
Pattern Effect	-1.5	2.7	4.0	3.6	8.8
Percent	(percent over the 1981 energy consumption)				
Final Demand Shift	77.9	84.4	88.5	87.4	79.9
Level Effect	84.3	84.3	84.3	84.3	84.3
Distribution Effect	-6.0	-2.1	-19.5	-10.3	-5.8
Pattern Effect	-0.3	2.2	23.7	13.4	1.4

Source: SDA Modeling and Computations.

Note: 1. Each percentage in the table represents a change as the percent of total energy consumption for the respective energy type in 1981.

2. Numbers may not add to totals or subtotals due to rounding.

TABLE 4-4

CHANGES IN FINAL DEMAND IN CHINA, 1981 TO 1987

(Billion RMB in 1981 Producer Prices)

Demand Sector	1981	1987	Change	% Change
Rural Consumption	169.5	275.2	105.7	62.3
Urban Consumption	101.3	200.2	98.9	97.6
Social Consumption	45.6	97.2	51.6	113.0
Capital Investment	124.8	279.5	154.6	123.9
Inventory Change	32.8	46.9	14.1	42.9
Exports	42.5	151.2	108.7	255.8
Imports	-38.9	-164.7	-125.8	323.6
Other	3.0	0.4	-2.7	-88.1
Total Demand	480.7	885.8	405.1	84.3

Source: SDA Modeling and Computations.

TABLE 4-5

CHANGES IN FINAL-DEMAND DISTRIBUTION IN CHINA, 1981 TO 1987

(percent of total final demand)

Demand Sector	1981 Share	1987 Share	Share Change
Rural Consumption	35.3	31.1	-4.2
Urban Consumption	21.1	22.6	1.5
Social Consumption	9.5	11.0	1.5
Capital Investment	26.0	31.5	5.6
Inventory Change	6.8	5.3	-1.5
Exports	8.8	17.1	8.2
Imports	-8.1	-18.6	-10.5
Other	0.6	0.0	-0.6
Total Demand	100.0	100.0	0.0

Source: SDA Modeling and Computations.

The final-demand pattern also changed between 1981 and 1987. Table 4-6 shows, for example, that the mix of goods and services changed in four final- demand sectors--rural personal consumption, urban personal consumption, exports, and imports.[3] Compared with the 1981 spending mix, rural households spent relatively less on agricultural products and services and relatively more on industrial products and

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[3] The mix changes in Table 4-6 are for illustration only. We actually conduct the analysis at an 18-sector industrial disaggregation.

TABLE 4-6

CHANGES IN THE MIX OF SPENDING IN SELECTED FINAL-DEMAND SECTORS

Final Demand	Agriculture	Industry	Transport	Service	Total
Rural Consumption					
1981 Mix	48.2	34.2	1.8	15.9	100.0
1987 Mix	40.8	43.9	2.9	12.4	100.0
Change	-7.4	9.8	1.1	-3.5	0.0
Urban Consumption					
1981 Mix	15.0	55.6	2.6	26.8	100.0
1987 Mix	21.2	58.8	3.0	17.1	100.0
Change	6.1	3.2	0.4	-9.7	0.0
Exports					
1981 Mix	6.0	57.5	11.4	25.1	100.0
1987 Mix	8.8	73.2	8.1	10.0	100.0
Change	2.8	15.7	-3.3	-15.1	0.0
Imports					
1981 Mix	23.8	70.8	0.3	5.1	100.0
1987 Mix	4.7	80.1	3.0	12.1	100.0
Change	-19.1	9.3	2.8	7.0	0.0

Source: SDA Modeling and Computations.

transportation in 1987 than in 1981. Urban households, on the other hand, increased the percentage of their expenditures on agriculture products, but reduced that on services.[4] In the export sector, there was a shift away from services towards industrial products. In the import sector, the importance of agriculture declined while that of industrial products and services increased. This demand-pattern change affected different fuels differently. It reduced slightly the growth in

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[4] This was the result of the gradual elimination of food rationing and the increased availability of agricultural products in the free market.

coal consumption but increased the demand for all other types of energy--by 2.2 percent for petroleum, 23.7 percent for natural gas, and 13.4 percent for hydropower (Table 4-3). On balance, however, the pattern change resulted in only a 9 million tsce energy saving, about 1.4 percent of the 1981 total energy consumption in China because coal is such a dominant fuel (see Table 4-3).

To summarize, in the absence of production-technology changes, final-demand shifts from 1981 to 1987 would lead to an 80 percent or 488 million tsce increase in total energy consumption, which consisted of 348 million tsce coal, 102 million tsce petroleum, 15 million tsce natural gas, and 23 million tsce hydropower (see Table 4-3). This 488 million energy-use increase was the net result of final-demand level, distribution, and pattern effects. Economic growth--the increase in the overall level of final demand--exerted a strong upward pressure on China's energy consumption. Everything else being equal, it would cause total energy consumption to increase by 84 percent or 515 million tsce. The shift from low to high energy-intensive products within the demand sectors increased total energy use by another 1 percent or 9 million tsce. The change in the distribution of final demand, on the other hand, reduced energy use by 6 percent or 36 million tsce.

SOURCES OF FINAL DEMAND

Final demand is a heterogeneous group, composed of rural personal consumption, urban personal consumption, social consumption, capital investment, inventory change, exports, and imports. Total final demand is the sum of the expenditures from all those sources. Its level, distribution, and pattern are determined by how much each individual group of final consumers spends (level) and what goods and services they purchase (mix). Spending by different groups, however, depends on widely different factors and may develop along divergent paths (OTA, 1990). For example, personal consumption is closely related to disposable income, social consumption is constrained by the government's revenue and budget, capital investment is affected by bank lending policies, and exports are influenced by the currency-exchange rates. Given these differences, it is important to look at changes in spending from each demand source and quantify their individual impacts on energy consumption of China's economy.

Table 4-7 displays the contribution of individual demand sectors to the energy-use changes associated with final-demand shifts. The increase in imports from 1981 to 1987 exerted a downward pressure on energy consumption. Everything else being equal, it would lead to a 233 million tsce reduction in energy consumption. Changes in spending from all other demand sources generated an upward pressure on energy use. Among them, the effect of the capital-investment expansion was the most prominent. Holding all other factors constant, it would result in 266 million tsce increase in energy consumption over 1981. We exclude the "other" demand, a residual item for account balancing, from our discussion because it is a small component of the final demand and because the concepts of level and mix cannot be so meaningfully applied to it.

For each demand group, we calculate how much of the energy-use change was due to a change in the level of spending and how much was due

TABLE 4-7

PRIMARY ENERGY-USE CHANGES ASSOCIATED WITH SOURCES OF FINAL DEMAND IN CHINA, 1981 TO 1987

(million tonnes standard coal equivalent)

Source	Coal	Petroleum	Natural-Gas	Hydropower	Total
Rural Consumption	89.3	27.0	4.0	6.3	126.7
Level Effect	88.1	24.6	4.2	5.6	122.5
Mix Effect	1.2	2.5	-0.1	0.7	4.3
Urban Consumption	86.2	25.6	4.8	6.3	122.9
Level Effect	113.9	23.8	3.6	5.7	147.0
Mix Effect	-27.7	1.8	1.2	0.6	-24.1
Social Consumption	23.7	9.8	0.9	1.7	36.1
Level Effect	23.7	10.0	0.9	1.7	36.4
Mix Effect	0.0	-0.2	0.0	0.0	-0.2
Capital Investment	198.1	49.2	6.7	11.8	265.8
Level Effect	197.1	49.0	6.7	11.8	264.5
Mix Effect	1.0	0.2	0.0	0.0	1.3
Inventory Change	21.4	6.3	1.1	1.6	30.4
Level Effect	10.1	3.4	0.5	0.8	14.9
Mix Effect	11.3	2.9	0.6	0.8	15.5
Exports	100.8	36.6	5.1	7.7	150.2
Level Effect	85.1	36.9	5.2	6.5	133.7
Mix Effect	15.7	-0.3	-0.2	1.2	16.5
Imports	-164.0	-50.1	-7.2	-11.7	-233.0
Level Effect	-166.3	-47.8	-10.1	-12.2	-236.4
Mix Effect	2.4	-2.2	2.8	0.5	3.5
Other	-7.9	-2.7	-0.4	-0.5	-11.5
Total Demand	347.5	101.9	15.0	23.3	487.7

Source: SDA Modeling and Computations.

to a change in the mix of what was being purchased (Table 4-7). We find that except for inventory changes, the level-effect component was far greater than the mix-effect and largely determined the direction and magnitude of energy-use changes associated with each demand sector. This is consistent with our finding in the last section that the final-demand level effect played the dominant role and that the final-demand pattern change had only a minor effect on energy consumption in China's economy. We also find that increases in the level of personal consumption (rural consumption and urban consumption), capital investment, and international trade (exports and imports) were responsible for almost all the energy-use changes attributable to final-demand shifts. We, therefore, focus our discussion on what factors caused the spending-level changes in those sectors from 1981 to 1987.

Personal Consumption

Personal consumption expenditures consist of rural and urban personal consumption. It is the largest component of final demand in China, accounting for about 65 percent of the GDP in 1981 and 1987 (see Table 4-5). Between 1981 and 1987, total consumption expenditures increased by 205 million RMB (in 1981 constant producer prices)--106 million RMB from the rural-consumption growth and 99 million RMB from the urban-consumption growth (Table 4-4). Holding all other factors constant, this consumption increase would result in 250 million tsce growth in total energy consumption. For individual fuels, the consumption increase would cause 176 million tsce increase in coal consumption, 53 million tsce increase in petroleum consumption, 9 million tsce increase in the use of natural gas, and 13 million tsce increase in the demand for hydropower (Table 4-7).

Personal consumption expenditures may grow because of the increase in population and/or because of the increase in per capita consumption expenditures. Mathematically,

$$CON = POP * CON_{POP}$$

where CON = personal consumption expenditures,
POP = population, and
CON_{POP} = per capita consumption expenditures.

Using the equation, we can decompose the growth rate of personal consumption into three components: population growth, growth in per capita consumption (spending level), and an interaction factor, which indicates the joint effect of the population and per-capita-consumption growth.

$$\begin{aligned} \Delta CON/CON = {} & \Delta POP/POP && \text{(population growth)} \\ & + \Delta CON_{POP}/CON_{POP} && \text{(spending-level increase)} \\ & + (\Delta POP/POP)*(\Delta CON_{POP}/CON_{POP}) && \text{(interaction factor)} \end{aligned}$$

Table 4-8 shows the results of our decomposition calculation. We find that rural and urban areas had a different pattern of personal consumption growth in the 1980s. In rural areas, the increase in per capita spending accounted for almost all of the personal-consumption increase from 1981 to 1987. In urban areas, population growth and higher spending level were about equally important. China was increasingly urbanized in the 1980s.

TABLE 4-8

DECOMPOSITION OF PERSONAL CONSUMPTION INCREASES FROM 1981 TO 1987

Consumption	1981	1987	Change	% Change
Urban Consumption (Billion RMB)	101.3	200.2	98.9	97.6
Population (Million)	202.0	277.0	75.0	37.1
Per Capita Consumption (RMB/person)	501.4	722.6	221.1	44.1
Interaction Factor				16.4
Rural Consumption (Billion RMB)	169.5	275.2	105.7	62.3
Population (Million)	799.0	816.0	17.0	2.1
Per Capita Consumption (RMB/person)	212.2	337.2	125.1	58.9
Interaction Factor				1.3
Total Consumption (Billion RMB)	270.8	475.3	204.5	75.5
Population (Million)	1001.0	1093.0	92.0	9.2
Per Capita Consumption (RMB/person)	270.5	434.9	164.3	60.7
Interaction Factor				5.6

Source: Calculated from data in China Statistical Yearbook, 1981 and China Input-Output Table, 1981 and 1987.

The percentage of population living in urban areas increased from 20 percent in 1981 to 25 percent in 1987. As more population began living in urban areas consuming more goods and services, it is not surprising that urban personal consumption increased. For the country as a whole, China's population and total personal consumption grew by 9 percent and 24 percent, respectively. This indicates that the rise in per capita spending level was the dominant force behind the personal consumption growth from 1981 to 1987.

Two factors were primarily responsible for the increase in spending level per person during 1981-1987. First, personal income grew rapidly since 1978 because the economic-reform program placed an emphasis on material incentives and because there was an overall increase in productivity and income-earning possibilities. Between 1981 and 1987, China's per capita GDP, in 1980 constant prices, increased by over 300 percent from 470 RMB to 803 RMB (SSB, 1990a; 1992). Nominal disposable income per person in rural and urban areas grew by 108 percent and 100 percent, respectively, during the same period. Higher income gave households greater purchasing power to buy goods and services.

Second, households had a "hunger" for consumption as the quantity, quality, and diversity of consumer commodities increased dramatically in the 1980s and as Chinese people became more informed about the life styles and higher living standards in the advanced countries (Xia and Li, 1987). For years, China's economic planners emphasized the expansion of heavy industry at the expense of the production of consumer goods. Many consumer items were in chronic shortage, so that the government had to restrict their purchases by rationing. The government, for example, limited cotton cloth consumption to between 4 to 6 meters a year per person in the 1970s. The shortage and rationing caused a gradual accumulation of suppressed consumer demand, which was relieved in the 1980s and created a big boom in the consumer market. Interestingly, one of the most visible signs of the economic "revolution" and higher consumption in the 1980s was the appearance in Chinese cities of large quantities of relatively modern, varied, colorful, Western-style clothes, a sharp contrast to the monotone image of blue, yellow-green, or gray suits that typified Chinese dress in the Cultural Revolution period (1966-1976). There was an increase in per capita consumption of almost all the major consumer items between 1981 and 1987.

Capital Investment

Capital investment includes expenditures on capital goods, such as plant, machinery, and equipment, and on housing construction. It grew by 124 percent from 125 billion RMB in 1981 to 280 billion RMB in 1987 (see Table 4-4). This investment growth was the single most important factor increasing energy consumption in China's economy between 1981 and 1987. It was responsible for 266 of the 488 million tsce (55 percent) energy-use increase attributable to the final-demand shift, almost all of which comes from the level effect (Table 4-7). Of this 266 million tsce, 198 million tsce (74 percent) was from coal, 49 million tsce (18 percent) from petroleum products, 7 million tsce (3 percent) from natural gas, and 12 million (5 percent) tsce from hydropower.

The rapid expansion in capital investment is not a new phenomenon in China (Chen et al., 1988). Since the 1950s, overinvestment in construction had been a persistent problem. Under the socialist system of "everyone eating from one big pot," those who undertook construction projects enjoyed the entire benefit of the projects, but, in most cases, they were only partially responsible or not responsible at all for the project failures. Thus, enterprises and government agencies had a great "thirst for investment." There were also frequent construction delays and cost overruns because planners and managers often failed to predict accurately the need for such critical inputs as transportation and raw materials. In addition, poor cooperation among ministries and provincial/local level units resulted in many unnecessary duplications.

Decentralization of investment authority in the 1980s exacerbated overinvestment by allowing enterprises and local governments to retain a larger percentage of their own revenue and giving them greater power to authorize the investment projects (Zhou and Zhu, 1988). The decentralization effectively removed the central government's control over the project approval because now few projects were big enough to require the approval of the central government ministries. For those projects needing such an approval, they could be divided into smaller pieces and approved separately by local investment decision-making authorities. This gave enterprises and local governments a golden opportunity to satisfy the accumulated demand for nonproductive projects, such as housing construction and urban renovation, which had long been suppressed by the central government. According to researchers from the China Economic System Reform Research Institute

(CESRRI) of the State Council, the increase in the nonproductive investment represented approximately 60 percent of gross investment and over 85 percent of the increase in capital construction during the Sixth Five-Year period (1981-1985) (Chen et al., 1988).

Liberal bank lending provided additional fuel for the construction boom stimulated by the decentralization of investment authority (Zhou and Zhu, 1988). The bank's share in total enterprise investment loans increased rapidly in the 1980s as banks relaxed funding constraints on enterprises. Chen et al. (1988, pp. 183-184) illustrate nicely how the mechanism worked:

> . . . enterprises have a bias against productive investment and in favor of investing in consumption projects; more and more self-own funds are used for consumption or investment in consumption projects; and investment in productive projects is financed in the main by bank loans. The expansion of consumption and investment in consumption projects generates an economic boom that offers an excellent investment environment at all levels. This exerts tremendous pressure on individual banks to provide more loans for investment in fixed assets, and the shortage of investment in productive projects creates in broad terms a strong impetus to increase the supply of funds from banks.[5]

In fact, in a nation-wide enterprise survey, managers ranked "inadequate funds" as the second most important constraint on enterprise operation and placed "borrowing from banks" as the top choice for sources of fund.

International Trade

International trade includes the foreign demand for China's goods and services (exports) and domestic demand for foreign goods and

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[5] As we would expect, this mechanism caused high inflation in 1987 and 1988, which led to the introduction of an austerity program in 1989-1990.

services (imports). It was the fastest growing segment of China's economy in the 1980s. Between 1981 and 1987, China's exports and imports rose by 256 percent and 324 percent, respectively, much higher than the 84 percent growth in total final demand (Table 4-4). The combined volume of exports and imports, as a percentage of GDP, rose from 17 percent in 1981 to 36 percent in 1987 (Table 4-5). We estimate that an additional 150 million tsce of energy was consumed because of the increase in exports and that 233 million tsce of energy was saved or avoided due to the higher volume of imports (Table 4-7).[6] On balance, the change in international trade from 1981 to 1987 resulted in 84 million tsce energy savings, which was about 14 percent of the 1981 total energy consumption in China (Table 4-7).

The explosive growth in exports and imports was a direct consequence of China's "opening up" policy since 1979. In contrast to past policies of "self-reliance," the post-Mao Chinese leadership emphasized the role of international trade and foreign investment in economic development and adopted a policy of being more open to the outside world. The opening-up policy led to a relaxation of some controls over exports and imports and decentralization of foreign trade institutions in the 1980s. The number of controlled export items was reduced, and the strict administrative control over imports was gradually replaced with a more flexible import quota/permit system. The

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[6] Tracking the effect of imports on China's energy use is a difficult task because energy requirements of imported products may be very different in China and in foreign countries and because some of the import goods may not be available domestically. Our estimation of energy savings from imports was a rough approximation based on the energy that would have been used if the imported products were produced domestically by the same or similar industry.

central government also transferred some trade powers to provinces, municipalities, and enterprises while cutting back or eliminating export subsidies to foreign trade corporations and industrial enterprises.

The new foreign trade policy was highly successful in promoting international trade. In only seven years, between 1981 and 1987, China's exports, in 1981 producer prices, were doubled and its imports more than tripled, as shown in Table 4-4. It also, however, brought a problem of periodic trade deficits. Net exports, the difference between exports and imports, changed from a surplus of just under 4 billion RMB in 1981 to a deficit of over 17 billion RMB in 1987 (Table 4-4). Two factors contributed to the more rapid growth in imports than exports. First, because of the overvalued exchange rate and irrational pricing mechanism, domestic sales were often more profitable than exports, while imports were relatively cheap, sometimes cheaper than domestic supply.[7] In fact, many exporting enterprises suffered losses, which, before the foreign-trade reform, had been routinely covered by budgetary transfers of billions of RMB annually. With the reduction in export subsidies and relaxation of import restrictions in the 1980s, the outcome was just as analysts would expect: export growth slowed and imports soared. (Reynolds, 1988)

Second, China experienced a much faster economic growth from 1981 to 1987 than its major trading partners--Japan, Hongkong, European-Community countries, and the United States. The economic boom generated

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[7] Despite several rounds of devaluation, RMB was still overvalued during the 1981-1987 period. One obvious piece of evidence was that foreign currencies commanded a much higher value in the black market than that implied by the official exchange rate.

a strong demand for both domestic and foreign products. It also tended to reduce the goods and services available for exports, for example, crude oil, which was China's single largest export item, could barely keep up with increase in domestic demand in the 1980s. Contrary to the common perception in China, the most important source of import growth was the increase in imports of producer goods, such as steel and chemical fertilizers, rather than imports of consumer goods, such as television sets and passenger cars. As shown in Table 4-9, the imports of major energy-intensive industrial materials rose dramatically between 1981 and 1987. The imports of rolled steel, for example, increased by about 260 percent from 3.5 million tonnes in 1981 to 12 million tonnes in 1987. Those imports saved China a large amount of energy and served as a major factor dampening China's energy-use increases.

TABLE 4-9

IMPORTS OF MAJOR ENERGY-INTENSIVE PRODUCTS

Products	Unit	1981	1987	Change	% Change
Rolled Steel	kilotonnes	3450	12400	8950	259.4
Iron & Steel Wire	tonnes	3784	52184	48400	1279.1
Copper & Alloys	tonnes	53689	75482	21793	40.6
Aluminum & Alloys	tonnes	57772	184130	126358	218.7
Zinc & Alloys	tonnes	12409	68153	55744	449.2
Caustic Soda	tonnes	51674	304927	253253	490.1
Soda Ash	tonnes	203846	853373	649527	318.6
Chemical Fertilizers	kilotonnes	5550	10900	5350	96.4
Paper Pulp	tonnes	681833	683343	1510	0.2
Textile Syn. Fibers	tonnes	497461	240634	-256827	-51.6

Source: Calculated from data in China Energy Statistics, 1990 and 1991.

Note: Textile Syn. Fibers = Textile Synthetic Fibers.

Table 4-10 summarizes, in terms of percentage change over the 1981 total energy consumption, the energy effect of changing expenditures originating from individual demand sectors between 1981 and 1987. The expansion in capital investment was the largest source of the energy-use increase, causing China's total energy consumption to increase by 44 percent. The rapid growth in imports was the largest source of energy saving; holding all other factors constant, it would cut the growth of energy consumption in China by 38 percentage points. In general, changes in spending from individual demand sectors had similar impacts on different types of energy. As we can see from Table 4-10, with a few exceptions, the percentage changes associated with each factor were in the same direction and had a similar magnitude across fuel types.

EXPENDITURES ON DIFFERENT PRODUCT GROUPS

The decisions of final consumers--households, government agencies, inventory controllers, investment-project managers, importers, and exporters--on how much to spend and what to purchase will determine a nation's aggregate demand for final goods and services and the amount and composition of final products produced in the economy. Most products go through several stages of production. Final products are goods and services that are sold to final consumers at the end of the production chain. They are not, in the time period under consideration, used as inputs to produce other outputs. We call those goods and services that are used as inputs in the intermediate stages of production "intermediate products". Intuitively, we can think of final

TABLE 4-10

GROWTH RATE OF PRIMARY ENERGY CONSUMPTION ASSOCIATED WITH SOURCES OF FINAL DEMAND IN CHINA, 1981 TO 1987

(percent of the 1981 total energy consumption)

Demand Source	Coal	Petroleum	Natural Gas	Hydropower	Total
Rural Consumption	20.0	22.4	23.8	23.8	20.8
Level Effect	19.7	20.4	24.6	21.0	20.1
Mix Effect	0.3	2.0	-0.8	2.8	0.7
Urban Consumption	19.3	21.2	28.4	23.8	20.1
Level Effect	25.5	19.7	21.5	21.4	24.1
Mix Effect	-6.2	1.5	6.9	2.4	-3.9
Social Consumption	5.3	8.1	5.6	6.5	5.9
Level Effect	5.3	8.3	5.5	6.5	6.0
Mix Effect	0.0	-0.2	0.0	0.0	0.0
Capital Investment	44.4	40.8	39.5	44.2	43.5
Level Effect	44.2	40.6	39.3	44.1	43.3
Mix Effect	0.2	0.2	0.2	0.1	0.2
Inventory Change	4.8	5.3	6.5	5.8	5.0
Level Effect	2.3	2.9	3.2	3.0	2.4
Mix Effect	2.5	2.4	3.4	2.8	2.5
Exports	22.6	30.4	29.8	28.9	24.6
Level Effect	19.1	30.6	30.7	24.3	21.9
Mix Effect	3.5	-0.2	-0.9	4.6	2.7
Imports	-36.7	-41.5	-42.6	-43.9	-38.2
Level Effect	-37.3	-39.6	-59.4	-45.7	-38.7
Mix Effect	0.5	-1.9	16.8	1.8	0.6
Other	-1.8	-2.2	-2.5	-1.7	-1.9
Total Demand	77.9	84.4	88.5	87.4	79.9

Source: SDA Modeling and Computations.

Note: Each percentage figure is calculated by dividing the percent of energy-use changes from 1981 to 1987 by the 1981 total coal, petroleum, natural gas, hydropower, and all-primary-energy consumption.

products as the ultimate purpose or end result of the economic production and intermediate products as a means to achieve such an end. The total value of all final goods and services produced domestically during a given time period (usually a year) is exactly what we refer to as the gross domestic product (GDP).

Tables 11 and 12 present, in terms of value (Table 11) and percentage distribution (Table 12), the breakdown of final demand for goods and services by product groups in China's economy in 1981 and 1987. The numbers for many heavy-industry products were negative because China was a net importer of those products.[8] We see that, on a RMB-basis, the direct purchase of energy products by final customers represented less than 2 percent of the total demand and that over 98 percent of final expenditures were spent on nonenergy goods and services. The light-industry sector had the largest share of the final-consumption purchase, accounting for over 30 percent of the total final demand. The agriculture, construction, and service sector each accounts for another 15-22 percent. The heavy-industry sector, one of the largest sectors of China's economy, represents only about 7 percent of the final demand because most of its products were purchased by producers as intermediate inputs and because China imported a large quantity of industrial materials and semi-finished products, such as iron and steel, nonferrous metals, heavy chemicals, and cement.

Between 1981 and 1987, total final expenditures on goods and services grew by 84 percent (Table 4-11). For the seven product groups,

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[8] Imports are entered into the final demand portion of an input-output account with negative values.

TABLE 4-11

FINAL GOODS AND SERVICES IN CHINA BY PRODUCT GROUPS, 1981 AND 1987
(million RMB, 1981 producer prices)

Product Group	1981	1987	Change	% Change
Agriculture	99458	177369	77910	78.3
Energy	7298	11407	4109	56.3
Heavy Industry	33572	56988	23416	69.7
Iron and Steel	-2309	-9689	-7380	319.6
Nonferrous Metals	-44	-118	-74	168.7
Chemical Fertilizers	-2095	-3729	-1634	78.0
Heavy Chemicals	-568	-6540	-5972	1051.5
Cement	-17	-1263	-1246	7350.3
Construction Materials	345	731	386	111.8
Heavy Machinery	38260	77597	39337	102.8
Light Industry	146761	292950	146190	99.6
Construction	75762	167405	91644	121.0
Transportation	11128	23766	12637	113.6
Freight & Communication	7135	17848	10714	150.2
Passenger Transport	3994	5918	1924	48.2
Services	106743	155904	49161	46.1
Commerce	32814	30224	-2590	-7.9
Services	73929	125680	51751	70.0
All Products	480722	885788	405067	84.3

Source: SDA Modeling and Computations.

TABLE 4-12

COMPOSITION OF FINAL PRODUCTS IN CHINA, 1981 AND 1987
(percent)

Product Group	1981	1987	Change
Agriculture	20.7	20.0	-0.7
Energy	1.5	1.3	-0.2
Heavy Industry	7.0	6.4	-0.6
Iron and Steel	-0.5	-1.1	-0.6
Nonferrous Metals	0.0	0.0	0.0
Chemical Fertilizers	-0.4	-0.4	0.0
Heavy Chemicals	-0.1	-0.7	-0.6
Cement	0.0	-0.1	-0.1
Construction Materials	0.1	0.1	0.0
Heavy Machinery	8.0	8.8	0.8
Light Industry	30.5	33.1	2.5
Construction	15.8	18.9	3.1
Transportation	2.3	2.7	0.4
Freight and Communication	1.5	2.0	0.5
Passenger Transport	0.8	0.7	-0.2
Services	22.2	17.6	-4.6
Commerce	6.8	3.4	-3.4
Services	15.4	14.2	-1.2
All Products	100.0	100.0	0.0

Source: SDA Modeling and Computations.

growth rates were, from the highest to the lowest, 121 percent for construction, 114 percent for transportation, 100 percent for light industry, 78 percent for agriculture, 70 percent for heavy industry, 56 percent for energy, and 46 for services. Within heavy industry, there was a rapid increase in the imports of iron and steel, nonferrous metals, heavy chemicals, and cement. China's domestic production could not meet the explosive demand for those products during 1981-1987. The imports of cement in 1987, for example, were 70-times greater than those in 1981. This pattern of expenditure growth is consistent with our earlier observation that China experienced a construction boom in the 1980s and its imports soared after the introduction of the "opening up" policy in 1978. In terms of the amount of change, total expenditures increased by 405 billion RMB between 1981 and 1987, 146 billion of which (36 percent) came from higher spending on light-industry goods, 92 billion (23 percent) from construction projects, 78 billion (19 percent) from agricultural products, and the other 89 billion (22 percent) from energy, heavy-industry, transportation, and service products.

Energy Impacts of Different Product Groups

Table 4-13 and Figure 4-3 display energy-use changes associated with changes in the purchase of different products. Of the 488 million tsce energy-use increase due to final-demand shifts, only 48 million tsce or less than 10 percent was due to the increase in the direct purchase of energy products. The other 440 million tsce or 90 percent was caused indirectly by changes in the purchase of nonenergy goods and services, which require energy to produce. For individual fuels, the

TABLE 4-13

PRIMARY ENERGY-USE CHANGES ASSOCIATED WITH DIFFERENT PRODUCT GROUPS IN CHINA, 1981 TO 1987

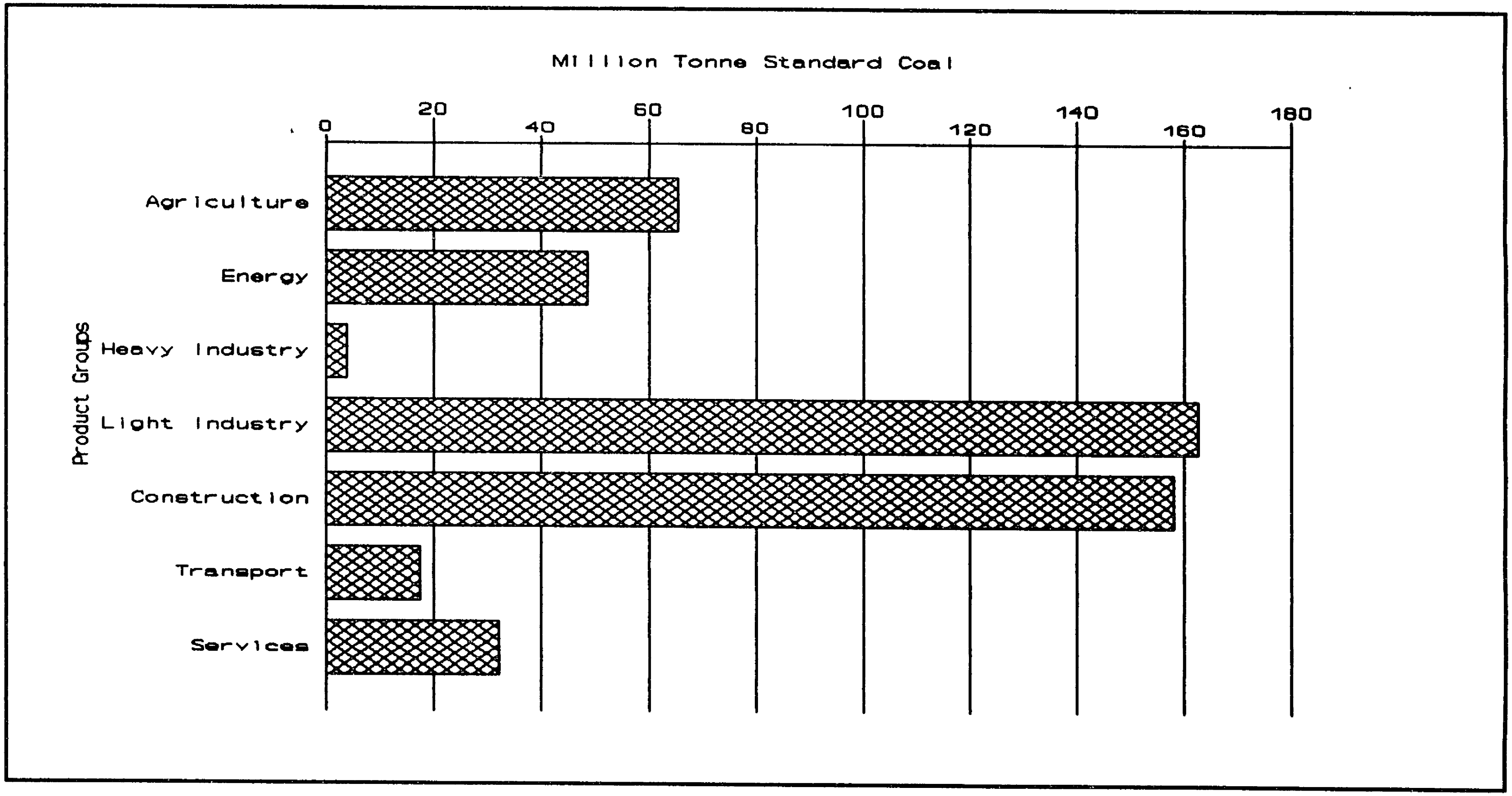
(1000 tonne standard coal equivalent)

Product Group	Coal	Petroleum	Natural-Gas	Hydropower	Total
Energy	40458	4403	1565	1983	48409
Coal	33422	363	25	167	33977
Petroleum	1423	2326	477	183	4409
Natural Gas	38	23	1011	4	1076
Electricity	5574	1691	52	1629	8947
Agriculture	41986	15712	3860	3788	65346
Heavy Industry	4721	-804	-840	816	3893
Iron and Steel	-27576	-5025	-683	-1260	-34543
Nonferrous Metals	-131	-39	-3	-20	-194
Chemical Fertilizers	-7290	-1568	-915	-528	-10300
Heavy Chemicals	-8944	-7116	-980	-1077	-18117
Cement	-4756	-514	-36	-158	-5464
Construction Materials	678	154	12	28	872
Heavy Machinery	52740	13303	1764	3831	71639
Light Industry	110632	37758	5431	8761	162582
Construction	119333	28612	3930	6110	157986
Transportation	9840	6890	293	374	17397
Freight & Communication	8678	6191	258	321	15448
Passenger Transport	1162	699	35	53	1949
Services	20577	9286	757	1483	32103
Commerce	-1088	-342	-39	-74	-1544
Services	21665	9628	796	1557	33646
Total	347547	101858	14996	23315	487715

Source: SDA Modeling and Computations.

FIGURE 4-3

PRIMARY ENERGY-USE CHANGES ASSOCIATED WITH DIFFERENT PRODUCT GROUPS IN CHINA, 1981 TO 1987



Source: Data in Table 4-13.

direct purchase of energy products accounted for only 40 of the total 348 million tsce (12 percent) coal increases attributable to final demand, 4 of the 102 million tsce (4 percent) petroleum increases, 2 of the 15 million tsce (13 percent) natural-gas increase, and 2 of the 23 million tsce (9 percent) increase in the use of hydropower. The relatively high percentages for coal and natural gas reflect the fact that coal was the dominant fuel for cooking and space heating in the residential units and that natural-gas use increased dramatically in China's urban households between 1981 and 1987.[9]

The major engine behind the energy-use growth from final-demand shifts was the increasing spending on light-industry products and construction projects (Table 4-13 and Figure 4-3). Everything else being equal, the increase in the final purchase of light-industry products would lead to a 163 million tsce increase in energy use, which was about 27 percent of total energy consumption in China in 1981. Although light-industry products are not energy intensive, the large segment of final expenditures they constitute, coupled with the 100-percent growth they experienced, means that they are an important demand-side factor augmenting energy use. The higher spending on construction projects in 1987 relative to 1981, which required many energy-intensive materials, such as iron and steel, cement, and glass, resulted in almost an equal amount of energy-use increase in China's economy, 158 million tsce (26 percent of the 1981 total energy use), as that of light industry. Thus, those two products alone caused China's

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[9] See the next section, "Direct versus Intermediate Energy Use," for more details on China's residential energy use.

energy consumption to increase by 321 million tsce or 53 percent between 1981 and 1987.

Final-demand shifts would have resulted in an even greater energy-use increase if there had been no energy savings from the increase in the imports of iron and steel, nonferrous metals, chemical fertilizers, heavy chemicals, and cement, which were among the most energy-intensive products in China. Had China produced the imported amount of these products domestically using the 1981 production technology, she would have needed an additional 69 million tsce energy. The largest energy savings came from the imports of iron and steel (35 million tsce), heavy chemicals (18 million tsce), and chemical fertilizers (10 million tsce). There was also a 1.5 million tsce energy savings from the reduction in final demand for commerce. We do not, however, place much faith on this number because it may be due to the reclassification of some firms, which were classified in the commerce sector in 1981, but in the service sector in 1987.

Table 4-14 summarizes the energy-use changes associated with different product groups in terms of percentage of the 1981 total consumption of coal, petroleum, natural gas, hydropower, and all primary energy. Overall, the change in the demand for each product group had a similar impact on different types of energy. A higher spending on construction projects, for example, would lead to 27 percent increase in coal, 24 percent increase in oil, 23 percent increase in natural gas and in hydropower. A major exception was heavy industry, which caused an increase in the consumption of coal and hydropower but a decrease in the

TABLE 4-14

PERCENT CHANGES IN PRIMARY ENERGY CONSUMPTION ASSOCIATED WITH DIFFERENT PRODUCT GROUPS

(percent)

	Coal	Petroleum	Natural Gas	Hydropower	Total
Energy	9.1	3.7	9.2	7.4	7.9
Coal	7.5	0.3	0.1	0.6	5.6
Petroleum	0.3	1.9	2.8	0.7	0.7
Natural Gas	0.0	0.0	6.0	0.0	0.2
Electricity	1.2	1.4	0.3	6.1	1.5
Agriculture	9.4	13.0	22.8	14.2	10.7
Heavy Industry	1.1	-0.7	-5.0	3.1	0.6
Iron and Steel	-6.2	-4.2	-4.0	-4.7	-5.7
Nonferrous Metals	0.0	0.0	0.0	-0.1	0.0
Chemical Fertilizers	-1.6	-1.3	-5.4	-2.0	-1.7
Heavy Chemicals	-2.0	-5.9	-5.8	-4.0	-3.0
Cement	-1.1	-0.4	-0.2	-0.6	-0.9
Construction Materials	0.2	0.1	0.1	0.1	0.1
Heavy Machinery	11.8	11.0	10.4	14.4	11.7
Light Industry	24.8	31.3	32.1	32.8	26.6
Construction	26.7	23.7	23.2	22.9	25.9
Transportation	2.2	5.7	1.7	1.4	2.8
Freight & Communication	1.9	5.1	1.5	1.2	2.5
Passenger Transport	0.3	0.6	0.2	0.2	0.3
Services	4.6	7.7	4.5	5.6	5.3
Commerce	-0.2	-0.3	-0.2	-0.3	-0.3
Services	4.9	8.0	4.7	5.8	5.5
Total	77.9	84.4	88.5	87.4	79.9

Source: SDA Modeling and Computations.

use of petroleum and natural gas. This was mainly because of (1) a petroleum saving from the increasing imports of heavy chemicals and (2) a natural-gas saving from the increasing imports of both chemical fertilizers and heavy chemicals.

Direct Versus Intermediate Energy Use

The energy use associated with energy products actually consists of two parts: direct energy consumption by domestic customers and intermediate energy required to deliver final demand for energy products. By separating the two, we can distinguish the effect of final-demand shifts on direct energy consumption from that on intermediate energy use. Recall from Chapter 3 that we can express the final-demand shift component as:

$$\Delta E_Y = F_{81}(Y_{87}-Y_{81})+e(Y_{87}-Y_{81})n$$

where ΔE_Y = energy-use changes due to final-demand shifts;
F_{81} = 1981 total intermediate energy requirement matrix;
Y_{81} = 1981 final-demand matrix;
Y_{87} = 1987 final-demand matrix;
e = matrix consisting of ones and zeros, with ones in the row locations corresponding to energy sectors and zeros in all other elements of the matrix. It selects the energy rows from the input-output table; and
n = matrix consisting of ones and zeros, with ones in the diagonal locations corresponding to those columns that are not imports, exports, and inventory change and zeros in all other elements of the matrix. It excludes energy imports, exports, and inventory change from the calculation of direct energy consumption.

The first item in the equation indicates the changes in the intermediate energy consumption that are required to satisfy final demand for all goods and services, including energy products. The second item is the changes in direct energy consumption by domestic customers.

In our energy input-output model, the direct energy consumption is more or less equal to the primary-energy portion of the residential energy use by rural and urban households, which accounted for about 19 percent of total end-use energy consumption in 1981 and 1987. The residential sector in China consists of over one billion population. In 1987, about 70 percent of them lived in rural areas and the other 30 percent were located in urban areas. Urban residents, however, account for over half of the total residential energy consumption and, on average, use 4-5 times more commercial energy per person than their rural counterparts. Most rural households rely on traditional biomass as a source of energy because of an insufficient supply of commercial energy. Some analysts estimate that as much as 80 percent of rural residential energy use comes from biomass (Smil, 1988; Liu, 1993).

Despite the rapid increase in income, urbanization, and energy-using appliances, total residential energy consumption increased by only 39 percent between 1981 and 1987, far lower than the growth rate of GDP (84 percent) and aggregate personal consumption (76 percent), as shown in Table 4-15. Four factors helped to slow the residential energy growth. First, most households in China had only limited access to commercial energy because of severe energy, especially power, shortages during the 1981-1987 period, and because of China's energy allocation policy that emphasized meeting industrial demand and restricted residential energy use. In Beijing, the capital city, for example, the government allowed each household to buy only 10-12 cylinders of liquified petroleum gas (LPG) per year at a subsidized price of 3.6 RMB/15 kilogram (kg) cylinder and an additional 4 cylinders at a price of 9.9 RMB per kg cylinder (Sathaye and Tyuler, 1991). The government also charged higher prices for residential energy use than for industrial energy consumption. In rural areas, many households had no access to commercial energy at all (Smil, 1990; Liu, 1993).

TABLE 4-15

CHANGES IN RESIDENTIAL ENERGY USE, 1981 AND 1987
(1000 tonnes standard coal equivalent)

	Coal	Petroleum	Natural Gas	Electri -city	Total Primary	Gross Total
Rural Households						
1981 consumption	37545	1516	0	659	39061	39720
1987 consumption	53094	1820	0	1526	54914	56441
change	15549	304	0	867	15853	16720
percent change	41.4	20.1	NA	131.5	40.6	42.1
Urban Households						
1981 consumption	48809	154	293	791	49256	50047
1987 consumption	64986	318	1024	1995	66328	68323
change	16177	163	732	1204	17072	18275
percent change	33.1	105.6	250.0	152.2	34.7	36.5
All Households						
1981 consumption	86355	1670	293	1450	88317	89767
1987 consumption	118081	2138	1024	3521	121242	124763
change	31726	467	732	2071	32925	34996
percent change	36.7	28.0	250.0	142.8	37.3	39.0

Source: SDA Modeling and Computations.

Note: Total primary includes only energy from primary sources--coal, petroleum, and natural gas--while the gross total is the sum of all four energy types. In our SDA model, all the hydropower output is allocated to the electricity sector.

Second, China made some progress in increasing residential energy-use efficiency. A large number of households, especially in urban areas, improved their stoves in the 1980s and replaced the traditional practice of raw coal burning with burning honey-comb coal briquettes. There was also an increase in the use of concentrated district heating in major cities, which according to some experts, can reduce coal inputs by 30 percent (Liu, 1993).

Third, both rural and urban areas experienced a fuel transition towards higher-quality energy. In rural areas, the increased access to electricity allowed many rural households to make a transition from kerosene lighting to electricity lighting, which generated some petroleum saving, as it is evident from the rapid growth in electricity and the slow increase in petroleum consumption in rural households shown in Table 4-15. In urban areas, the residential energy mix started to shift away from coal towards more convenient petroleum, natural gas, and electricity. The share of coal in urban residential energy consumption declined from 98 percent in 1981 to 95 percent in 1987 (Table 4-15). Because the liquid, gaseous, and electric energy had a higher end-use efficiency than coal, this shift tended to increase energy efficiency in the urban residential sector.

Fourth, the relatively efficient electric appliances and wiring-capacity constraints dampen the growth of electricity consumption. Liu (1993) reviews some of the common appliances in China's urban households and their energy efficiency. He finds that major appliances in China are products of relatively recent technologies and are usually smaller in size and power input than popular models in the Western countries, especially the United States. Almost all color television production lines, for example, were imported from Japan and most refrigerator production lines were imported form Japan and Italy in the 1980s. The popular television models in China include 18- and 20-inch sets and popular refrigerator models are two-door 170-200 liter system. In addition, electricity wiring in Chinese households has a capacity to carry only a 5-ampere current (U.S. households often have 100-ampere wiring). This limits the simultaneous use of appliance and lighting to about 1000 watts. The wiring limitation forces households to purchase appliances that are small and efficient, and to use them in a frugal manner. Chinese households, for example, often turn lights off while watching television (Sathaye and Tyuler, 1991).

By subtracting changes in the direct (i.e., residential) primary energy use from total primary energy-use changes due to final-demand shifts, we can calculate how much of the demand-related energy-use change was in the form of direct energy consumption and how much was in the form of intermediate energy use. Table 4-16 presents the results of our calculations. We estimate that only 33 or 7 percent of the final-demand related energy-use changes from 1981 to 1987 was due to an increase in direct energy consumption and the other 455 million or 93 percent came from the increase in intermediate energy use as firms produce more outputs in order to satisfy the increased final demand. Expressed as percentages of 1981 total energy consumption, final-demand shifts would result in an approximately 80 percent growth in total energy consumption--5 percent from direct energy consumption and 75 percent from intermediate energy use. For individual fuels, the increase in direct energy use would result in only about 7 percent growth in coal consumption, less than 1 percent rise in petroleum and natural-gas consumption, and increase in hydropower requirement.[10]

TABLE 4-16

PRIMARY ENERGY-USE CHANGES DUE TO FINAL-DEMAND SHIFTS: DIRECT ENERGY VS INTERMEDIATE ENERGY

	Coal	Petroleum	Natural-Gas	Hydropower	Total
Amount	(million tons of standard coal equivalent)				
Direct Energy	31.7	0.5	0.7	0.0	32.9
Intermediate Use	315.8	101.4	14.3	23.3	454.8
Total Effect	347.5	101.9	15.0	23.3	487.7
Percent	(percent over the 1981 total energy consumption)				
Direct Energy	7.1	0.4	4.3	0.0	5.4
Intermediate Use	70.8	84.0	84.2	87.4	74.5
Total Effect	77.9	84.4	88.5	87.4	79.9

Source: SDA Modeling and Computations.

Note: 1. The percentage represents percentage changes over 1981 total consumption of coal, petroleum, natural gas, hydropower, and all energy types. In other words, it indicates the effect of final-demand shift on the growth rates of individual and total energy consumption.

2. Subcomponents may not add up to the total because of rounding errors.

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[10] In this research, hydropower is considered as an intermediate input to electricity generation and does not contribute to the direct energy consumption as we define here.

SUMMARY OF ENERGY-USE CHANGES DUE TO FINAL-DEMAND SHIFTS

In the absence of production-technology changes, final-demand shifts from 1981 to 1987 would lead to a 488 million tsce or 80 percent increase in China's energy consumption. For individual fuels, the final-demand shifts would result in 348 million tsce (78 percent) increase in coal consumption, 102 million tsce (84 percent) increase in petroleum consumption, 15 million tsce (89 percent) increase in natural-gas use, and 23 million (87 percent) increase in hydropower use. We can view those energy-use increases from three different angles or dimensions:

1. **Level, Distribution, and Pattern.** Almost all of the energy-use increases due to final-demand shifts came from the increase in the overall level of spending, which, other things being equal, would cause China's total energy consumption to increase by 515 million tsce. The changes in spending mix of the individual demand sectors led to additional 9 million tsce growth in energy use. The changes in final-demand distribution, on the other hand, cut the energy-consumption growth between 1981 and 1987 by 36 million tsce. China has over one-fifth of the world's population and one of the largest and fastest growing economies in the world. The sheer size of population and economic growth is the single most important factor driving China's energy-consumption growth.

2. **Sources of Final Demand.** The expansion in capital investment, the increase in personal consumption, and the rise in exports were the main engine behind the energy-use increase associated with final-demand shifts. Holding all other factors constant, they would result in a 665

million tsce increase in China's energy consumption. This strong upward pressure on energy use was dampened by the rapid growth in imports, which saved China 233 million tsce of energy. It is sometimes argued that the energy saving from imports is a zero-sum gain at the global level. In other words, China's energy saving from imports must be accompanied by an equal amount of energy-use increase in exporting countries. This is not necessarily so because some countries use energy more efficiently than others. As a result, the energy intensity of the same product often varies across countries. There is a real possibility, therefore, to reduce the global energy consumption through international trade.

3. **Different Product Groups.** Only 48 out of the 488 million tsce (10 percent) of the demand-related energy-use increases can be attributable to the purchases of energy by final customers and the other 440 million tsce (90 percent) was due to the purchases of nonenergy products. The expenditures on light-industry products and construction projects were the most important factor augmenting China's energy consumption from 1981 to 1987. This underscores the importance of going beyond energy products in promoting energy conservation. Some activities that have no apparent relation to energy, such as recycling of scrap, conservation of nonenergy products, and increased product durability, may have an enormous impact on energy consumption. "An even better solution [for saving energy] than using energy efficiently is not using it at all (Ross and Steinmeyer, 1990, p. 89)."

Our examination of the energy impacts of final-demand shifts presents only half of the energy dynamics that was occurring in China between 1981 and 1987. The other half is the changes in the production technology, which may increase or decrease the amount of intermediate energy used to deliver one unit of final goods and services. Because final-demand shifts alone would cause China's energy consumption to grow at a much higher rate than what actually happened from 1981 to 1987, production-technology changes must generate a sizable energy savings to offset the strong upward pressure on China's energy consumption. We will quantify these energy savings and identify their sources in the next chapter.

CHAPTER 5

ENERGY EFFECTS OF PRODUCTION-TECHNOLOGY CHANGES

It is sometimes useful to think of an economic production system as a machine. At one end, energy and other inputs of productive resources are fed into the machine, where they are combined, processed, and transformed. From the other end, a flow of final goods and services emerges. The machines with different technologies may require different quantities and combinations of energy and other inputs to produce the same set of final goods and services, some of which use more energy than others. The amount of energy required in the production system, therefore, will change if there is a technological change, either due to a modification of the existing production "machine" or due to a complete replacement of the old "machine" with a new one.

In this chapter, we fix final demand at that of 1987 and examine how changes in production technology--the way firms combine energy with other inputs to produce output--from 1981 to 1987 affected energy consumption of China's economy. We do so by comparing actual energy consumption in 1987 with the amount of energy that would have been required if China had to use 1981, rather than 1987, production technology to satisfy 1987 final demand. We describe production technology in terms of a production-input mix and define production-technology changes broadly as any changes, from whatever cause, in the production-input mix of an industry.[1] This can result from, for

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[1] As we indicated in Chapter 3, this definition of production technology is an economics one and differs from that of engineers. We define production technology in terms of the input mix, while engineers

example, changes in the output mix of the industry, changes in production facilities, or changes in the operation/utilization of production facilities.

CONCEPT OF PRODUCTION TECHNOLOGY

In this study, we use a production-input mix to describe production technology. The production-input mix refers to a column of direct input or technical coefficients in the input-output model. The technical coefficients are obtained by dividing the entries in a column of the input-output transaction table, which represent a sector's inputs, by that sector's output. Each coefficient states the amount of each particular input required by a particular sector to produce one unit of that sector's output. The production-input mix, then, gives a quantitative description of the technique of production used by a sector (Carter, 1970). It explicitly includes a recipe--a list of ingredients (inputs)--by which firms make their products and implicitly reflects the method and capital equipment employed in the production process (OTA, 1990). A systematic tabulation of production-input mixes of all sectors of an economy provides a concise and detailed description of the technological structure of the economy at a given time (Leontief, 1985).

It is important to understand that the production-input mix shows the average technology of a sector. In most sectors, there are a series of production technologies in operation: from the oldest one, which has been there for years, to the newest process just introduced in the most

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define it primarily in terms of the operations and equipment used in the production process.

modern plants. In addition, within a given sector, there may be a number of heterogeneous subsectors, producing different products and having different input structures. What the production-input mix shows, therefore, is the average input structure of different subsectors, different technologies, and/or different products. Changes in it can result not only from actual technological changes (process-mix changes), but also from changes in the mix of subsectors and/or in the product mix within the subsectors (output-mix changes).

We can reduce the heterogeneity of subsectors or products through the use of a more detailed industrial classification. As long as we use the sector as an aggregate, however, there will always be production-input mix changes due to changes in process mix and those due to changes in output mix (Carter, 1970). More generally, there are limits to what industrial disaggregation can do to achieve homogeneous output and process simultaneously. This is because of the existence of multiple products from the same process, the availability of multiple processes to make the same product, and the multi-attributes or dimensions of many products (Holzman, 1953).

The output-mix changes imply that products from the same sector are different in different years. So strictly speaking, we cannot assume the inputs used and outputs produced by the same sector to be the same over time. Leontief (1953) even suggests that we call each year's output of any given sector a different product--this year's television sets are not the same product as last year's, and so on--because there may be substantial changes in product design, functions, and quality. Thus, what a given production-input mix actually shows is the underlying structural relationship of production technology, that is, the relationship between the output of a given sector and its required inputs. When we examine the energy effect of production-technology changes from 1981 to 1987, what we really ask is: How much would total energy consumption change if China had to produce the 1987 final output according to the 1981, rather than 1987, structural relationships of production technologies?

Main Factors Affecting the Production Technology

There are at least five separate (but overlapping) kinds of activities that can cause the production-input mix of a given industry to change:

1. Changes in the types and quality of goods and services produced (output mix). A shift from less to more energy-intensive products, for example, will lead to a decline in direct energy input coefficients.

2. Changes in production facilities, such as the introduction of a new assembly line, a modification of existing facilities, and retirement of obsolete equipment (hardware changes). For example, replacement of open hearth furnace with electric arc furnace in steel production will reduce total energy input requirement but increase electricity input requirement.

3. Changes in the quality of inputs (input quality). Energy can be saved, for instance, by better matching coal quality to the input specification of a furnace or boiler or by switching from low-quality coal to high-quality oil.[2]

4. Changes in management practice and operations of production facilities (operation and management). For example, direct energy input coefficients may be lowered through improving operations of energy-intensive equipment and better energy housekeeping.

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[2] Quality in terms of easiness to use, convenience/flexibility, and energy content.

5. Changes in the capacity utilization and/or scale of production (production level). We can divide input uses in production activities into two categories: those that vary with level of output (variable inputs) and those that remain relatively constant when output changes (fixed inputs). Within the limit of capacity, higher capacity utilization or output level reduces fixed inputs per unit of output therefore input requirements. An obvious example is passenger transportation. Fuel consumption per passenger generally decreases as more passengers travel in a given vehicle.

Within the framework of structural-decomposition analysis, we are unable to separate the contribution of each individual activity to production-technology changes. To remedy this limitation, we will place production-technology changes into a general context of China's economic development in the 1980s to identify those macroeconomic factors that were primarily responsible for the production-technology changes. We will also conduct a micro-level case study of energy-efficiency improvements in the iron and steel industry, to be presented in the next chapter, to complement our macro-level structural decomposition analysis of production-technology changes and to find out what enterprises actually did to reduce energy input requirements.

Energy and Nonenergy Portions of the Production Technology

To distinguish energy-use changes associated with changes in energy efficiency from those due to changes in the use of nonenergy inputs, we decompose the production technology into two portions: energy and nonenergy. The energy portion represents the direct use of energy inputs, like coal, oil, and electricity, by sector. Its changes, to a large degree, indicate changes in energy efficiency. The nonenergy portion contains all the other inputs used in the production, such as plastics, steel, and chemical fertilizers. Those nonenergy inputs indirectly embody energy because energy inputs are required to produce them.

The inclusion of nonenergy inputs is important because on the value basis, the direct use of energy inputs in production represent less than 10 percent of all inputs in China's economy. A large percentage of the energy requirements of providing final products comes indirectly from the remaining 90 percent of the inputs, which require a significant amount of energy to produce. In the construction sector, for example, the direct energy use in the sector was only 85 grams of standard coal equivalent (gsce) per RMB of output in 1981, but 1724 gsce of energy were indirectly used because many construction materials, such as steel, glass, and cement, embody a large quantity of energy. Changes in nonenergy inputs, therefore, can have an important impact on energy consumption.

CHANGES IN THE ENERGY PORTION OF PRODUCTION TECHNOLOGY

Direct energy input coefficients varied significantly across the 18 production sectors of China's economy both in 1981 and 1987, as shown in Table 5-1. For energy sectors, total direct energy input requirement of the electricity sector was more than 10 times that of the natural gas sector, almost 40 times that of the petroleum production, and over 100 times that of the coal sector. This large disparity was due to (1) the energy intensiveness of electricity generation, (2) conversion and other losses, and (3) the bias in our energy accounting. Although we convert electricity into standard coal equivalent according to its net carolic

TABLE 5-1

DIRECT ENERGY INPUT COEFFICIENTS IN CHINA, 1981

Sector	Direct Energy Input Required					
	Coal	Petroleum	Natural-Gas	Hydropower	Electricity	Total
(kgsce input per kgsce of output)						
Coal	0.0227	0.0021	0.0000	0.0000	0.0049	0.0297
Petroleum	0.0039	0.0711	0.0161	0.0000	0.0071	0.0982
Natural Gas	0.0021	0.0123	0.2755	0.0000	0.0022	0.2922
Electricity	2.2543	0.6397	0.0021	0.7019	0.1490	3.7469
(kgsce input per RMB of output in 1981 constant prices)						
Agriculture	0.0533	0.0534	0.0000	0.0000	0.0163	0.1230
Iron and Steel	1.9871	0.2536	0.0341	0.0000	0.1062	2.3810
Nonferrous Metals	0.3330	0.0832	0.0036	0.0000	0.1826	0.6024
Chemical Fertilizers	2.7699	0.4224	0.3448	0.0000	0.3006	3.8377
Heavy Chemicals	0.4721	0.6542	0.0670	0.0000	0.1321	1.3255
Cement	2.5507	0.1129	0.0011	0.0000	0.0823	2.7470
Construction Materials	1.2226	0.1897	0.0048	0.0000	0.0456	1.4627
Heavy Machinery	0.2815	0.0506	0.0083	0.0000	0.0370	0.3775
Light Industry	0.1624	0.0372	0.0028	0.0000	0.0171	0.2195
Construction	0.0358	0.0326	0.0088	0.0000	0.0076	0.0847
Freight & Communication	0.5402	0.4521	0.0034	0.0000	0.0130	1.0087
Passenger Transport	0.3070	0.2483	0.0018	0.0000	0.0072	0.5643
Commerce	0.0744	0.0100	0.0000	0.0000	0.0047	0.0890
Services	0.0732	0.0587	0.0007	0.0000	0.0083	0.1410
All Sectors	0.3526	0.1165	0.0163	0.0261	0.0358	0.5115*

Source: SDA Modeling and Computations.

* To avoid double counting, the total direct energy input coefficient for all sectors as a whole includes only primary energy inputs--coal, petroleum, natural gas, and hydropower--and excludes electricity input.

value, we estimate the standard coal equivalent of hydropower based on the amount of fossil fuel that would be required to generate the same kilowatt hours of hydro-electricity, which assigns hydropower energy value several times greater than the work equivalence of hydro-electricity. In other words, the hydropower input to the electricity sector is somewhat overstated. This means that direct hydropower input coefficient of the electricity sector--i.e., hydropower input per unit of electricity output--is overstated.

For nonenergy sectors, the iron and steel, chemical fertilizers, and cement required over 2 kilograms standard coal equivalent (kgsce) of energy to produce one RMB of output in 1981, while the energy requirement of the construction sector was only 0.08 kgsce/RMB and that of the commerce sector, 0.09 kgsce/RMB (Table 5-1). Unlike construction activities in advanced countries, such as the United States, the construction sector in China is labor intensive, has a low level of automation/mechanization, and consumes only a small amount of energy directly at the construction sites.

Changes in Direct Energy Input Coefficients

The overall energy efficiency of China's economy increased dramatically between 1981 and 1987. With the exception of three energy sectors--coal, petroleum, and natural gas, all sectors reduced direct energy-input requirements in their production during 1981-1987, as shown in Table 5-2 and Figure 5-1. In terms of the amount of change, the largest reduction occurred in three energy-intensive heavy industries--

TABLE 5-2

CHANGES IN TOTAL DIRECT ENERGY INPUT REQUIREMENTS, 1981 TO 1987

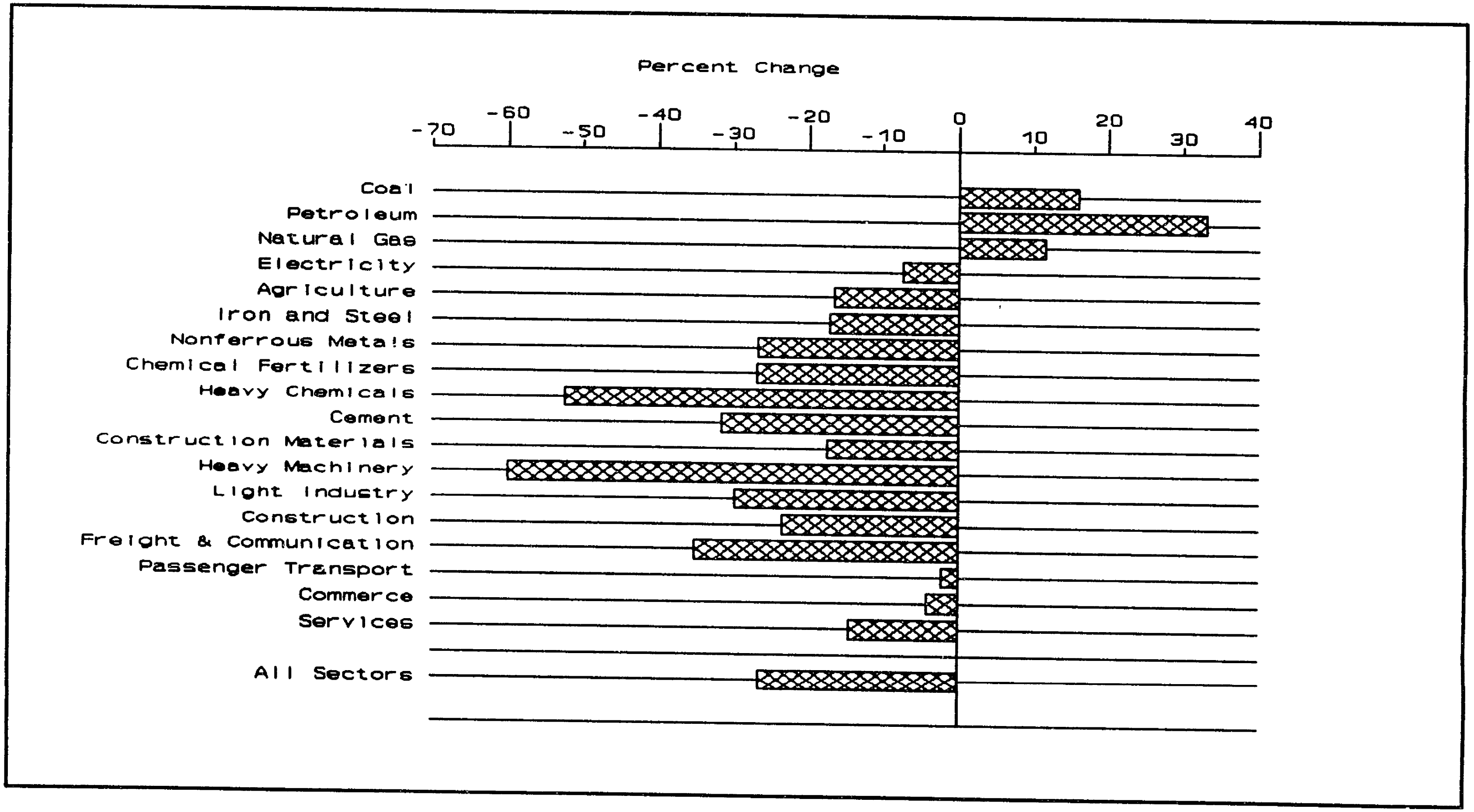
	Direct Energy Input Required			
Sector	1981	1987	Change	% Change
(kgsce input per kgsce of output)				
Coal	0.0297	0.0345	0.0047	16.0
Petroleum	0.0982	0.1307	0.0325	33.1
Natural Gas	0.2922	0.3258	0.0336	11.5
Electricity	3.7469	3.4724	-0.2745	-7.3
(kgsce input per RMB of output in 1981 constant prices)				
Agriculture	0.1230	0.1027	-0.0203	-16.5
Iron and Steel	2.3810	1.9728	-0.4083	-17.1
Nonferrous Metals	0.6024	0.4409	-0.1615	-26.8
Chemical Fertilizers	3.8377	2.8076	-1.0301	-26.8
Heavy Chemicals	1.3255	0.6315	-0.6940	-52.4
Cement	2.7470	1.8777	-0.8693	-31.6
Construction Materials	1.4627	1.2075	-0.2552	-17.4
Heavy Machinery	0.3775	0.1512	-0.2263	-60.0
Light Industry	0.2195	0.1539	-0.0656	-29.9
Construction	0.0847	0.0648	-0.0199	-23.5
Freight & Communication	1.0087	0.6541	-0.3546	-35.2
Passenger Transport	0.5643	0.5516	-0.0127	-2.2
Commerce	0.0890	0.0853	-0.0037	-4.1
Services	0.1410	0.1206	-0.0204	-14.5
All Sectors	0.5115	0.3759	-0.1356	-26.5*

Source: SDA Modeling and Computations.

* To avoid double counting, the total direct energy input coefficient for all sectors as a whole includes only primary energy inputs--coal, petroleum, natural gas, and hydropower--and excludes electricity input.

FIGURE 5-1

CHANGES IN DIRECT PRIMARY ENERGY INPUT REQUIREMENTS, 1981 TO 1987



Source: Data in Table 5-2.

Chemical Fertilizers (-1.0301), Cement (-0.8693), and Heavy Chemicals (-0.6940). In terms of the percentage changes, the highest rate of reduction was in Heavy Machinery (60.0 percent), Heavy Chemicals (52.4 percent), Freight Transportation & Telecommunication (35.2 percent), and cement (31.6 percent). For all production sectors as a whole, direct *primary* energy input requirements fell by 0.1356 kgsce/RMB, or 26.5 percent, from 0.5115 kgsce/RMB in 1981 to 0.3759 kgsce/RMB in 1987.

Table 5-3 provides additional details on changes in energy-input uses by breaking down the changes into individual fuel components. Let us look at energy sectors first. Three out of the four energy sectors--coal, petroleum, and natural gas--experienced an increase in energy-input uses per unit of output, most of which came from self-consumption of their own products. In the electricity sector, there was fuel-switching from petroleum to coal--a 0.3322 kgsce/kgsce decrease in direct petroleum requirements was accompanied by 0.1094 kgsce/kgsce increase in direct coal requirements. This was, partly, a consequence of the Chinese government's program to substitute short-supplied oil with more abundant coal. The direct hydropower requirement was down, reflecting the fact that the percentage of electricity from hydropower stations declined from 21 in 1981 to 20 in 1987 (SSB, 1992, p. 88).

For seven of the nonenergy sectors--agriculture, iron and steel, nonferrous metals, chemical fertilizers, heavy chemicals, heavy machinery, and light industry, energy efficiency of all four fuels was improved. The construction sector reduced its use of coal, natural gas, and electricity, but increased its use of petroleum. The freight transportation and telecommunication sector decreased its input

TABLE 5-3

CHANGES IN DIRECT ENERGY INPUT COEFFICIENTS, 1981 TO 1987

Sector	Direct Energy Input Required					
	Coal	Petroleum	Natural-Gas	Hydropower	Electricity	Total
(kgsce input per kgsce of output)						
Coal	0.0037	0.0008	0.0002	0.0000	0.0000	0.0047
Petroleum	0.0013	0.0386	-0.0102	0.0000	0.0028	0.0325
Natural Gas	0.0015	0.0051	0.0247	0.0000	0.0023	0.0336
Electricity	0.1094	-0.3322	0.0068	-0.0523	-0.0062	-0.2745
(kgsce input per RMB of output in 1981 constant prices)						
Agriculture	-0.0027	-0.0146	0.0000	0.0000	-0.0030	-0.0203
Iron and Steel	-0.2587	-0.1334	-0.0162	0.0000	0.0001	-0.4083
Nonferrous Metals	-0.0750	-0.0258	-0.0020	0.0000	-0.0587	-0.1615
Chemical Fertilizers	-0.6657	-0.1032	-0.1463	0.0000	-0.1148	-1.0301
Heavy Chemicals	-0.2319	-0.3569	-0.0346	0.0000	-0.0706	-0.6940
Cement	-0.8463	-0.0362	0.0004	0.0000	0.0128	-0.8693
Construction Materials	-0.2152	-0.0492	0.0020	0.0000	0.0072	-0.2552
Heavy Machinery	-0.1720	-0.0304	-0.0060	0.0000	-0.0179	-0.2263
Light Industry	-0.0448	-0.0188	-0.0015	0.0000	-0.0005	-0.0656
Construction	-0.0157	0.0011	-0.0019	0.0000	-0.0033	-0.0199
Freight & Communication	-0.2662	-0.0899	-0.0023	0.0000	0.0039	-0.3546
Passenger Transport	-0.0858	0.0713	-0.0006	0.0000	0.0024	-0.0127
Commerce	-0.0060	0.0000	0.0000	0.0000	0.0022	-0.0037
Services	-0.0067	-0.0154	0.0002	0.0000	0.0015	-0.0204
All Sectors	-0.0791	-0.0426	-0.0076	-0.0063	-0.0070	-0.1356*

Source: SDA Modeling and Computations.

* To avoid double counting, the total direct energy input coefficient for all sectors as a whole includes only primary energy inputs--coal, petroleum, natural gas, and hydropower--and excludes electricity input.

requirements of coal, petroleum, and natural gas while increasing its use of electricity. For cement, construction materials, and services, the reduction in their uses of coal and petroleum was accompanied by the increase in their uses of natural gas and electricity. In commerce, all the energy saving came from the improvement in coal-use efficiency. In passenger transportation, there was a shift from coal to petroleum, primarily due to the increasing importance of road transportation and the declining share of railway in passenger transportation (SSB Yearbook, 1988). For the 18 production sectors as a whole, the direct coal input coefficient declined by 0.0791 kgsce/RMB, the petroleum coefficient by 0.0426 kgsce/RMB, the natural-gas coefficient by 0.0076 kgsce/RMB, and the hydropower coefficient by 0.0063 kgsce/RMB.

The coexistence of increasing direct energy input coefficients in three energy sectors and the improvement in over-all energy efficiency of China's economy was not a coincident. The main reason for higher direct energy-input requirements in coal, petroleum, and natural-gas sectors was that an increased percentage of raw energy was processed in the energy sectors before it was distributed to end users. In China, the majority of coal was unwashed and burnt directly in industrial boilers, kilns, furnaces, and domestic stoves. Only 30 percent was used to generate electricity, coke-oven gas, or other secondary energy (B. Wang, 1990). During the 1980s, an increasing amount of coal was used to generate electricity, which had much higher end-use efficiency than coal. The government also encouraged coal washing and processing to reduce transportation costs and improve coal end-use efficiency. Although there was energy loss in conversion and processing, it was outweighed by improvements in the end-use efficiency of using electricity and processed/washed coal. This paradoxical relationship between energy conversion and higher end-use efficiency has also been observed in other countries. In the United States, for example, the increasing share of electricity has been cited as one main reason for the decoupling of energy and GNP growth in the late 1970s and early 1980s (Weinberg, 1988).

Factors Behind the Increase in Energy Efficiency

Why did so many sectors of China's economy improve their energy efficiency between 1981 a [illegible] 987? What caused them to reduce relative energy-input use in the [illegible] duction processes? Although specific reasons and measures for energy-efficiency improvements often varied from sector to sector and differed among enterprises, we can identify three macroeconomic factors that affected most sectors and appeared to be primarily responsible for the reduction in relative energy-input uses in China's production activities in the 1980s, namely energy-conservation programs, improved performance of the macroeconomy, and increased energy prices.

Energy-Conservation Programs

The improvement in energy efficiency was partly a result of China's energy-conservation programs. Energy conservation was not a matter of major concern to China's policy makers until rapid economic growth in the 1980s placed far greater demands on energy supply than could be met. Between 1980 and 1988, total primary energy production grew at just about 5 percent a year, compared with the 10 percent average annual growth rate of real GDP (in 1980 constant prices) (SSB, 1990a; 1992; Qu, 1992). The total primary energy supply actually fell in 1980 because of the decline in coal, oil, and natural gas production and again in 1981 because of the further reduction in oil and natural gas production. Consequently, there was a severe energy shortage problem, which was made worse by inadequate transportation capacity to move coal from production centers located in Northwest China, especially Shanxi Province, to major consumption points in Eastern and Southern coastal regions (Huang, 1991). The shortage was most acute in the power sector, which had inadequate capacity to meet full demand in most locations. When peak loads occurred, forced outages could idle up to a quarter of China's industrial capacity, with estimated economic costs ranging from 100 to 400 billion RMB compared to an industrial output of about 1300 billion RMB (Perlack and Russel, 1991). In many cities, brownouts were common among residential and commercial users.

The severe energy shortage problem led to a major shift in energy policy from conventional complete devotion to increasing supply to the one placing equal emphasis on supply expansion and energy conservation, with priority given to conservation efforts in the short run (Tomitate, 1989; Smil, 1988, 1990). Starting in 1981, energy-conservation targets had been incorporated into the Five-Year Social Economic Development Plan as well as annual plans. They included targets for the amount of energy to be saved, limits on energy consumption in production sectors, and energy-saving targets for provinces and ministries (B. Wang, 1990). The state investment in energy-saving equipment and conservation projects increased from 779 million RMB in 1981, to 1,737 million RMB in

1985, and to 3,077 million RMB in 1988. Every year since 1979, it accounted for about four percent of total technical renovation investment (SSB Yearbook, 1981-1990).

China promoted energy conservation mainly through administrative measures (Zhu et al., 1990). In the 1980s, the Chinese government promulgated 17 regulations concerning various unit energy-consumption limits, interfuel substitution, and energy-conservation requirements and issued over 400 efficiency standards for energy-consuming equipment and products (B. Wang, 1990). Unless enterprises complied with those regulations, they faced possible financial penalties, such as fines, higher prices for the above-quota energy consumption, and losing bonuses or additional profits for above-quota production. Enterprises that consumed more than 10,000 tsce per year were required to establish energy-conservation units, which were responsible for calculation of energy balances, implementation and evaluation of conservation measures, and long-term energy planning. Enterprises using energy imported from other provinces and those with energy consumption per unit product higher than that of others making similar products were required to spend at least 20 percent of their investment funds on energy conservation. All other enterprises were required to spend at least 10 percent of their investment funds on energy conservation (Levine et al., 1991). Several ministries, such as the Ministry of Metallurgical Industry and Ministry of Machinery, made energy conservation part of the job-responsibility system and included energy-saving targets in the enterprise contract (B. Wang, 1990; Zhu et al., 1990).

The government also provided financial incentives and technical assistance for energy conservation (B. Wang, 1990). The State provided subsidies and low- or no-interest loans for energy-conservation projects and offered financial rewards to energy-saving enterprises. Enterprises could receive rewards of 3-8 percent of the cost of saved oil and coal and up to 15 percent for saved electricity (Taylor, 1982; Levine et al., 1991). About 200 energy-conservation service centers were set up in different provinces and cities to provide technical assistance on energy saving technologies, energy management, and feasibility studies (B. Wang, 1990). The service center in Shenyang city, capital of Liaoning Province, for example, developed a method to upgrade 880 boilers in 1982, which resulted in an estimated coal saving of about 10-25 percent (Tian, 1983). An energy-conservation service team in Shanghai city helped a solvent factory raise the heat efficiency of its furnaces which consumed 60,000 tonnes of coal annually. Between 1981 and 1983, the factory's output value increased at an annual rate of 13 percent, while energy consumption decreased at an annual rate of 5.5 percent (Tian, 1983).

China placed particular emphasis on oil conservation because of the stagnation of domestic oil production after peaking at 106 million tonnes in 1979 (Taylor, 1982). In 1980, the State Council issued a decree, calling for strict oil conservation and a switch from oil to coal. The decree introduced a permit system to limit oil supplies only to those sectors where they were essential or would yield the greatest economic return. It also required that all furnaces, boilers, and kilns that were converted from coal to oil be reconverted to coal by May 1985. Furnaces and boilers that were designed to burn oil should also be converted to coal if it was possible. Recognizing the costs involved in conversion, the government set up a special fund for "switching from oil to coal" projects.

Overall, the energy-conservation program has been highly successful and has resulted in large energy savings (World Bank, 1985b). In some cases, however, the government-conservation programs and plans were more wish than reality. They may not necessarily be implemented at all or as originally designed at the local or enterprise level, as the Chinese saying goes, "where the mountain is high, the emperor is far way," meaning that the central government only has limited control over local affairs. The state council, for example, required that enterprises allocate about 10-15 percent of their technical renovation funds to energy conservation purposes in the Sixth Five-Year Plan (1981-1985), but, in practice, only about 3-5 percent of the technical renovation investment from the state budget was spent on energy-saving measures. Furthermore, China's energy-conservation program in the 1980s was focused primarily in the industrial sectors, especially energy-intensive heavy industries, which does not explain significant energy efficiency increases in other sectors. The direct primary energy input requirement, for example, declined by 36 percent in freight transportation and telecommunication industry and 23 percent in construction sector.

Improvement in Macroeconomic Performance

The improvement in energy efficiency was also a by-product of China's economic reform and reflected the improvement in macroeconomic performance in the 1980s. Between 1949 and 1977, China's economic-development strategy largely followed the Soviet growth model, which emphasized high output growth and development of heavy industry. This strategy did result in high output growth, but at very high resource costs. The growth achieved was accompanied by great wastes and inefficiency so that more and more investment and resources were required to attain a given increase in national income. Li et al. (1993) found that all the output growth in China from 1953 to 1978 came from increases in the factor inputs; factor productivity actually went down during this period. Chen et al. (1988) and Perkins (1986) reach a similar conclusion. In addition, managers of firms in this overly centralized economic system ignored supply and demand conditions and failed to produce what was most needed. Some goods were overproduced and stockpiled, while others, especially consumer goods, were in chronic shortage (Naughton, 1987).

Since 1978, China has initiated a series of reform measures in the hope that such measures would raise the economic efficiency and rate of productivity growth of its economy (Barnett and Clough, 1986; Lampton, 1987; Reynolds, 1988; World Bank, 1985a; 1990). The reform started in rural areas in 1978 with the piecemeal dissolution of collective agriculture through the introduction of a household-land-contract or agricultural responsibility system. It penetrated into the urban economy in the mid-1980s in three basic forms: (1) greater decisionmaking autonomy for enterprises in production and, to a lesser extent, in investment; (2) reinstitution of financial incentives for enterprises and individuals; and (3) expansion of the role of markets in the allocation of industrial goods and corresponding reductions in the role of planning and administrative allocation (Byrd, 1991; 1992).[3] The basic objective of the reform was to "marketize" China's economy--to shift from a centrally planned economy (in which planning and administrative directives guided the allocation of resources) to an eclectic, market oriented, socialist commodity economy (in which resource allocation was determined largely by interactions in the market among autonomous, competitive, and profit-oriented economic agents).

China's economy responded strongly to the reform measures. Between 1978 and 1990, China's real GDP (in 1980 constant prices) grew at an average rate of about 10 percent a year. There was also a significant improvement in productivity. Using the methodology developed by Jorgenson, Li et al. (1993) estimate that about 30 percent of the GDP growth between 1979 and 1990 in China can be attributed to the growth in factor productivity. Jefferson, Rawski, and Zheng (forthcoming) find that during 1980-1988, total factor productivity grew at an average annual rate of 2.4 percent in China's state enterprises, accounting for 28 percent of total output growth, while in collective enterprises, productivity advanced at an annual rate of 4.6 percent, accounting for 27 percent of the output growth. Enterprises not only became more productive, they started to be more market-oriented and to

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[3] China has entered a new period in its development since 1978. Under the leadership of Deng Xiaoping, China initiated dramatic economic and institutional reforms, fundamentally departing from the all-encompassing emphasis on revolutionary struggle and ideological transformation that characterized the Cultural Revolution era. See Barnett and Clough (1986), Lampton (1987), Reynolds (1987), and the World Bank (1985a; 1990) for excellent discussions of China's economic-reform policies and their implementation.

produce goods and services according to market demand. There was a general shift in sectoral output distribution and in output mix within the sector towards high value-added products. Using enterprise survey data, Jefferson and Xu (1991; 1992) find that Chinese factory managers economize on factor inputs in response to increases in managerial autonomy and market orientation. They also find evidence of increasing allocative efficiency, as measured by patterns of factor return equalization and rapid capacity growth among the most profitable enterprises.

The output and productivity growth made an important contribution to the energy-efficiency improvement between 1981 and 1987. First, the rapid economic growth in the 1980s was accompanied by an expansion in production capacities and addition of new equipment and facilities, which usually embodied better technology and had higher energy efficiency than old existing capital equipment. China's capital stock grew rapidly in the 1980s and a large percentage of capital stock in China's economy was added after 1980. According to the 1985 industrial census, total fixed capital in China's industrial sector in that year was valued at about RMB 317.8 billion, of which 123.7 billion (38.9 percent) was installed in the 1980s (Industrial Census Office, 1991, p. 97). In the agriculture sector, 91.6 out of 248.4 billion watts or 37 percent of total mechanical power in 1987 was formed after 1981 (SSB, 1992, p. 331). The addition of new capital, combined with renovation and retirement of old obsolete equipment, was one of the most important reasons for China's energy-efficiency improvements in the 1980s.

Second, energy-efficiency increases were part of the overall trend towards higher productivity in the 1980s. A direct energy input coefficient, which we use to measure energy efficiency in this study, is the ratio of energy input to gross output. An increase in total or multi-factor productivity accelerates the growth of output, which, other things being equal, will lead to a drop in the energy/output ratio. So, even if there were no changes in the way energy is utilized, we would still observe a decline in the direct energy input coefficients, thus an increase in energy efficiency. More importantly, many measures aiming at increasing productivity and profitability also help to save energy. For example, worker training to improve equipment operations enhances both productivity and energy efficiency. The introduction of a modern, large-scale blast furnace results in an increase in production capacity as well as a decrease in the coke rate. When a farmer shifts from producing low value-added rice to high value-added cash crops, s/he not only increases profits, but also reduces energy per unit of output.

Increases in Energy Prices

Finally, the improvement in energy efficiency was an enterprise's rational response to energy-price increases in China in the 1980s. For years, energy had been underpriced in China to promote industrial development. Coal prices, for example, were about 60 percent of the long-run marginal cost of coal production in the early 1980s (World Bank, 1985b). Furthermore, energy prices were not changed to adjust for inflation and increasing production costs until 1979. The price of crude oil, for example, increased by only 10 RMB for 25 years from 1964 to 1989. Yet, the average costs of crude oil production, grew by more than 60 percent between 1976 and 1982 alone, with an annual growth rate of about 8 percent. The greatly under-priced energy encouraged energy over-consumption and provided no incentives for energy-efficiency improvements. Energy was consumed as if its value to the country were much lower than it really was. Processes were designed, machinery and appliances built, and buildings constructed that used more energy than justified considering their real value in other uses. Low prices also caused people to operate those facilities in ways that used more energy than they would if managers took account of energy's true value.

This problem of the irrational energy pricing was mitigated, to some degree, by the price reforms in the energy sector (mainly in the coal industry) in the early 1980s (Byrd, 1987; Chen et al., 1987). The reform began in 1979 with an increase in the price of state-produced coal. Since 1980, the State also levies 50 percent surcharges on the above-quota coal consumption in enterprises, and, since 1981, it imposes a special tax on users of oil as fuel to reduce oil consumption. In the early 1980s, the price of electricity was raised in areas of short supply--Northeast, North, and East China (Perlack and Russell, 1991). In 1985, the government raised the prices of coal across the board. This included: (1) a 10-25 percent increase for all coal produced in the coal-deficit regions in East China; (2) a 5-9 percent price increase to reflect coal-quality differences; and (3) an approximately 50 percent price increase for production in excess of the 1984 base quota (World Bank, 1985b). There was a further price increase for coal produced in Northeast and East China in 1987 (CMM et al., 1991). More fundamentally, the dual-price system was introduced into the energy sector in about 1983-1984 (Byrd, 1987; CMM et al., 1991). Under this system, goods are exchanged at two different prices: a state-set price, for the amount produced under central planning, and a higher free-market price, for above-plan-output. The state also removed price controls on locally produced coal, which accounted for an increasing share of total coal production. Some economists believe that this system helps to generate efficient behavior because the market-generated prices determine decisions of producers and consumers at the margin; their impact is significant despite a small "market" share (Byrd, 1987).

We agree that China's energy-price increases in the 1980s provided some incentives for enterprises to reduce energy wastes and improve efficiency of energy utilization. Those incentives, however, were limited because energy prices remained low despite the price hikes. The two-track price system, which was supposed to generate market-like energy-consumption behavior, did not function as well as expected. The energy sector was still heavily planned and regulated during 1981-1987. Most fuels continued to be allocated through State planning, and the share of market-allocated energy was too small to affect the overall energy price structure. In addition, the government set a price ceiling for most fuels, thus reducing the ability of the two-track price system to clear the energy market at the margin. Due to low energy prices, energy expenditures made up a very small share of the total production cost. In 1987, for example, energy accounted for just about 1 percent of the total input cost in the textile, food, and electronics industry, and 3 percent in the machinery industry. Even in the chemicals and construction material industry, two of the most energy intensive sectors in China's economy, the cost share of energy was only 8 percent and 15 percent, respectively (Wu and Wei, 1991). Managers in most enterprises, therefore, did not view cutting energy costs as a top priority.

Energy Impacts of Energy Production-Technology Changes

Energy-efficiency improvements in China's production sector between 1981 and 1987 resulted in large energy savings. As shown in Table 5-4, other things being equal, energy production-technology changes would lower primary energy consumption in China's economy by 278.1 million tsce, which consisted of 167.1 million tsce coal, 83.6 million tsce petroleum, 14.2 million tsce natural gas, and 13.2 million tsce hydropower. Expressed as percentage of the 1981 total primary energy consumption, the energy-input changes from 1981 to 1987 cut the primary energy-consumption growth in China from 1981 to 1987 by 45.6 percent, as shown in Table 5-5. For individual energy types, the energy saving rate was 37.4 percent for coal, 69.3 percent for petroleum, 83.9 percent for natural gas, and 49.6 percent for hydropower.

The energy-efficiency increases in nonenergy industrial sectors were the most important source of energy savings, as shown in Table 5-4 and Figure 5-2. Between 1981 and 1987, they collectively accounted for 229.6 million out of 278.1 million tsce energy savings associated with energy production-technology changes. The sectors with the largest contribution were Heavy Machinery (46.3 million tsce), Heavy Chemicals (45.6 million tsce), Light Industry (43.3 million tsce), and Chemical Fertilizers (36.0 million tsce). The rest of the energy savings came from the efficiency improvements in Agriculture (13.2 million tsce), Freight Transportation and Telecommunication (18.7 million tsce),

TABLE 5-4

PRIMARY ENERGY-USE CHANGES DUE TO ENERGY PRODUCTION-TECHNOLOGY CHANGES, 1981 TO 1987

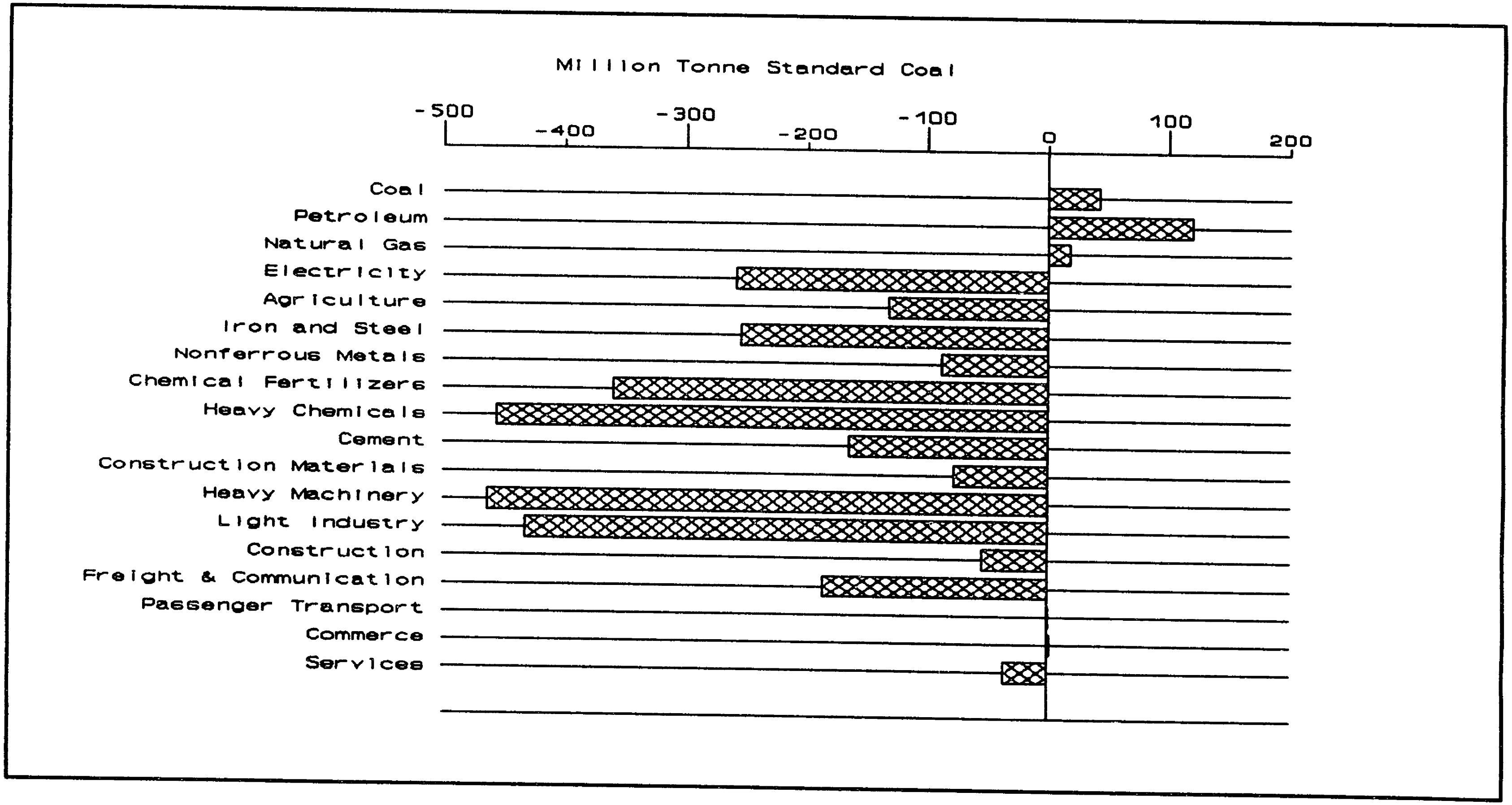
(1000 tonnes standard coal equivalent)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Total
<u>Energy Sectors</u>					
Coal	3202	731	259	28	4220
Petroleum	3201	11828	-3724	668	11973
Natural Gas	324	249	1132	64	1770
Electricity	5123	-27059	438	-4292	-25789
<u>Nonenergy Sectors</u>					
Agriculture	-5103	-7034	-89	-990	-13215
Iron and Steel	-15469	-8442	-1354	-149	-25414
Nonferrous Metals	-6159	-1354	-110	-1111	-8734
Chemical Fertilizers	-24659	-4191	-4957	-2201	-36007
Heavy Chemicals	-21236	-19326	-2410	-2639	-45611
Cement	-15781	-786	-3	102	-16468
Construction Materials	-6327	-1651	72	123	-7783
Heavy Machinery	-35920	-6710	-1427	-2286	-46343
Light Industry	-28777	-12652	-1376	-461	-43266
Construction	-4426	-74	-478	-440	-5417
Freight & Communication	-13492	-5034	-216	36	-18707
Passenger Transport	-940	984	-1	27	70
Commerce	28	64	3	108	203
Services	-697	-3125	26	178	-3618
Total	-167107	-83580	-14215	-13236	-278138

Source: SDA Modeling and Computations.

FIGURE 5-2

PRIMARY ENERGY-USE CHANGES DUE TO ENERGY PRODUCTION-TECHNOLOGY CHANGES IN DIFFERENT SECTORS



Source: Data in Table 5-4.

TABLE 5-5

PERCENT CHANGES IN PRIMARY ENERGY CONSUMPTION DUE TO ENERGY PRODUCTION-TECHNOLOGY CHANGES, 1981 TO 1987
(percent of the 1981 total consumption of respective energy)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Total
Energy Sectors					
Coal	0.7	0.6	1.5	0.1	0.7
Petroleum	0.7	9.8	-22.0	2.5	2.0
Natural Gas	0.1	0.2	6.7	0.2	0.3
Electricity	1.1	-22.4	2.6	-16.1	-4.2
Nonenergy Sectors					
Agriculture	-1.1	-5.8	-0.5	-3.7	-2.2
Iron and Steel	-3.5	-7.0	-8.0	-0.6	-4.2
Nonferrous Metals	-1.4	-1.1	-0.6	-4.2	-1.4
Chemical Fertilizers	-5.5	-3.5	-29.3	-8.3	-5.9
Heavy Chemicals	-4.8	-16.0	-14.2	-9.9	-7.5
Cement	-3.5	-0.7	0.0	0.4	-2.7
Construction Materials	-1.4	-1.4	0.4	0.5	-1.3
Heavy Machinery	-8.0	-5.6	-8.4	-8.6	-7.6
Light Industry	-6.4	-10.5	-8.1	-1.7	-7.1
Construction	-1.0	-0.1	-2.8	-1.6	-0.9
Freight & Communication	-3.0	-4.2	-1.3	0.1	-3.1
Passenger Transport	-0.2	0.8	0.0	0.1	0.0
Commerce	0.0	0.1	0.0	0.4	0.0
Services	-0.2	-2.6	0.2	0.7	-0.6
Total	-37.4	-69.3	-83.9	-49.6	-45.6

Source: SDA Modeling and Computations.

Construction (5.4 million tsce), and Services (3.6 million tsce).

In Table 5-4, the sectoral distribution indicates energy-use changes originating from energy production-technology changes in each sector. It included not only energy-use changes within the sector, but also those in other sectors that supply energy inputs to the sector and/or use the sector's output as an input. Through interindustry input-output linkages, the energy-efficiency improvement of any one sector will be multiplied across the entire economy by reducing the indirect energy requirements of those sectors who use the industry's product as inputs. A large percentage of the total energy requirements of the agricultural sector, for example, came from the use of chemical fertilizers. Thus, higher energy efficiency in the chemicals industry not only reduces its own energy intensity but also that of the agricultural sector. The multiplier effect is especially important for energy-intensive basic materials industries, such as chemicals, metallurgy, and building materials.

The multiplier effect of energy-efficiency benefits have two principal implications for energy conservation policies. First, there appears to be a positive externality associated with energy-efficiency investment. The ripple effect throughout the entire economy of introducing a more-efficient energy technology generates energy savings that are greater than those estimated by examining each industry in isolation. Ignoring this ripple effect may lead to an under-investment in energy-saving technologies. Second, not all energy-saving opportunities are equal. The same magnitude of energy-efficiency improvement in different sectors may have a very different impact on total energy consumption in the macroeconomy. To achieve a maximum return, an energy-conservation effort should give priority to those sectors whose energy-efficiency improvement, through interindustry linkages, will result in the largest total energy savings.

CHANGES IN THE NONENERGY PORTION OF PRODUCTION TECHNOLOGY

Before we examine changes in nonenergy inputs and quantify their energy impacts, it is important to point out that the input-output model used in this study is an open model.[4] Under the open model, the primary inputs, such as labor and capital depreciation, are not included in the calculation of intermediate energy input requirements. Instead, the energy consumption of workers and capital-investment projects are included as part of final demand. This failure to include primary inputs in the endogenous portion of the production technology results in an underestimation of the energy embodied in products. The magnitude of underestimation, however, should be small because about 85 percent of energy was used as intermediate inputs in China in the 1980s.

Changes in Direct Nonenergy Input Coefficients

The nonenergy portion of production technology was more stable than the energy portion in China between 1981 and 1987. In 12 out of the 18 business sectors that constituted China's economy, the change in total direct nonenergy intermediate input requirements per unit of

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[4] The main reason for choosing the open, rather than partially closed input-output model, is that in China's economy, we cannot assume the relationship between labor income and household consumption and that between capital depreciation and gross capital investment to be linear and have fixed proportions.

output from 1981 to 1987 was less than 15 percent, as shown in Table 5-6 and Figure 5-3. In four sectors--Natural Gas, Heavy Machinery, Light Industry, and Passenger Transportation, the change was under 5 percent. The 1981 and 1987 direct nonenergy input requirement in the natural-gas industry, for example, was almost identical, at about 0.18 RMB per kgsce of output. For all production sectors as a whole, the change in the nonenergy inputs used per unit of output from 1981 to 1987 was less than 8 percent.

There was an overall trend, however, towards higher nonenergy input uses between 1981 and 1987. Out of the 18 production sectors in our energy input-output model, direct nonenergy intermediate input coefficients increased in 15 sectors and declined in only 3 sectors. The largest increases occurred in 5 sectors: Electricity (40.4 percent), Chemical Fertilizers (38.7 percent), Construction Materials (51.4 percent), Freight Transportation & Telecommunication (35.7 percent), and Commerce (30.1 percent). For all sectors as a whole, it required 0.5105 RMB worth of nonenergy intermediate inputs to produce every RMB of output in 1987, a slight increase from 0.4738 RMB per RMB of output in 1981.

In addition, there was a general tendency towards substituting less energy-intensive agricultural inputs with more energy-intensive heavy-industrial inputs. Table 5-7 presents the breakdown of the nonenergy-input changes by five broad product groups--Agriculture, Heavy Industry, Light Industry, Transportation, and Services. We see that all sectors increased their direct heavy-industry input coefficients between 1981 and 1987. In the construction materials sector, for example,

TABLE 5-6

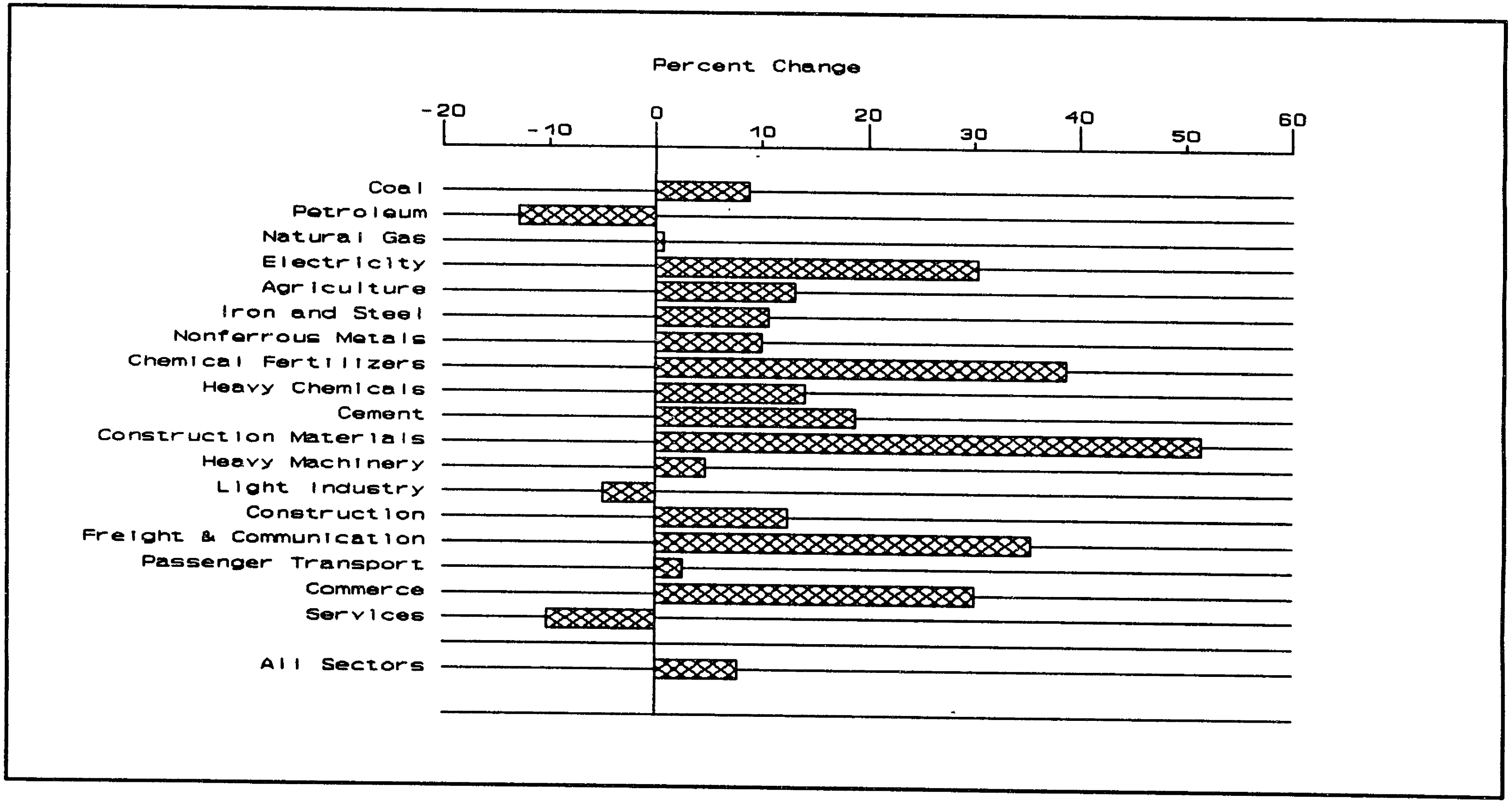
DIRECT NONENERGY INTERMEDIATE INPUTS, 1981 AND 1987
(constant 1981 RMB)

Sector	Direct Intermediate Inputs Required			
	1981	1987	Change	% Change
(RMB of input per kgsce of output)				
Coal	0.0114	0.0124	0.0010	8.8
Petroleum	0.0389	0.0339	-0.0050	-12.9
Natural Gas	0.0181	0.0182	0.0001	0.7
Electricity	0.0512	0.0668	0.0156	30.4
(RMB of input per RMB of output)				
Agriculture	0.2915	0.3297	0.0382	13.1
Iron and Steel	0.5022	0.5555	0.0533	10.6
Nonferrous Metals	0.5766	0.6344	0.0578	10.0
Chemical Fertilizers	0.3147	0.4365	0.1217	38.7
Heavy Chemicals	0.4994	0.5692	0.0699	14.0
Cement	0.4354	0.5174	0.0820	18.8
Construction Materials	0.3327	0.5039	0.1712	51.4
Heavy Machinery	0.5614	0.5880	0.0266	4.7
Light Industry	0.6426	0.6103	-0.0323	-5.0
Construction	0.6687	0.7516	0.0829	12.4
Freight & Communication	0.1826	0.2478	0.0652	35.7
Passenger Transport	0.2811	0.2880	0.0069	2.5
Commerce	0.4580	0.5957	0.1377	30.1
Services	0.4271	0.3831	-0.0440	-10.3
All Sectors	0.4738	0.5105	0.0367	7.7

Source: SDA Modeling and Computations.

FIGURE 5-3

CHANGES IN DIRECT NONENERGY INTERMEDIATE INPUT REQUIREMENTS, 1981 TO 1987



Source: Data in Table 5-6.

TABLE 5-7

CHANGES IN DIRECT NONENERGY INTERMEDIATE INPUTS, 1981 TO 1987
(constant 1981 RMB)

	Direct Intermediate Inputs Required					
Sector	Agriculture	Heavy Industry	Light Industry	Transport	Service	Total
(RMB of input per kgsce of output)						
Coal	0.0000	0.0016	-0.0014	-0.0001	0.0008	0.0010
Petroleum	-0.0011	0.0033	-0.0027	0.0010	-0.0056	-0.0050
Natural Gas	-0.0007	0.0039	-0.0023	0.0001	-0.0007	0.0001
Electricity	-0.0004	0.0154	0.0100	-0.0074	-0.0020	0.0156
(RMB of input per RMB of output)						
Agriculture	-0.0121	0.0011	0.0338	0.0058	0.0097	0.0382
Iron and Steel	-0.0012	0.0569	0.0060	-0.0340	0.0256	0.0533
Nonferrous Metals	0.0013	0.0786	-0.0325	-0.0054	0.0158	0.0578
Chemical Fertilizers	-0.0010	0.0696	0.0480	-0.0073	0.0124	0.1217
Heavy Chemicals	-0.0381	0.0705	0.0383	-0.0076	0.0067	0.0699
Cement	-0.0032	0.0421	0.0429	-0.0306	0.0308	0.0820
Construction Materials	-0.0281	0.1490	0.0425	-0.0264	0.0343	0.1712
Heavy Machinery	-0.0080	0.0891	-0.0600	-0.0054	0.0109	0.0266
Light Industry	-0.0772	0.0073	0.0044	0.0050	0.0282	-0.0323
Construction	-0.0434	0.1659	-0.0483	-0.0128	0.0216	0.0829
Freight & Communication	-0.0003	0.0672	0.0091	-0.0120	0.0012	0.0652
Passenger Transport	0.0000	0.0399	0.0111	0.0043	-0.0484	0.0069
Commerce	0.0472	0.0168	-0.0065	-0.0033	0.0835	0.1377
Services	0.0010	0.0153	0.0309	0.0070	-0.0981	-0.0440
All Sectors	-0.0328	0.0570	0.0059	-0.0009	0.0075	0.0367

Source: SDA Modeling and Computations.

the consumption of heavy-industry inputs rose by 0.1490 RMB per RMB of output. Meanwhile, all sectors except commerce and services reduced their direct agricultural input coefficients. The largest reduction occurred in the light industry, over .0772 RMB per RMB of output. As a whole, China's production sectors used 0.0328 RMB less agricultural output and 0.0570 RMB more heavy-industry output per RMB of output in 1987 than in 1981.

Reasons for Nonenergy Production-Technology Changes

Two reasons are often cited by Chinese economists to explain the increased use of material inputs in the 1980s (Li and Zheng, 1989; Ma et al., 1990; H. Wang, 1990). First, there was a relative decline in the prices of industrial materials, such as iron, cement, and basic chemicals, due to the uneven economic reform across sectors. While prices of agricultural products and consumer goods were increased substantially and/or allowed to float relatively freely, the prices of industrial producer goods continued to be tightly controlled and only increased slightly in the 1980s. This led to a decrease in the relative prices of industrial materials, which provided an incentive for enterprises to increase their use. Second, the production of industrial materials could not keep up with the increase in demand. Facing seller's market, material producers focused on output increases and neglected quality control. The quality of some industrial materials were deteriorating. Inferior quality, combined with obsolete equipment and poor management and operation, increased material requirements per unit of output in production sectors.

It is important to realize, however, that the increase in the use of nonenergy intermediate inputs and the shift from agricultural to heavy-industry inputs may just be a natural outcome of industrialization and economic modernization. As a country industrializes, the relative importance of agricultural products, in both the consumers' market basket and producers' cost structure, typically decline while that of industrial products increased. In China, the agricultural sector accounted for 57 percent of the total value of gross agricultural and industrial output in 1952, and the industrial sector accounted for only 43 percent. By 1987, the order of importance was completely reversed: the share of the agriculture sector fell to 25 percent while that of the industrial sector climbed up to 75 percent (SSB, 1991, p. 17).

In addition, economic development is often accompanied by an increase in specialization, and, consequently, interindustry transaction or linkages. Generally, this will lengthen the production chain and increase the use of intermediate inputs in the production process. In input-output economics, we refer to this trend as increasing roundaboutness of production in the economy. The more roundaboutness of production, the more interindustry connections, and the higher the intermediate input uses. Empirical evidence indicates that, for the economy as a whole, material inputs per unit of output have been gradually increasing in China for the past 40 years (Song, 1990). This process may be accelerating in the 1980s with the increases in the degree of specialization and intersectoral transactions resulting from the implementation of the economic-reform program.

The overall increase in the technical coefficients of nonenergy intermediate inputs may also be an artifact of the double-accounting principle used in the input-output table. With double-accounting, total inputs (costs) a sector purchases must be equal to total outputs (sales) the sector produces. The column sum of technical input coefficients, therefore, will always be unity if they are measured in current prices. This means that the reductions in some technical input coefficients expressed in current prices must be accompanied by equal increases in the other technical coefficients in the same column. When we measure inputs/outputs in constant prices or physical units, the coefficient changes do not necessarily abide by this rule, because the column sum of technical coefficients no longer has to be unity; but in most cases, there will still be an association between the decline in some coefficients and the increase in others. "The adoption of a new method of production involves a simultaneous change in all its input ratios and the reduction in some of them could not be realized without a corresponding increase in the others." (Leontief, 1953, p. 33).[5] As the relative important of energy inputs declined from 1981 to 1987 in China, the cost share of some other inputs tended to rise.

Energy Impacts of Nonenergy Production-Technology Changes

Tables 5-8 and 5-9 display, in terms of tonnes (Table 5-8) and percentage (Table 5-9), energy-use changes attributable to nonenergy production-technology changes. We see that the nonenergy-input changes from 1981 to 1987 had a much smaller impact on China's energy consumption than the energy-efficiency changes, reflecting the fact that direct nonenergy intermediate input coefficients were relatively stable during 1981-1987 period. Holding all other factors constant, nonenergy production-technology changes would increase energy use by 53.4 million tsce (Table 5-8), which was 8.8 percent of the 1981 total energy consumption (Table 5-9). For individual fuels, nonenergy production-technology changes increased the consumption of coal by 38.5 million tsce (8.6 percent of the 1981 total coal consumption), petroleum by 11.2

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[5] Fundamentally, we seldom observe all technical input coefficients changing in the same direction because most technological changes are not "neutral." The introduction of the electric arc furnace, for example, usually improves energy efficiency of China's iron and steel industry, but, at the same time, it increases the consumption of scrap steel.

TABLE 5-8

PRIMARY ENERGY-USE CHANGES DUE TO NONENERGY PRODUCTION-TECHNOLOGY CHANGES, 1981 TO 1987

(1000 tonnes standard coal equivalent)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Total
<u>Energy Sectors</u>					
Coal	-133	110	11	21	9
Petroleum	-1373	-374	-66	-83	-1896
Natural Gas	-96	11	1	-1	-84
Electricity	1318	146	42	94	1600
<u>Nonenergy Sectors</u>					
Agriculture	10681	1993	332	635	13641
Iron and Steel	1567	121	87	155	1930
Nonferrous Metals	1787	512	56	210	2566
Chemical Fertilizers	203	400	-182	60	480
Heavy Chemicals	3112	1123	137	246	4618
Cement	-327	118	32	32	-146
Construction Materials	7160	1437	187	448	9231
Heavy Machinery	-3485	1461	191	38	-1796
Light Industry	-23968	-2166	-979	-1500	-28612
Construction	32419	3981	511	1897	38808
Freight & Communication	2736	878	138	236	3988
Passenger Transport	375	108	16	29	527
Commerce	4895	1255	158	325	6633
Services	1721	83	77	101	1983
Total	38591	11197	748	2942	53478

Source: SDA Modeling and Computations.

TABLE 5-9

PERCENT CHANGES IN PRIMARY ENERGY CONSUMPTION DUE TO NONENERGY PRODUCTION-TECHNOLOGY CHANGES, 1981 TO 1987

(percent of the 1981 consumption of respective energy)

Sector	Coal	Petroleum	Natural-Gas	Hydropower	Total
<u>Energy Sectors</u>					
Coal	0.0	0.1	0.1	0.1	0.0
Petroleum	-0.3	-0.3	-0.4	-0.3	-0.3
Natural Gas	0.0	0.0	0.0	0.0	0.0
Electricity	0.3	0.1	0.2	0.4	0.3
<u>Nonenergy Sectors</u>					
Agriculture	2.4	1.7	2.0	2.4	2.2
Iron and Steel	0.4	0.1	0.5	0.6	0.3
Nonferrous Metals	0.4	0.4	0.3	0.8	0.4
Chemical Fertilizers	0.0	0.3	-1.1	0.2	0.1
Heavy Chemicals	0.7	0.9	0.8	0.9	0.8
Cement	-0.1	0.1	0.2	0.1	0.0
Construction Materials	1.6	1.2	1.1	1.7	1.5
Heavy Machinery	-0.8	1.2	1.1	0.1	-0.3
Light Industry	-5.4	-1.8	-5.8	-5.6	-4.7
Construction	7.3	3.3	3.0	7.1	6.4
Freight & Communication	0.6	0.7	0.8	0.9	0.7
Passenger Transport	0.1	0.1	0.1	0.1	0.1
Commerce	1.1	1.0	0.9	1.2	1.1
Services	0.4	0.1	0.5	0.4	0.3
Total	8.6	9.3	4.4	11.0	8.8

Source: SDA Modeling and Computations.

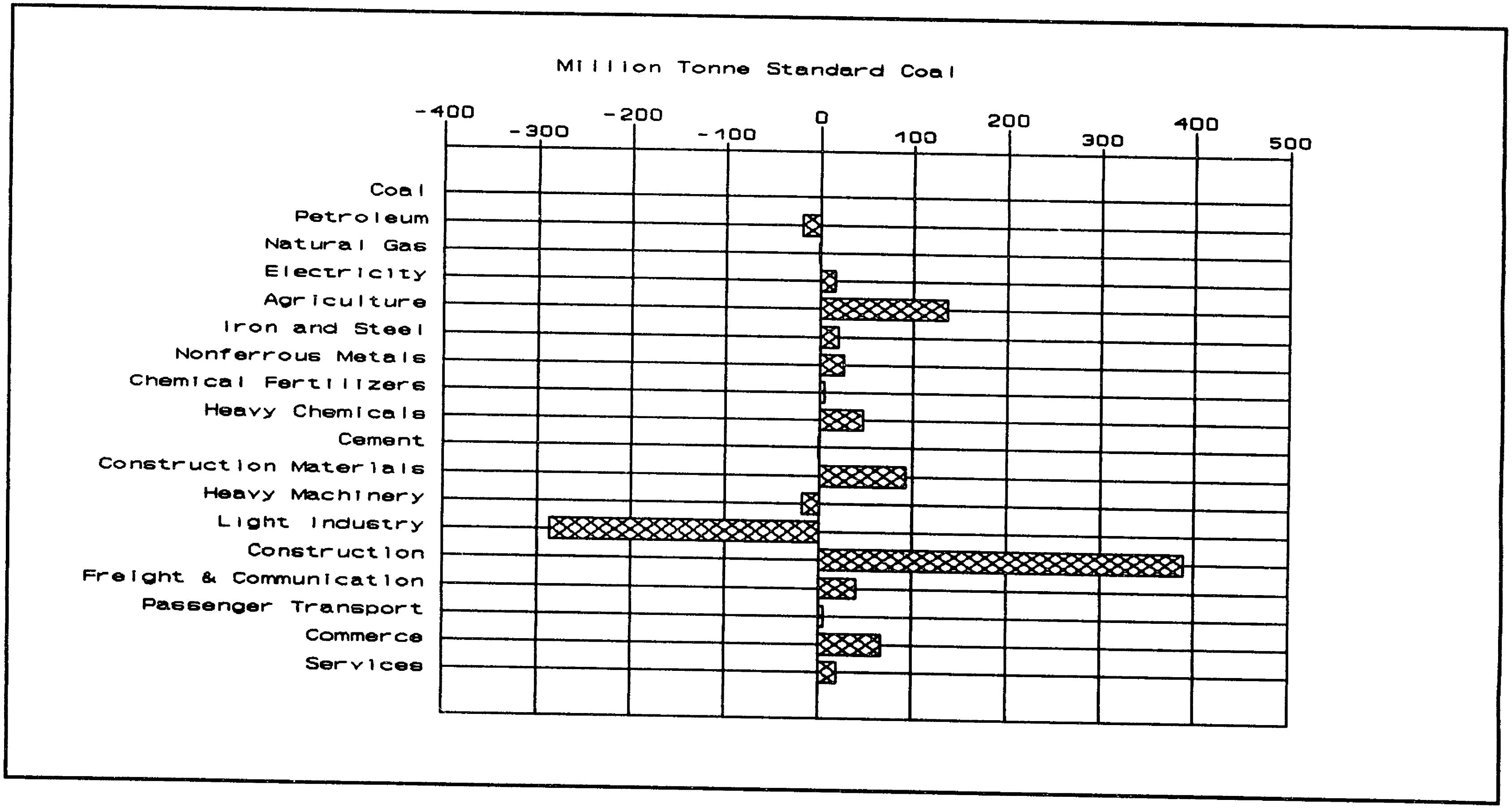
million tsce (9.3 percent), natural-gas by 7.5 million tsce (4.4 percent), and hydropower by 3.0 million tsce (11.0 percent).

A large portion of the energy-use changes associated with nonenergy inputs originated from technological changes in the agricultural, light-industry, and construction sectors. As shown in Table 5-8 and Figure 5-4, nonenergy production-technology changes in Agriculture and Construction increased energy consumption by 13.6 million tsce and 38.8 million tsce, respectively, while those in Light Industry resulted in energy savings of 28.6 million tsce. Although those three sectors did not experience the greatest changes in direct nonenergy input coefficients (see Table 5-6 and Figure 5-3), they were among the largest final-output producers in China, accounting for about 70 percent of China's GDP in the 1980s. When multiplied by a large final output, a small change in energy requirements resulting from the nonenergy production-technology changes can have a large effect on energy consumption. As we indicated in the last chapter, the size of a sector matters.

Although nonenergy production-technology changes between 1981 and 1987 increased China's energy consumption, we should not overlook the potential role nonenergy inputs can play in conserving energy. Material consumption per physical unit of output in China is far higher in China than in many other countries and there is a great potential to reduce the material intensity of China's economy (Ma, et al., 1990; H. Wang, 1990). In fact, the Chinese government has started to encourage enterprises to pursue material-intensity reduction jointly with energy-efficiency improvement, which, if implemented, can be an important

FIGURE 5-4

PRIMARY ENERGY-USE CHANGES DUE TO NONENERGY PRODUCTION-TECHNOLOGY CHANGES IN DIFFERENT SECTORS



Source: Data in Table 5-8.

source of energy savings because most industrial materials, such as chemical fertilizers, steel, and cement, are energy-intensive products.

In the long run, the decline in the use of material inputs may play a major role in reducing energy intensity of China's economy. Colombo (1988) and Herman et al. (1989) argue that dematerialization--the decline over time in the material content or "embedded energy" of industrial products--is a logical outcome of in an advanced economy. Larson, Ross, and William (1986) show that the demand for many energy-intensive basic materials in North America, Western Europe, and Japan has levelled off both because of material substitution and because of a saturation of demand for material-intensive products. Goldemberg (1991) believes that the growth of energy intensity in developing countries will be much slower after they complete their major infrastructure construction, which requires a large amount of energy-intensive materials, such as iron, steel, and cement.

SUMMARY OF ENERGY-USE CHANGES DUE TO PRODUCTION-TECHNOLOGY CHANGES

Production-technology changes act as an offset to the increased energy use associated with final-demand shifts. Table 5-10 and Figure 5-5 summarize the energy impacts of production-technology changes from 1981 to 1987. Compared with the energy requirements of using 1981 production technology to satisfy the 1987 final demand, adoption of 1987 production technology saved about 224.7 million tsce of primary energy, which was 36.8 percent of the 1981 total primary energy consumption. All of these energy savings came from the improvements in energy efficiency--reductions in direct energy input coefficients--which

TABLE 5-10

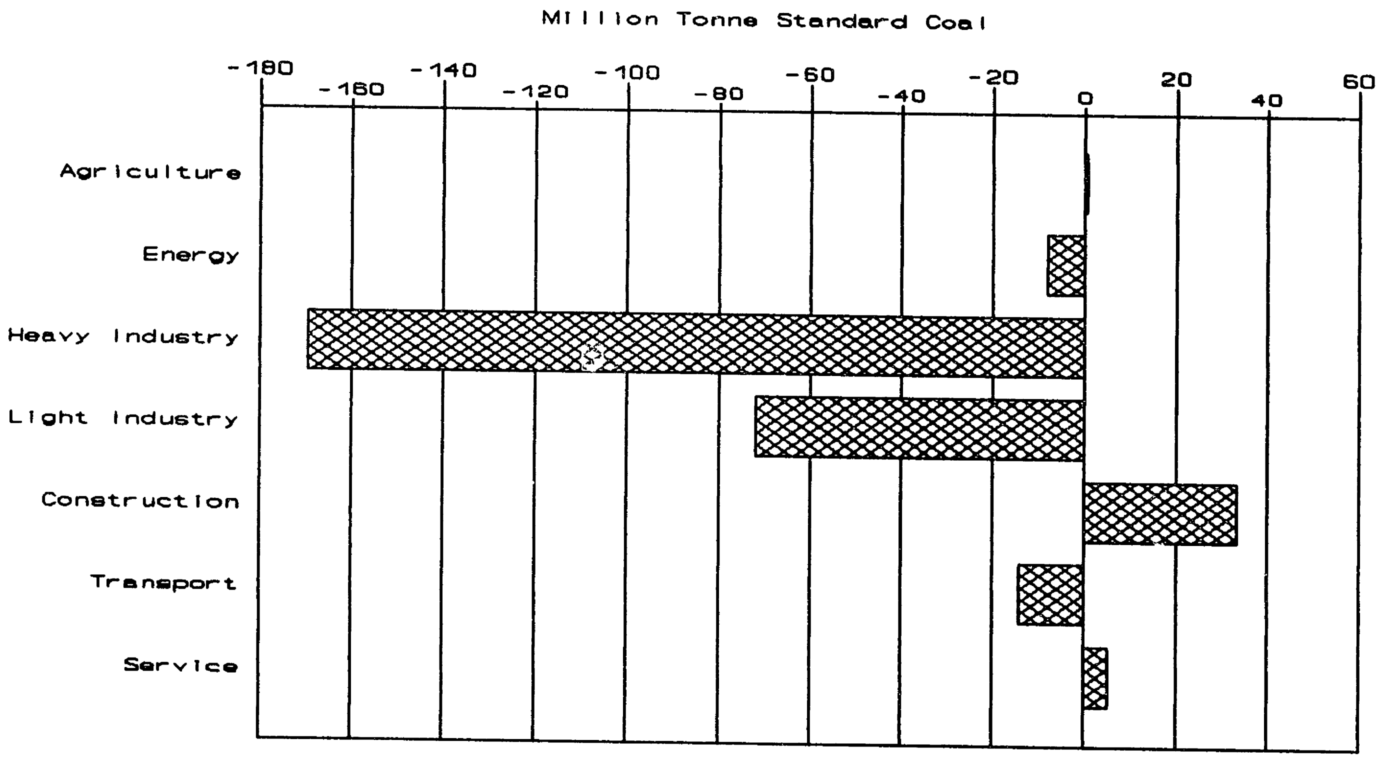
PRIMARY ENERGY-USE CHANGES ASSOCIATED WITH PRODUCTION-TECHNOLOGY CHANGES, 1981 TO 1987

Source	Coal	Petroleum	Natural-Gas	Hydropower	Total
Tonnage Change	(1000 tonnes standard coal equivalent)				
Total Changes	-128516	-72383	-13467	-10294	-224660
Energy Inputs	-167107	-83580	-14215	-13236	-278138
Nonenergy Inputs	38591	11197	748	2942	53478
By Sectors					
Agriculture	5578	-5041	243	-355	425
Energy	11567	-14356	-1908	-3501	-8198
Heavy Industry	-115536	-37289	-9680	-6974	-169479
Light Industry	-52744	-14818	-2355	-1961	-71878
Construction	27993	3907	33	1458	33391
Transport	-11321	-3064	-64	327	-14122
Service	5948	-1722	264	712	5201
Percent Change	(percent over the 1981 use of respective energy)				
Total Changes	-28.8	-60.0	-79.5	-38.6	-36.8
Energy Inputs	-37.4	-69.3	-83.9	-49.6	-45.6
Nonenergy Inputs	8.6	9.3	4.4	11.0	8.8
By Sectors					
Agriculture	1.2	-4.2	1.4	-1.3	0.1
Energy	2.6	-11.9	-11.3	-13.1	-1.3
Heavy Industry	-25.9	-30.9	-57.1	-26.1	-27.8
Light Industry	-11.8	-12.3	-13.9	-7.4	-11.8
Construction	6.3	3.2	0.2	5.5	5.5
Transport	-2.5	-2.5	-0.4	1.2	-2.3
Service	1.3	-1.4	1.6	2.7	0.9

Source: SDA Modeling and Computations.

FIGURE 5-5

PRIMARY ENERGY-USE CHANGES ASSOCIATED WITH PRODUCTION-TECHNOLOGY CHANGES IN DIFFERENT SECTORS



Source: Data in Table 5-10.

reduced primary energy use by 278.1 million tsce or 45.6 percent. The changes in the nonenergy portion of production technology, on the other hand, increased China's energy consumption and reduced energy savings from the efficiency improvement by 53.5 million tsce or 8.8 percent.

Of the total 224.7 million tsce energy savings from 1981 to 1987 due to production-technology changes, 128.5 million tsce (57.2 percent) was in the form of coal, 72.4 million tsce (32.2 percent) was petroleum, 13.5 million tsce (6.0 percent) was natural gas, and 10.3 million tsce (4.6 percent) was in the form of hydropower. The contribution of petroleum and natural gas was disproportionally large given that it accounted for, respectively, only about 19.8 percent and 2.8 percent of the total primary energy consumption in 1981. As shown in Table 5-10, the energy-savings rate was 60.0 percent for petroleum and 79.5 percent for natural gas, compared with 28.8 percent for coal and 38.6 percent for hydropower. In terms of sectoral contributions, the production-technology changes in the heavy and light industries were the most important source of energy savings, which, all other things being equal, reduce China's energy consumption by 169.5 million tsce and 71.9 million tsce, respectively. The rest of the energy savings came from technological changes in transportation (14.1 million tsce) and energy sectors (8.2 million tsce) (see Figure 5-5). On balance, changes in the energy and nonenergy portions of production technology in the construction, energy, and service sector increased, rather than decreased, energy consumption of China's economy.

We identified three macroeconomic factors that appeared to be primarily responsible for the energy-efficiency increases in China's economy between 1981 and 1987. They were: (1) extensive energy-conservation programs and policies implemented by the Chinese government since 1979; (2) the increase in overall economic efficiency, as a result of China's economic-reform program, which reduces central planning and increases the role of market mechanisms and incentive structures in the economy; (3) the increase in energy prices, which provides additional incentives for energy-conservation practices and for investing in energy-saving technologies. We argued that the first two factors were much more important than the third one because despite the energy-price increases, energy expenditures comprised a very small percentage of the total production cost in most sectors in the 1980s and were not that important in the overall scheme of production.

In the next chapter, we will conduct a case study of energy-efficiency improvements in China's iron and steel industry to complement our macro-level analysis of production-technology changes and to illustrate how the three macroeconomic factors identified were translated into energy savings. We will see that even in steel manufacturing, where energy represents about 10-15 percent of total production costs, many energy-efficiency gains achieved between 1981 and 1987 were not the result of direct efforts to reduce energy costs but of indirectly pursuing other economic goals, such as capacity expansion, improved product variety and quality, and higher productivity.

CHAPTER 6

ENERGY CONSERVATION IN ACTION: A CASE STUDY OF THE IRON AND STEEL INDUSTRY[1]

The results of our structural decomposition analysis indicate that energy-efficiency improvements--reductions in direct energy input coefficients of individual production sectors--accounted for most of the energy savings and were primarily responsible for the decline in China's energy intensity between 1981 and 1987. In this chapter, we conduct a case study of energy-efficiency increases in China's iron and steel industry to determine what one industry actually did to conserve energy and what motivated them to adopt more energy-efficient production technologies. We choose the iron and steel industry for two main reasons. First, it was one of the largest consumers of energy, accounting for about 17 percent of China's total end-use energy consumption in 1981 and 19 percent in 1987 (see Chapter 2). Second, the industry experienced significant increases in energy efficiency in the 1980s. Energy consumption per tonne of crude steel, a main indicator of the overall energy intensity of the iron and steel production, fell every year between 1981 and 1987. We estimate that the increased energy efficiency in the iron and steel industry from 1981 to 1987 saved China about 25 million tsce of energy in 1987, which was almost 5 percent of the total energy consumption in 1981 (see Chapter 5).

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[1] Unless otherwise cited or noted, all the materials presented in this chapter are based on the data and information Professor Karen R. Polenske and I collected during our field study in the summer of 1992 on the energy technologies and conservation measures in China's iron and steel industry.

We realize that the iron and steel industry has some unique characteristics and its pattern of technological changes may be different from that in other industries. Iron and steel, for example, is a typical continuous-process industry, producing a large volume of relatively homogeneous goods through several closely linked sequential processes. The continuity of production processes means that an improvement in one part of the production chain will bring about a pressure for corresponding improvements in other parts in order to break production "bottlenecks." This internal pressure for technological improvements is much less important in discontinuous "batch" production industries where a large variety of nonhomogeneous goods are produced on a workshop or "batch" basis (Herbert-Copley, 1990). Thus, some of the energy efficiency measures adopted by the iron and steel industry may be sector-specific and not applicable to other industries.

Our purpose in this chapter is not to determine "statistically" representative energy-efficiency measures implemented by China's production sectors. Rather, we are mainly interested in determining a general approach towards energy conservation, types of measures that were undertaken, and why those measures were successful. The chapter consists of four sections. We begin by providing some background information about iron and steel production in China. In the second section, we review the progress made towards more efficient energy use in China's iron and steel industry between 1981 and 1987. In the third section, we examine how this greater energy efficiency was achieved and identify three major sources of energy savings: structural readjustment, improved energy management, and technological advancement. Finally, in

Section 4, we summarize our research findings and present our conclusions.

IRON AND STEEL PRODUCTION IN CHINA

China is the fourth largest steel producer in the world, behind the former Soviet Union, Japan, and the United States. In 1987, it produced 56.3 million tonnes of crude steel, which was about 7.6 percent of the world total (MMI, 1989, p. 221). The backbone of China's iron and steel industry are 14 large iron and steel complexes--each capable of producing at least 1 million tonnes of crude steel per year. As a whole, the 14 complexes generate more than 65 percent of China's total crude steel output. The largest ones, in terms of 1987 crude steel production capacity, are the Anshan Iron and Steel Company in Liaoning Province (7.7 million tonnes), Wuhan Iron and Steel Company in Hubei Province (4.6 million tonnes), Capital Iron and Steel Company in Beijing Municipality (3.2 million tonnes), and Baoshan Iron and Steel Company in Shanghai Municipality (3.2 million tonnes) (MMI, 1989).

For administrative and statistical purposes, the iron and steel enterprises in China are divided into two categories--enterprises under the Ministry of Metallurgical Industry (MMI) (metallurgical system) and those associated with other ministries (nonmetallurgical system). Within the metallurgical system, there are three sub-categories: key enterprises, medium and small enterprises, and non-iron-and-steel enterprises. Collectively, the key enterprises, which include all the 14 largest complexes and some other major plants, produce about 70-75 percent of China's crude steel. The medium and small enterprises within the metallurgical system account for another 20-25 percent of the crude steel output and the nonmetallurgical iron and steel enterprises account for the remaining 5 percent (Kothari, 1990). Because of data limitations, we will focus our analysis almost exclusively on energy-use changes in enterprises within the metallurgical system. The output and energy data presented in this chapter, therefore, will be different from those of the iron and steel industry in the SDA modeling.

Manufacturing Processes

Figure 6-1 depicts major iron and steel manufacturing processes used in China's integrated plants. The production begins with the agglomeration of the iron ore, coke-making, and the production of limestone, which is fed into the blast furnace that produces molten pig iron.[2] There are two basic agglomeration methods: sintering and pelletizing. Sintering converts a mixture of enriched iron ores into granular lumps, while pelletizing adds a binder to the ore and forms pellets by means of heating in a rotating drum or disk. The energy requirements for the sintering process is about 2-3 times that of the pelletizing. Coke is produced in the coke oven using metallurgical coal. It serves both as a source of energy and as an iron-ore reduction agent in the blast furnace.

Pig iron from the blast furnace is refined into steel in steel furnaces. There are three major types of steel furnaces. In the basic

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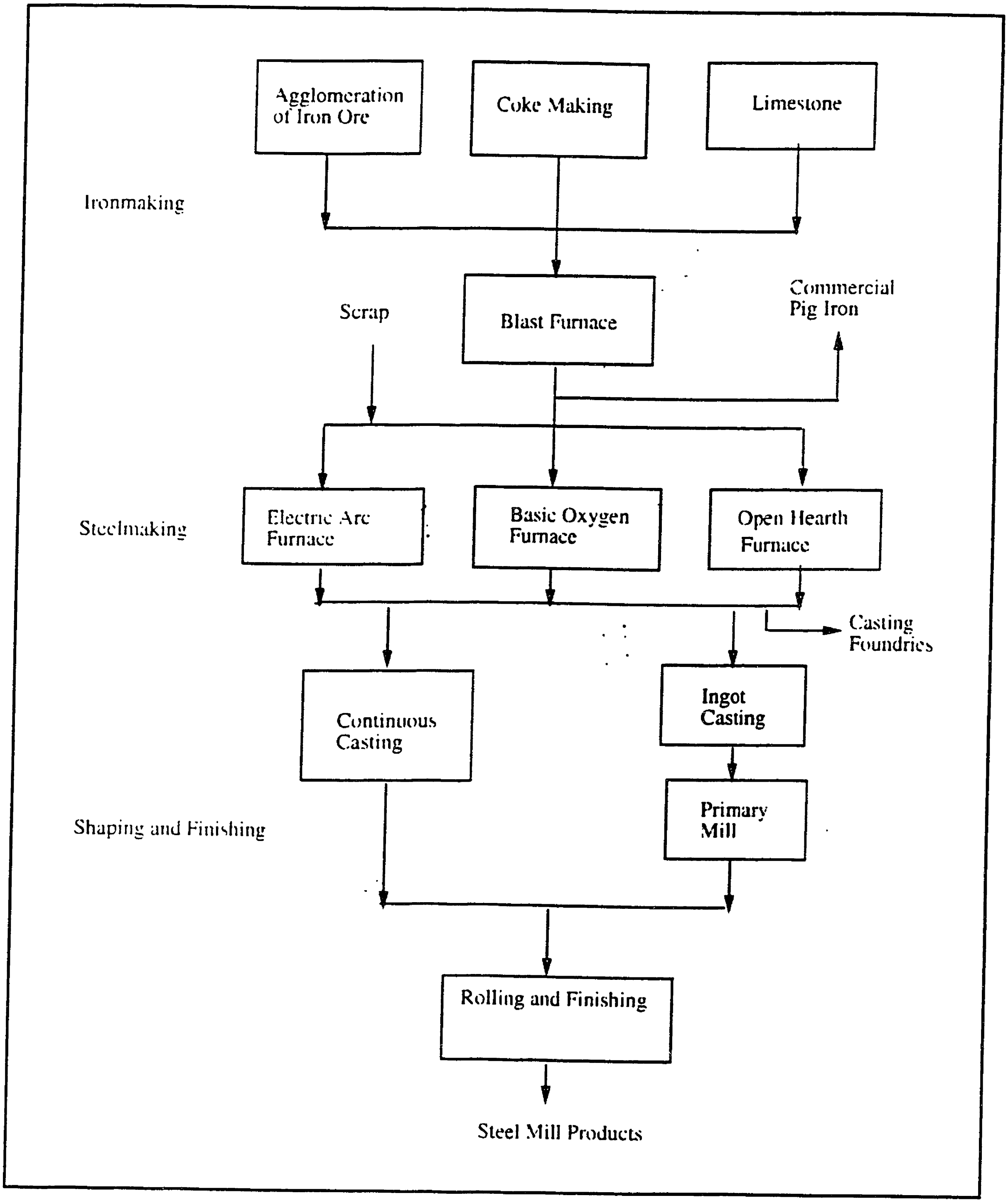
[2] An alternative technology to the blast furnace operation, which has not been applied in China, is direct reduction of iron ores. The principal direct reduction method utilizes a countercurrent shaft furnace which uses reformed natural gas as the fuel and either coarse ore or pelletized concentrates as the ore feed.

FIGURE 6-1

IRON AND STEEL MANUFACTURING PROCESS



Source: The Author Based on Plant Visits in China, 1992.

oxygen furnace (BOF) or converter, oxygen is blown into the molten high-carbon metal to reduce carbon to a desired level of 0.1-1.0 percent. The BOF depends heavily on molten pig iron since melted pig iron supplies most of the energy needed for refining. The maximum cold charge (i.e., scrap) is about 25-30 percent of the total charge.[3] In an open hearth furnace (OHF), which is older process and largely obsolete, energy for the steelmaking comes primarily from fuel, rather than hot pig-iron. The OHF, therefore, can take almost any combination of molten pig iron and cold charge. Compared with BOF, OHF has three disadvantages: it is capital intensive, has a low productivity (i.e., longer hour per batch or heat), and has high energy costs. Furthermore, the environmental impact of the OHF is severe and continued operation of these furnaces would require increased efforts to control emissions. The third type of steel furnace is the electric arc furnace (EAF). It is mainly a smelting device and thus only employed in steel-making with steel scrap as raw materials. The heat required to melt the scrap, remove impurities, and add alloying elements is supplied by high-voltage electricity. In 1981, BOF, OHF, and EAF accounted for 32 percent, 50 percent, and 18 percent, respectively, of China's total crude steel production. In 1987, the output distribution changed to 23 percent, 57 percent, and 20 percent, respectively.[4]

The output from steel furnaces is either continuously cast into

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[3] Cold charge is the fraction of the cold scrap in the total metal inputs (i.e., molten pig iron and cold scrap) charged into steelmaking furnaces.

[4] See Table 6-12 of this chapter for details on the steel output by production precesses in 1981 and 1987.

semifinished shapes, such as slabs, blooms, and billets (continuous casting), or into large ingots (ingot casting), which are then heated in soaking pits and rolled into semifinished shapes in the primary mill. Continuous casting saves energy because it eliminates the ingot stage of the steel shaping process and increases yields by about 10 percent over the ingot-casting method (Chiogiogi, 1979). Because of the time intervals between casting and rolling, the semifinished products become solidified. In the rolling and finishing stage, those solidified products are heated in a reheat furnace, rolled, heat treated (annealing), and/or surface treated to form a wide variety of products, such as steel plates, rails, structural materials, rods and bars, pipes and tubes, hot rolled sheets and strips, wires and wire products, and galvanized products.

Process Energy Requirements

Table 6-1 shows energy requirements, in terms of Gigacalorie (Gcal) per tonne of crude steel, of different stages in the iron and steel production, based on a World Bank technical report prepared by Meunier and Kops (1984). Although these numbers do not represent energy-use patterns in China, they provide an overall picture of energy consumption in iron and steel manufacturing and help us to understand main factors affecting energy intensity of the industry. From the table, we see that the ironmaking stage is by far the most energy-intensive stage in iron and steel manufacturing, accounting for 72 percent of total energy consumption in the BF-BOF process and 63 percent in the BF-OHF process. The blast furnace alone accounts for about 50 percent of the total energy requirements in those two processes.

TABLE 6-1

ENERGY CONSUMPTION BY STEELMAKING PROCESS IN DEVELOPING COUNTRIES

(Gcal per tonne of crude steel)

	BF-BOF		BF-OHF		Scrap-EAF	
	Gcal	%	Gcal	%	Gcal	%
Ironmaking						
Sinter and pellet plant	0.7	11.6	0.7	10.3	-	-
Coke ovens	0.4	6.6	0.4	5.9	-	-
Blast Furnace	3.2	53.4	3.0	41.0	-	-
Subtotal	4.3	71.6	4.1	63.2	-	-
Steelmaking						
BOF/OHF/EAF	0.2	3.4	1.1	14.7	1.4	56.0
Rolling Mills	1.0	16.6	1.0	14.7	1.0	40.0
Power Plant & Others	0.5	8.4	0.5	7.4	0.1	4.0
Total	6.0	100.0	6.7	100.0	2.5	100.0

Source: Maurice Y. Meunier and Oscar de Bruyn Kops. 1984. Energy Efficiency in the Steel Industry with Emphasis on Developing Countries. Washington, DC: the World Bank, p. 16.

Note: BF = Blast Furnace.
BOF = Basic Oxygen Furnace.
EAF = Electric Arc Furnace.
OHF = Open Hearth Furnace.
Gcal = GigaCalorie.

In the steelmaking stage, the BOF requires very little additional energy because the energy coming naturally from the ironmaking stage. In fact, the incoming molten pig iron into the BOF contains greater energy content than outgoing steel. The OHF is more energy intensive because it requires energy to melt the high share of steel scrap charged with the hot metal and because it has a lower steel yield than the BOF. The EAF is also energy intensive, requiring 550-600 kWh of electricity (1.4-1.5 Gcal) per tonne of liquid steel plus some fuel and oxygen (Meunier and Kops, 1984). It accounts for about 56 percent of the total energy consumption in the Scrap-EAF process (Table 6-1). Despite this high energy intensity, the scrap-EAF process needs much lower energy per tonne of crude steel than either BF-BOF or BF-OHF route because it eliminates the more energy-intensive ironmaking stage.

The shaping and finishing stage requires about 1 Gcal per tonne of crude steel, which represents 17 percent of total energy use in the BF-BOF process, 15 percent in the BF-OHF process, and 40 percent in the scrap-EAF process (Table 6-1). The actual energy requirements in real-world operations can be significantly larger or smaller than the 1 Gcal/tonne steel, depending on the share of continuous casting and the type and mix of finished steel products. Continuous casting requires only about 0.09 Gcal per tonne of semifinished shapes, while ingot casting uses 0.3 Gcal per tonne of ingot plus energy consumption in the primary mill. The type and mix of finished steel products are important because some products only go through hot rolling, others need cold rolling, while still others require additional heat treating, coating, or other treatments. When many rolling steps are used, the energy requirements in the rolling process alone can be as high as 4.0 Gcal/tonne of crude steel.

From our review of process-energy requirements, it is apparent that four factors have major impacts on energy intensity of an iron and steel industry. They are: (1) the energy efficiency of the blast furnace, (2) the steelmaking process used--the BF-BOF and Scrap-EAP processes have much lower energy requirements per tonne of crude steel than the BF-OHF process, (3) the iron-to-steel ratio, which depends primarily on the relative importance of iron and steel in the final-output mix and on the scrap-charge fraction, and (4) the extent to which continuous casting is used. The energy intensity of the steel production can be reduced substantially by improving the energy efficiency of the BF operation, phasing out OHF, reducing the iron-to-steel ratio, and increasing the continuous-casting ratio.

Energy Intensity of the Industry

China consumes more energy to produce one tonne of steel than many other countries. To produce one tonne of crude steel, China required 13.51 Gcal (1.93 tsce) in 1981 and 11.62 Gcal (1.66 tsce) in 1987, which were far higher than the typical energy requirement of 6.0-7.0 Gcal (0.86-1.00 tsce) shown in Table 6-1. In comparison, specific energy consumption in 1980 was 4.2 Gcal per tonne of crude steel in Italy, 4.5 Gcal in Japan, 5.7 Gcal in Brazil, and 6.2 Gcal in the United States (World Bank, 1985b, p. 220).[5]

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[5] Specific energy consumption refers to energy consumption per unit of output.

Seven main factors contributed to the exceptionally high specific energy consumption in China's iron and steel industry.

1. **Different Accounting Practice.** The energy consumption data reported by MMI includes energy consumed not only in steel production but also in associated operations, such as captive iron ore, machine building, equipment repairing, and food services, and in residential and office buildings. Because China's steel plants typically have many nonsteel production activities and provide a large variety of worker services, this accounting practice greatly distorts the specific energy consumption. Ross and Liu (1991) estimate that captive mining alone accounted for about 4 percent of total energy consumption in China's iron and steel industry.

2. **Poor Quality of Iron Ore.** In 1987, the average grade for run- of-mine iron ore was only 31 percent and that of iron concentrate, 63 percent (MMI, 1989, p. 202). In addition, about 95 percent of the ore charged to blast furnaces in China is in the form of sinter. This is in contrast with the situation in the United States where pellets provide some 80 percent of the ore input (Ross and Liu, 1991). Experts believe that China's steel enterprises could improve the yield of blast furnaces by 20-30 percent if they substituted pelletizing technology for sintering technology to agglomerate its own low-grade ores, and/or substituted imported high-grade ore for domestic ore (Weil, 1985).

3. **Obsolete Equipment and Processes.** Several indicators in 1981 illustrate the low technological level of China's iron and steel industry. About 31 percent of the crude steel was produced using the OHF process. Only 7 percent of liquid steel was continuously casted--one of the lowest percentages in the world (MMI, 1989). Primitive coke ovens still accounted for 16-19 percent of coke production (Liu, 1992).[6]

4. **High Iron-to-Steel Ratio.** In 1981, the iron/steel ratio in China was 0.96, compared with 0.50 in Italy, 0.61 in the United States, 0.62 in the United Kingdom, and 0.79 in Japan (MMI, 1989, p. 198; 1991, p. 407). The high ratio was mainly due to a large production of commercial pig iron (about 22.1 percent of the pig-iron output) and the small fraction of external scrap used (less than 14 percent).

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[6] Although many blast-furnaces in China are small and old, their operations are fairly efficient. Both the coke rate and utilization coefficients are comparable to those in advanced countries.

5. **Small Scale of Production.** Small and medium-scale plants, whose specific energy consumption was over 30 percent higher than that in China's large, key plants, contributed approximately 20-25 percent of crude steel production in the 1980s (World Bank, 1985).

6. **Low Utilization of Waste and By-Product Energy.** Only a tiny fraction of blast-furnace gas, converter gas, coke-oven gas, and other waste/by-product energy was recovered and utilized.

7. **Lack of Production Integration.** This results in large energy requirements for reheating pig iron and cold steel. Some pig iron and steel ingots are even transported over long distances to be remelted due to the irrational spatial distribution of iron and steel mills.

Liu (1992) conducts a detailed comparative study to determine why China used about 55 percent more energy to produce one tonne of steel than Japan in 1985. He finds that about one-third of the energy-intensity difference could be attributed to the differences in energy accounting, material-input quality, and other incomparable factors. Another 29.0 percent was due to process differences, such as the share of BF-OHF, BF-BOF, and Scrap-EAF in the steel production. Other major factors contributing to higher specific energy consumption in China relative to Japan included: a high iron/steel ratio, which accounted for about 16.0 percent of the intensity difference; the small scale of production, 7.6 percent; low utilization of waste heat and by-product fuels, 4.3 percent; differences in energy-using equipment, such as ovens and furnaces, 2.6 percent; and low continuous-casting ratio, 2.2 percent.[7]

When adjusted for incomparable factors, China's specific energy

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[7] Other factors accounted for the remaining 5 percent of the intensity difference between Chinese and Japanese steel producers.

consumption, therefore, was approximately 37 percent higher than Japan's in 1985. Ross and Liu (1991) similarly report that after adjusting for production of cast iron, captive mining operations, product-mix differences, and residential energy use, energy consumption per tonne of steel-mill product (i.e., rolled steel) in China's steel industry is about one-third higher than that in the U.S. integrated steel plants.

The high energy intensity indicates that there are many opportunities for energy conservation and that specific energy consumption in China's iron and steel industry can be reduced substantially. The Shenyang No. 3 Steel Rolling Mill in Shenyang City, Liaoning Province, is a case in point (Taylor, 1982).[8] For years, the mill totally disregarded energy conservation. "Flames coming out of the furnace and billows of smoke coming out of the chimney were mistaken as normal phenomena." (Taylor, 1982, p. 17). In 1979, the mill consumed an average of 180 kilograms (kg) of oil for every tonne of rolled steel it produced, which was about five times the amount consumed in China's more advanced plants, and six times the national average for the Japanese steel-rolling industry.

The mill was dubbed an "oil tiger" and ordered to shut down its furnace for two weeks for modifications in the summer of 1979. The mill managers just then realized that the size of the furnace was far too large for the capacity of the plant's other equipment, a very common situation in China described as "a big horse pulling a small wagon." To downsize the furnace, a wall was hastily constructed to divide the furnace into two isolated chambers and only one chamber was used. In

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[8] The story was originally reported in Liaoning Daily.

addition, insulation wrappings were installed around the furnace's water pipes. With these two modifications, oil consumption per tonne of rolled steel dropped from 170 kg in the first half of 1979 to 80 kg during the fourth quarter.

The 80 kg consumption rate, however, was still above the specific energy consumption ceiling set by the MMI, so that the mill had to make further modifications in the summer of 1980. One major water pipe was eliminated and heat-resistant steel tracks were installed on the two remaining water pipes. Air preheaters and new burner nozzle tips were also installed. After these changes, oil consumption per tonne of rolled steel dropped to 54.8 kg in the last quarter of 1980. Although this was still a high consumption rate by advanced standards, it had been decreased to less than one-third of the original level at the beginning of 1979, by implementing relatively simple measures without any major capital investment.

ENERGY-EFFICIENCY INCREASES IN THE 1980S

The Shengyang No. 3 Steel Rolling Mill was not alone. Hundreds of iron and steel enterprises similarly had cut down their energy wastes and improved energy efficiencies of their production since 1978. Between 1978 and 1988, the gross output of China's iron and steel industry (in 1980 constant prices) increased by 85.3 percent from 29.8 million RMB to 55.1 million RMB while energy consumption grew by only 23.2 percent from 73.6 million tsce to 90.7 million tsce (Table 6-2). Energy consumption per unit of output, which is equivalent to the direct energy input coefficient in the input-output analysis, declined by 33.5

TABLE 6-2

ENERGY CONSUMPTION, GROSS OUTPUT, AND STEEL PRODUCTION IN CHINA'S IRON AND STEEL INDUSTRY, 1978-1988

Year	Primary Energy Consumption		Gross Industrial Output Value		Crude Steel Production	
	mil. tsce	%change	bil. RMB	%change	mil. tonne	%change
1978	73.6	--	29.8	--	29.2	--
1979	72.7	-1.2	33.1	11.4	31.9	8.9
1980	70.9	-2.5	34.2	3.3	34.8	9.1
1981	65.0	-8.4	32.3	-5.8	33.6	-3.3
1982	66.8	2.8	34.4	6.7	35.0	4.2
1983	69.1	3.6	36.9	7.3	37.4	6.8
1984	73.6	6.4	40.1	8.4	40.5	8.3
1985	77.8	5.8	44.0	9.9	43.7	8.0
1986	84.0	8.0	48.9	11.1	48.9	11.7
1987	87.7	4.3	53.5	9.3	52.7	7.8
1988	90.7	3.4	55.1	3.1	55.7	5.8
1978-88		23.2		85.3		90.6
1981-87		34.9		65.8		56.8

Source: Ministry of Metallurgical Industry.

Note: mil. = million.
bil. = billion.
-- = not applicable.

percent from 2.473 kgsce/RMB in 1978 to 1.644 kgsce/RMB in 1988 (Table 6-3). Using crude steel production as an indicator of the output level, the energy intensity dropped by 35.4 percent from 2.517 tsce per tonne of crude steel to 1.626 tsce/tonne between 1978 and 1988. In fact, China's iron and steel producers consumed no more energy in 1979-1984 than in 1978 but generated 30-40 percent higher output (Table 6-2).

In this study, we focus mainly on energy-intensity changes between 1981 and 1987. During this period, the primary energy consumption in China's iron and steel industry increased by 34.9 percent from 65 million tsce in 1981 to 88 million tsce in 1987. Meanwhile, the gross output and crude steel production grew by 65.8 percent and 56.8 percent, respectively. Energy consumption per RMB of output declined by 18.6 percent from kgsce/RMB in 1981 to 1.639 kgsce/RMB in 1987 and that per tonne of crude steel fell by 13.9 percent from 1.932 tsce/tonne to 1.664 tsce/tonne.

Utilization of Individual Fuels

In 1981, the iron and steel industry consumed 65 million tsce of primary energy, which accounted for about 12 percent of China's total energy consumption and 18 percent of the total industrial energy consumption. This included approximately 43 million tonnes of coking coal, 17 million tonnes of fuel coal, 30 billion kwh of electricity, 3.8 million tonnes of heavy oil, and 1 billion cubic meters of natural gas, as shown in Table 6-4. Coking coal was used to produce coke, which was then fed into blast furnaces for ironmaking. Fuel coal was mainly used for heating boilers, sintering and pelletizing, coal-gas generation, and

TABLE 6-3

ENERGY INTENSITY OF CHINA'S IRON AND STEEL INDUSTRY, 1978-1988

	Energy Per RMB of Output			Energy Per Tonne of Crude Steel		
	kgsce/RMB	change	%change	tsce/tonne	change	%change
1978	2.473	--	--	2.517	--	--
1979	2.194	-0.280	-11.3	2.283	-0.235	-9.3
1980	2.071	-0.122	-5.6	2.040	-0.242	-10.6
1981	2.013	-0.058	-2.8	1.932	-0.108	-5.3
1982	1.939	-0.075	-3.7	1.906	-0.026	-1.4
1983	1.871	-0.068	-3.5	1.849	-0.057	-3.0
1984	1.836	-0.035	-1.9	1.817	-0.032	-1.7
1985	1.767	-0.069	-3.8	1.779	-0.038	-2.1
1986	1.718	-0.049	-2.8	1.720	-0.059	-3.3
1987	1.639	-0.079	-4.6	1.664	-0.056	-3.3
1988	1.644	0.005	0.3	1.626	-0.037	-2.2
1978-88		-0.829	-33.5		-0.891	-35.4
1981-87		-0.374	-18.6		-0.269	-13.9

Source: Calculated based on data in Table 6-2.

Note: kgsce = kilogram standard coal equivalent.
tsce = tonne standard coal equivalent.
-- = not applicable.

TABLE 6-4

COMPOSITION OF ENERGY CONSUMPTION IN CHINA'S IRON AND STEEL INDUSTRY, 1981 AND 1987

	1981			1987		
Energy Forms	Quantity	mtsce	% share	Quantity	mtsce	% share
Electricity	30.15 b kwh	12.7	19.5	46.89 b kwh	19.7	22.5
Coking Coal	38.61 m tonne	34.7	53.5	50.99 m tonne	45.9	52.4
Fuel Coal	15.87 m tonne	11.3	17.4	22.43 m tonne	16.0	18.2
Heavy Oil	3.77 m tonne	5.3	8.1	4.15 m tonne	5.8	6.6
Natural Gas	0.74 b m^3	1.0	1.5	0.73 b m^3	1.0	1.1
Total		65.0	100.0		87.7	100.0

Source: Ministry of Metallurgical Industry. 1986. Statistics of Iron and Steel Industry of China. Beijing: Economic Information and Agency, p. 108. Marc Ross and Liu Feng. 1991. "The Energy Efficiency of The Steel Industry of China." Energy, Vol. 16, No. 5, pp. 833-848.

Note: b = billion, m = billion, m^3 = cubic meters, kwh = kilowatt hours.

blast furnace injecting; electricity for rolling and forging steel, transportation, ferroalloy production, steelmaking in electric arc furnaces, and mineral processing; heavy oil for rolling and forging steel, open hearth furnace injecting; and natural gas for rolling and forging steel (MMI, 1986, pp. 271-274). Converting different energy types into standard coal equivalent, we find that about 71 percent of the energy used in China's iron and steel industry in 1981 came from coking and fuel coal, 20 percent from electricity, 8 percent from heavy oil, and 1 percent from natural gas (Table 6-4).

The magnitude of energy-efficiency improvements varied across individual fuels. Table 6-5 shows the changes in individual fuel intensities in China's iron and steel industry between 1981 and 1987. The energy consumption per RMB of gross output declined by 41 percent for natural gas, 34 percent for heavy oil, 20 percent for coking coal, 14 percent for fuel coal, and 6 percent for electricity. In terms of energy per tonne of crude steel, the energy-saving rate was 37 percent for natural gas, 30 percent for heavy oil, 16 percent for coking coal, 10 percent for fuel coal, and less than 1 percent for electricity. The large efficiency gains in the utilization of heavy oil and natural gas, in part, reflected China's emphasis on saving oil and natural gas and on switching from oil to coal in the 1980s. Some iron and steel

TABLE 6-5

INDIVIDUAL FUEL INTENSITIES IN CHINA'S IRON AND STEEL INDUSTRY, 1981 AND 1987

Fuel Types	Unit	1981	1987	change	% change
		Energy Per Unit of Gross Output			
Electricity	kwh/kRMB	934.71	876.94	-57.77	-6.2
Coking Coal	tonne/kRMB	1.20	0.95	-0.24	-20.3
Fuel Coal	tonne/kRMB	0.49	0.42	-0.07	-14.8
Heavy Oil	tonne/kRMB	0.12	0.08	-0.04	-33.6
Natural Gas	m^3/kRMB	23.03	13.65	-9.38	-40.7
Total	tonne/kRMB	2.01	1.64	-0.37	-18.6
		Energy Per Tonne of Crude Steel			
Electricity	kwh/tonne	897.11	889.92	-7.19	-0.8
Coking Coal	tonne/tonne	1.15	0.97	-0.18	-15.8
Fuel Coal	tonne/tonne	0.47	0.43	-0.05	-9.9
Heavy Oil	tonne/tonne	0.11	0.08	-0.03	-29.8
Natural Gas	m^3/tonne	22.11	13.85	-8.25	-37.3
Total	tonne/tonne	1.93	1.66	-0.27	-13.9

Source: Calculated based on data in Tables 6-2 and 6-4.

Note: m^3 = cubic meters, kwh = kilowatt hours, kRMB = 1000 RMB.

enterprises, for example, had converted their coal-fueled equipment into burning oil in the 1960s and 1970s when China's oil production grew rapidly. As the oil production stagnated and lagged behind the demand growth in the 1980s, the Chinese government ordered those enterprises to reconvert the equipment to burning coal. The government also restricted the manufacturing and installation of oil-burning equipment in all enterprises.

Despite the differential rates of efficiency improvements of individual fuels, the overall fuel mix of China's iron and steel industry changed only slightly between 1981 and 1987. As shown in Table 6-4, the share of electricity and fuel coal increased by 3 percent while that of heavy oil decreased by just over 1 percent. The share of coking coal, fuel coal, and natural gas remained almost unchanged (less than 1 percent difference). This suggests that fuel substitution played little role in energy-efficiency improvements in China's iron and steel industry during 1981-1987.

Energy Efficiencies of Major Processes

Overall energy intensity provides only an aggregated measure of energy efficiency of the iron and steel production. To understand what underlies the changes in the overall energy intensity, we must analyze changes in energy intensities of individual process units, such as coke making, iron making, steel making, and steel rolling. Unfortunately, there is a paucity of data on energy consumption in individual processes of China's iron and steel production. The MMI does release some energy-consumption data by processes in its statistical yearbook of iron and steel industry, but those data are fragmented, incomplete, and not of sufficient detail and/or quality for our study purposes.

Because of data limitations, we have to rely on energy-intensity indicators for major processes in 1980 and 1985, which we obtained from the Economic Development Research Center of the MMI in our 1992 field trip, to infer where the largest energy-efficiency improvements occurred between 1981 and 1987. As shown in Table 6-6, all major processes experienced energy- efficiency improvements during 1981-1987. The rate of improvements was the largest in the OHF and BOF steelmaking and in primary mills. Energy consumption per ton of crude fell by 64 percent and 22 percent, respectively, in BOF and OHF, primarily due to technical renovation and improved operations. Unit energy consumption in primary mills declined by 23 percent, mainly resulting from the introduction of

TABLE 6-6

ENERGY INTENSITY OF MAJOR PROCESSES IN
CHINA'S IRON AND STEEL INDUSTRY, 1980 AND 1985
(kgsce energy per tonne of respective product)

	1980	1985	Change	% Change
Cokemaking	196	183	-13	-6.6
Sintering	95	85	-10	-10.5
Ironmaking	531	514	-17	-3.2
OHF Steel	200	156	-44	-22.0
BOF Steel	107	39	-68	-63.6
EAF Steel	381	325	-56	-14.7
Primary Mill	86	66	-20	-23.3
Steel Rolling	157	152	-5	-3.2

Source: Ministry of Metallurgical Industry.

continuous-casting technology. The magnitude of energy-efficiency increases was relatively small in blast furnace and steel rolling, because China's blast-furnace operations were reasonably good to begin with and because many easy and cost-effective energy conservation potentials in steel rolling had been explored between 1978 and 1980, during which period the energy intensity of steel rolling fell by more than 40 percent (Meng, 1992).

We quantify, in Table 6-7, the amount of energy saved each year between 1981 and 1987, using the following formula:

$$S_t = O_t * (\alpha_t - \alpha_{t-1})$$

where, S_t = amount of energy saving in year t,
O_t = output level in year t, and
α_t, α_{t-1} = energy per unit of output (energy intensity) in years t and t-1.

We make two sets of calculations: one based on gross output and the other based on crude steel production. As shown in Table 6-7, the results from the two calculations are similar for most years. Using crude steel production as the output measure, the annual energy savings averaged 2.2 million tsce or 3.0 percent of total energy consumption in the iron and steel industry in that year. The average annual energy savings estimated based on gross output was slightly higher, 2.5 million tsce or 3.4 percent of the energy consumption in the particular year.

SOURCES OF THE INCREASED ENERGY EFFICIENCY

The dramatic energy-efficiency increases in China's iron and steel industry in the 1980s came primarily from three sources: the readjustment of enterprise structure and product mix, improvements in

TABLE 6-7

QUANTIFICATION OF ENERGY SAVINGS IN
CHINA'S IRON AND STEEL INDUSTRY, 1978-1988

	Based on Gross Output		Based on Crude Steel	
	Million tsce	% of Energy Consumption	Million tsce	% of Energy Consumption
1978	--	--	--	--
1979	-9.28	-12.8	-7.47	-10.3
1980	-4.18	-5.9	-8.42	-11.9
1981	-1.87	-2.9	-3.62	-5.6
1982	-2.57	-3.8	-0.92	-1.4
1983	-2.50	-3.6	-2.15	-3.1
1984	-1.40	-1.9	-1.29	-1.8
1985	-3.05	-3.9	-1.66	-2.1
1986	-2.40	-2.9	-2.88	-3.4
1987	-4.21	-4.8	-2.96	-3.4
1988	0.28	0.3	-2.07	-2.3
Average				
1979-1988	-3.12	-4.2	-3.35	-4.5
1981-1987	-2.57	-3.4	-2.21	-3.0

Source: Calculated from data in Tables 6-2 and 6-3.

Note: -- = not applicable.

energy housekeeping and management, and technical renovation and modernization of production facilities.

Structural Readjustment

China's iron and steel industry consists of a large number of enterprises and plants, employing different vintages of technologies--from the oldest facilities still in use to the newest processes just introduced in the most modern plants--to produce a variety of iron and steel products. One approach the industry adopted to reduce its energy intensity in the 1980s was to increase the utilization of more energy-efficient plants, phase out inefficient small-scale production, and decrease the iron-to-steel ratio in its output mix.

Restructuring of Inefficient Small Enterprises

There were over 1000 small and medium-size iron and steel enterprises scattered throughout the country in the late 1970s and early 1980s (Zhang, 1990). They ranged from specialty mills producing 500,000 tonnes per year of crude steel to very small operations under local jurisdictions producing only pig iron, which was directly sold in the market. Unlike "mini-mills" in the United States that have created serious competition for large-scale integrated steel plants, most of China's small iron and steel enterprises used antiquated equipment and process, had poor maintenance and management, and were very inefficient. Many of the small enterprises were legacies of the Great Leap Forward movement,[9] when steel was viewed as the cornerstone or "key link" for economic development and every locality hurriedly established its own iron and/or steel-making facilities, regardless of profitability, quality, and the demand for the products.[10] They required large amount

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[9] The Great Leap Forward, which led to a great crisis in China's economy, occurred in 1958-1962. The general idea behind the Great Leap was "walking on two legs"--a simultaneous development of agriculture and industry. This was to be achieved by mass mobilization of surplus labor and by relying on labor-intensive small-scale methods of production. To some extent, the Great Leap could be viewed as a Nurkse-Eckaus type of economic development strategy in a somewhat distorted and extreme form (Eckstein, 1975; 1977). Advocates of the Nurkse-Eckaus strategy assume that surplus labor in developing countries could be converted into capital and call for simultaneous pursuit of dual sets of technology in the process of economic development.

[10] The most publicized campaign during this period was so called "All people making iron and steel" movement. Some 60 million persons were mobilized to build more than 1 million small backyard blast

of energy inputs per unit of output but produced low-quality or substandard products.[11]

Between 1978 and the mid-1980s, MMI emphasized production expansion from the key plants and imposed restrictions on the development of small enterprises, as part of a greater effort to carry out the central government's policy of readjusting, restructuring, consolidating, and improving the national economy. A number of the most inefficient plants were closed, merged with larger facilities, or converted into other operations to cut energy consumption and boost profitability. From 1978 to 1982, for example, 330 small iron works with high energy consumption rates and low production efficiency were closed, incorporated, or shifted to other lines of production (Tian, 1983). Another 120 small iron works were streamlined and upgraded technically to make more efficient use of energy. The restructuring program was largely completed in 1984. The total number of iron and steel enterprises declined from 1,820 in 1980 to 920 in 1984 and then rose to 946 in 1985 (Zhang and Xue, 1990, p. 156).

Reduction in the Iron-to-Steel Ratio

As we indicated earlier, one main reason for large specific energy consumption in China's iron and steel production is the high iron/steel

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furnaces using primitive production methods, many of which were closed later because their products had such poor quality that they were unusable.

[11] In some cases, nevertheless, small plant production in iron and steel may offer significant advantages, including reduced transport requirements, use of labor-intensive methods, and--at times--the use of locally available, relatively low-cost energy and raw materials.

ratio. MMI, therefore, saw reducing the iron/steel ratio as an important method to conserve energy and improve energy efficiency of their production activities. Three measures were undertaken. First, MMI restricted production of commercial pig iron (mainly foundry iron) that was directly sold in the market. This measure was related to the small-enterprise restructuring program because small and medium-size enterprises dominated in the production of commercial pig iron and over half of their pig iron produced were not charged to steelmaking furnaces. Many small mills were just iron mills. One by-product of small-plant closing, therefore, was a reduction in the iron-to-steel ratio in the industry's output mix. Second, the industry tried to increase the external scrap fraction--the fraction of metal inputs to steelmaking that comes from external scrap. The use of external scrap generates both energy and cost savings. Where about 1050 kgsce of primary energy per tonne of crude steel may be required at an integrated mill for the entire process, only about 600 kgsce/t is required for the process based on scrap alone (Ross and Liu, 1992). Finally, there was also an effort to increase the yield or productivity in the steelmaking process, which led to a fall in amount of pig-iron input per unit of crude-steel output.

Table 6-8 shows changes in iron output, steel output, and the iron/steel ratio by types of enterprises between 1981 and 1987. Although MMI closed some small businesses, it was not successful in reducing production from small and medium-size plants and accelerating output growth for large, more-efficient enterprises. In fact, key enterprises were losing their output share in both pig iron and crude steel production between 1981 and 1987. Small and medium-size enterprises, on the other hand, increased their pig-iron output share by 5.6 percentage points from 27.2 percent to 32.8 percent and their crude steel share by 4.8 percentage points from 18.4 percent to 23.2 percent. Because key plants used energy more efficiently than small and medium-size plants, it appears that this output-share change actually increased, rather than decreased, overall energy intensity of China's iron and steel industry.

There was a substantial decline in the iron/steel ratio in both key (by 0.025) and small and medium-size enterprises (by 0.068), which was an important source of energy saving. Based on 1987 crude steel output, this decline translated into pig iron savings of about 1 million tonnes in key enterprises and 0.8 million tonnes in small and medium-size enterprises. Considering that it required more than 500 kgsce of energy to produce one tonne of pig iron in the key enterprises and even more energy in small and medium-size enterprises, energy savings from the reduction in iron/steel ratio amounted to almost 1 million tsce. The iron/steel ratio for the entire industry, however, fell by only 0.008 from 1.009 in 1981 to 1.001 in 1987 because of the increasing output share of small and medium-size plants, whose iron/steel ratio was about 1.6 times that of key enterprises. This provides additional evidence that output-share changes increased energy consumption of China's iron and steel industry.

TABLE 6-8

IRON OUTPUT, STEEL OUTPUT, AND IRON/STEEL RATIO BY TYPES OF ENTERPRISES IN CHINA, 1981-1987

	1981	1982	1983	1984	1985	1986	1987
Crude Steel Production							
Output (million tonnes)							
All Enterprises	33.6	35.0	37.4	40.5	43.5	48.9	52.7
Key Enterprises	27.4	28.3	29.7	31.7	33.4	37.9	40.5
Small & Medium	6.2	6.7	7.7	8.8	10.1	10.9	12.2
Distribution (%)							
All Enterprises	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Key Enterprises	81.6	80.9	79.4	78.3	76.9	77.6	76.8
Small & Medium	18.4	19.1	20.6	21.7	23.1	22.4	23.2
Pig Iron Production							
Output (million tonnes)							
All Enterprises	33.9	35.3	37.1	39.6	43.0	48.9	52.8
Key Enterprises	24.7	25.9	26.7	28.1	29.8	33.4	35.4
Small & Medium	9.2	9.4	10.4	11.5	13.2	15.4	17.3
Distribution (%)							
All Enterprises	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Key Enterprises	72.8	73.5	71.9	71.0	69.3	68.4	67.2
Small & Medium	27.2	26.5	28.1	29.0	30.7	31.6	32.8
Iron/Steel Ratio (tonne/tonne)							
All Enterprises	1.009	1.007	0.991	0.977	0.990	1.000	1.001
Key Enterprises	0.901	0.914	0.898	0.885	0.893	0.881	0.876
Small & Medium	1.485	1.400	1.354	1.310	1.311	1.410	1.417

Source: Compiled by the author based on Table 11 in Marc Ross and Liu Feng. 1991. "The Energy Efficiency of the Steel Industry of China." Energy, Vol. 16, No. 5, pp. 833-848.

Improved Energy Management

Prior to 1978, China's iron and steel enterprises were preoccupied with production expansion and paid almost no attention to energy conservation. In fact, many enterprises did not even have information on the amount of energy consumed in different processes and on thermal efficiencies of energy-using equipment (Taylor, 1982). A large quantity of energy was wasted in performing unnecessary or useless tasks, as was exemplified by the phenomenon of "forever-on light" and "forever-flow water" in many enterprises. In the early 1980s, the industry achieved much of its energy-efficiency increase by improving energy housekeeping and management to reduce those energy wastes.

Energy Conservation Programs of the Ministry

In 1979, MMI issued a document specifying energy-efficiency regulations and standards for equipment selection, furnace operation, and energy-saving requirements for heating furnaces in rolling mills. Subsequently, a series of regulations on energy conservation were promulgated for other equipment in steel rolling and for other processes, such as sintering, coking, ironmaking, and steelmaking. The ministry imposed overall energy consumption quotas on large enterprises and required them to lower their energy consumption below the quotas within a certain time period. Beyond that period, enterprises were to must pay higher prices for above-quota energy supply or they had to secure additional energy outside the state-allocation system at even higher prices. The MMI also mandated all large enterprises and some small and medium-size enterprises to establish energy management offices or units. The offices had the primary responsibility of conducting energy audit, implementing energy conservation policies and regulations, preparing energy-saving plans and targets, designing implementation strategy, and diffusing energy-saving technologies.

In addition, progress in energy-conservation work was included as one of the items by which an enterprise was evaluated. In 1986, MMI introduced a unified evaluation system to grade enterprises and their individual processes (e.g., sintering, blast furnace, BO converters, and rolling machine) according to the quality of products, productivity/ profitability, and the consumption of materials per unit of output, especially energy, thus linking energy conservation with the overall performance of enterprises.[12] Four ratings were possible--national special, national first, national second, and provincial advanced--intended to correspond to meeting contemporary international standards, early 1980s international standards, domestic standards, and provincial standards. The rating was not permanent; it could be revised after periodic evaluations. Based on their rating, enterprises received preferential treatment in the granting of loans, export quotas, increased workers' salaries, and bonuses. This rating system thus encouraged enterprises to improve their management performances and product qualities, and, at the same time, made energy conservation an indispensable part of successful management.

The success of Project "55018"--that is, reducing coke ratio to

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[12] This was an implementation of the "Decisions Regarding Problems in Strengthening Management of Industrial Enterprises' Management" passed by the State Council, the highest governing body of China, in 1986.

550 kg/tonne and increasing BF utilization coefficient to 1.8--in Anshan Iron and Steel Company illustrates the effectiveness of enterprise/ process grading system in promoting energy conservation. As the biggest steel producer, Anshan had long been regarded as having the most advanced plants in the country. The result of a blast furnace evaluation in 1986, however, proved otherwise. Of the 9 blast furnaces operated at Anshan, only 1 was rated the national special and the other 8 could not even qualify as the provincial advanced. The Anshan managers were so embarrassed by the result that they immediately launched Project "55018." Twelve comprehensive service groups were organized to help mining and agglomeration units to process and prepare iron ore better and ironmaking units to adjust operations and increase yields. Special subsidies were also provided to encourage miners to improve the run-of-the-mine ore grade. The project was highly successful. During that year, the average utilization coefficient of 9 blast furnaces was increased to 1.78 and the coke ratio was reduced to near 500 kg/tonne.

MMI also facilitated learning from successful projects or enterprises and provided technical assistance. Hanzhou Iron and Steel Mill, for example, was held up as a model for energy conservation in 1983. From 1979 to 1983, the mill reduced its specific energy consumption per tonne of crude steel by 20 percent through improved operations and management, such as better scheduling, shortening shift intervals, and reducing interprocess delivery time (Zhang, 1990; Zhu et al., 1990). Several local agencies of the ministry had teams that provided organized energy conservation services, and some of the research and development institutes under the ministry had set up technical service centers for energy conservation. The ministry promoted 37 energy-saving technologies among key plants in the 1980s, which helped to save large amount of energy. For instance, following the popularization of fine screening and grinding and using low-carbon raw material, China's ore-dressing and sintering plants saved 600,000 tonnes of coke and 700,000 tonnes of standard coal (in terms of fuel) between 1979 and 1982.

Specific Management Measures at the Enterprise Level

In the summer of 1992, we visited six iron and steel companies in China to observe first hand the implementation of China's energy conservation programs at the enterprise level (Polenske and Lin, 1992). The six companies were the Capital Iron and Steel Company in Beijing Municipality; Baoshan Iron and Steel Company, Shanghai No. 5 Iron and Steel Works, Xinhu Iron and Steel Works in Shanghai Municipality; Anshan Iron and Steel Company, and Shenyang Iron and Steel General Works in Liaoning Province. Company managers and staff provided us with some examples of energy management activities.

Energy Audit. In 1979, the MMI organized 32 key steel plants and 58 major medium-size steel plants to construct the energy-balance table, which showed how much and where energy was consumed. Specific energy consumption in different processes was also calculated and shown in the table. Since then, the energy audit has become a routine activity in those enterprises. This made it possible to monitor energy consumption and served as an important information basis for identifying potential areas for energy savings and in drawing long-term, energy-conservation plans.

Worker Training. Several enterprises had periodical worker training sessions to increase energy-conservation awareness and to develop energy-efficient behavior or habits, such as switching off the lights when leaving the room and turning down energy-consuming equipment when it is not in use.

Better Housekeeping. Some of its examples were improved insulation of furnace body, elimination of steam and heat leaks, more thorough and frequent maintenance, inspection to encourage conservation activities, assignment of energy-saving quotas to specific production units, and inclusion of energy-conservation targets in the responsibility contracts.

Improved Operations. This included both measures to improve operations of individual processes and those to improve interprocess delivery conditions. Some examples for the former were (1) high preparation of materials to achieve optimal and stable mix of sinters, limestone, and coke in the blast-furnace operation, (2) better control of the air-fuel ratio in reheating furnaces, and (3) an increased utilization rate of energy-intensive equipment. Examples for the latter included (1) improved ingot hot-delivery temperature, (2) increasing the rate of delivery of hot ingot to soaking pit, (3) increasing the rate of delivery of hot slab or billet to reheating furnace, and (4) shortening the delivery time between processes. As it is apparent from these examples, some energy-efficient operations require a certain amount of capital investment to install add-on equipment.

From an input-output perspective, improved energy management essentially involved increased labor and management inputs to reduce energy inputs. These measures can produce quick results, but the lack of continuous attention may result in reductions or loss of energy savings. During our field visits to six enterprises in 1992, we found that most energy-management measures endured or were only partially reversed in the 1980s. This is not surprising because energy shortages persisted in China throughout 1980s, and the government pushed for energy efficiency continuously. More importantly, many energy-efficiency measures undertaken, such as better equipment maintenance and improved interprocess delivery conditions, were important not only for energy savings but for other management objectives, such as higher productivity and better products. There was an economic incentive, therefore, for enterprises to continue those practices even if energy conservation was not a concern.

Technological Advancement

In addition to the structural readjustment and management improvements, China's iron and steel industry also undertook many capital construction projects in the 1980s to upgrade technology and modernize production facilities. For the period of 1981 to 1987, a total of about 52 billion RMB was spent on fixed capital investment, as shown in Table 6-9. China divides the fixed capital investment into two categories: basic construction and technical renovation. Basic

TABLE 6-9

CAPITAL INVESTMENT IN CHINA'S IRON AND STEEL INDUSTRY, 1981-1987
(million RMB in current prices)

Year	Total	Investment in Capital Construction Amount	Investment in Capital Construction % of Total	Investment in Technical Renovation Amount	Investment in Technical Renovation % of Total
1981	4163	2524	60.6	1639	39.4
1982	5512	3636	66.0	1876	34.0
1983	5374	3302	61.4	2072	38.6
1984	6278	3633	57.9	2645	42.1
1985	7842	3881	49.5	3961	50.5
1986	9232	3768	40.8	5464	59.2
1987	13193	6046	45.8	7147	54.2
1981-87	51594	26790	51.9	24804	48.1

Source: Ministry of Metallurgical Industry. 1991. The Yearbook of Iron and Steel Industry of China, 1991. Beijing: China Metallurgical Industry Press, p. 290.

construction refers to "greenfield" construction[13] of new plants, addition of major production facilities, such as shops or mills, in existing plants, relocation of entire plants, and restoration of plants damaged by natural/human disasters. Technical renovation refers to renovation, transformation, modernization, and technical upgrading of existing plants. It also includes addition of new facilities that removes internal imbalances or expands production within an existing steel complex, in which case the line between basic construction and technical renovation becomes blurred. Between 1981 and 1987, the

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[13] Greenfield construction: constructing new facilities at a new site.

investment share of basic construction decreased from 60.6 percent to 45.8 percent while that of technical renovation increased from 39.4 percent to 54.2 percent, reflecting China's emphasis on production expansion through renovation of existing plants, rather than greenfield construction of new facilities.[14]

There are four main sources of funding for fixed capital investment. They are:

1. **Investment from the State Budget**, which is included in the state investment plan and is funded by appropriations from the budget (both from central and local government budgets according to the unified plan), and bank loans in substitution of budget appropriations.

2. **Domestic Loans**, which include loans from construction banks, industrial and commercial banks, loans from the local budget and other domestic loans.

3. **Foreign Investment**, which refers to investment in domestic projects by utilization of foreign capital (including equipment, materials, and technology).

4. **Self-Raised Funds**, include funds raised by various ministries of the State Council, by provinces, autonomous regions and municipalities, prefectures, counties, and enterprises, and other investment.

For the entire period between 1981 and 1987, about 40 percent of the investments came from enterprises' self-raised funds, 30 percent from foreign loans, 20 percent from the state budget, and 10 percent from domestic loans (MMI, 1986; 1989).

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[14] Expansion of existing facilities is generally less expensive than building new greenfield plants. Brand new capacity costs about $1000 per ton, while brownfield costs average about $500 per ton (Weil, 1985).

Construction of the Baoshan Iron and Steel Complex

A major share of the basic construction investment in the 1980s was spent on the greenfield construction of the Baoshan Iron and Steel Complex in the Wushong District of Shanghai Municipality. Baoshan's coastal location was chosen to facilitate transportation of imported iron ore from Australia and to provide the heavily industrialized Shanghai area with an expanded supply of high-quality steel. The project consists of two phases. The first phase began in December 1978 and was completed and put into production in September 1985. The second phase started in June 1985 and was basically completed in 1991. The total investment cost for the two phases was about 30 billion RMB (approximately US $8 billion), the greatest single investment in any of China's enterprises since the founding of the People's Republic of China in 1949 (Zhang, 1989). Because we are mainly interested in technological changes between 1981 and 1987 in this study, we will focus on the first phase of the project.

There were three main motivations for constructing the Baoshan complex. The first was to increase steel production capacity. Baoshan's designed capacity was 3.2 million tonnes of crude steel for the first phase and 6.7 million tonnes after the second phase, compared with China's annual steel output of about 30-40 million tonnes in the early 1980s. The second motivation was to narrow the technological gap between China and the advanced counties and to bring in much-needed systems planning. Typically, China's enterprises introduce foreign technologies by importing key equipment. This approach has lower costs than importing the entire production lines but does not allow enterprises to have access to knowledge of systems operations, which sometimes can be the most important element of new technology. By constructing the entire plant with imported equipment, the Baoshan project provides an opportunity to understand not only individual equipment, but also the links among different pieces of equipment and the functioning of the whole production process. The third main reason for the construction of the Baoshan complex was to relieve the shortage of high-quality steel, especially seamless tube. Of the 14 most badly needed types of steel in China, seven can be produced by the Baoshan complex.

The Baoshan project, however, did not go smoothly. The project was carried out with the cooperation of Nippon Steel, other Japanese companies, and several German companies. The early contracts had just been signed at the end of 1978 when the Chinese government decided to scale back the capital construction investment and slow down the economic expansion in the country. An inadequate feasibility study led to mutual complaints from the Chinese and the Japanese. The Baoshan's coastal site consists of soft river mud soils so that huge quantities of concrete piling were needed to support the heavy structures of the plant. Then came the necessity to build an entirely new deep water port in Beilun near Ningpo city, which was 130 nautical miles from Baoshan, to unload the iron ore imported from Australia on ships exceeding 100,000 tonnes.[15] In view of the escalating costs, the Chinese government suspended construction in 1980. It was resumed only in

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[15] It was not possible to build the port near Baoshan because of shallow water.

August 1981 after studies had shown that to drop the project could involve far greater losses than to proceed further. The first phase of the project was finally completed in September 1985, three years later than scheduled.

On the positive side, the Baoshan project did successfully incorporate the latest steelmaking technology and produce large quantities of seamless steel products badly needed in China. The Baoshan complex was modeled after Nippon's Kimitsu plant, one of the most modern in the world. Its major equipment was imported from Japan and Germany and ranked among the best in terms of new process, precision, and efficiency. The main facilities constructed in phase I of the project included (Chin and Chin, 1990):

1. one sintering machine of 450 m^2,
2. two large batteries of coke ovens (100 ovens each battery) and chemical plants,
3. one blast furnace of 4063 m^3,
4. two oxygen converters (300 tonne capacity each),
5. two stands diameter 1300 mm blooming mill and one set of billet tandem mill, and
6. one set of diameter 140 mm continuous seamless tube mill.

At an investment cost of about 13 billion RMB (approximately US $ 3 billion), Baoshan's production capacity after the completion of the first phase was annual output of 3 million tonnes of pig iron, 3.2 million tonnes of crude steel, 0.5 million tonnes of seamless steel tube, and 2.1 million tonnes of commercial slabs (Zhang, 1989). This implies a construction cost of about US $1000 per tonne of crude steel capacity, which, is comparable to similar plants around the world.

The Baoshan project had two major impacts on energy-using technology in China's iron and steel industry. First, it improves average energy efficiency of the industry. Specific energy consumption per tonne of crude steel in Baoshan was under 1000 kgsce in 1987, compared with the national average of over 1600 kgsce; therefore, for every tonne of steel produced in Baoshan, there is an energy savings of 600 kgsce. With a production capacity of 3.2 million tonnes crude steel, Baoshan saves the steel industry almost 2 million tsce energy annually. Second, Baoshan serves as an important source of new, advanced technologies for other iron and steel enterprises. In fact, the Baoshan Iron and Steel Technical Cooperation Corporation was founded in 1986 with the sole aim of diffusing Baoshan's advanced technologies, know-how, and management practices. Some principal activities of the corporation are providing technical assistance, publishing teaching materials, running management- training courses, and organizing plant visits. Some managers see a visit to the Baoshan as an alternative to going abroad for a study trip.

Technical Renovation of Existing Plants

Technical renovation is the principle mechanism through which China's enterprises upgrade their production technologies. It covers a wide variety of activities, ranging from merely adding computer control to existing equipment to virtually rebuilding production lines. In some cases, such as the addition of degassing units to a steel-making shop, the purpose is purely quality improvement. In others, the aim is to conserve energy and increase yield, which can entail the addition of extensive new facilities, such as continuous casters to replace soaking pits and preliminary rolling mills. The renovation projects also include such activities as installation of pollution- control equipment, worker-safety measures, solid-waste disposal, effluent-gas treatment, and road repairing.

Motivations for Technical Renovation

Energy conservation is just one of many considerations that led China's iron and steel producers to invest in technical renovation. Table 6-10 shows the breakdown of technical renovation investment by primary purpose of projects in 1983, 1984, and 1985, the three years for which we have data. Capacity expansion was the most important motivation for technical renovation, accounting for some 25-40 percent of the total investment. Projects aiming at improved product quality and variety accounted for another 10-15 percent. The investment share of energy-conservation projects was 12 percent in 1983, 9 percent in 1984, and 8 percent in 1985.

Most capacity-expansion projects involved breaking production bottlenecks. There is a structural imbalance in China's iron and steel industry. Output of iron ore lags behind the needs of the blast furnaces, pig-iron production cannot satisfy the requirements of the steel furnaces, and the steel-finishing sector is unable to process the outflow of crude steel. Because iron and steel production is a continuous process, this imbalance creates bottlenecks and prevents full utilization of production facilities. There were also structural imbalances within enterprises. At Wuhan, for example, the new continuous caster requires more frequent supplies of hot metal than the

TABLE 6-10

TECHNICAL-RENOVATION INVESTMENT BY PURPOSE IN CHINA'S IRON AND STEEL INDUSTRY, 1983-1985

	Investment (RMB million)			Proportion (%)		
	1983	1984	1985	1983	1984	1985
Total Investment	1626	2283	3618	100.0	100.0	100.0
Production Purpose	1344	1922	3151	82.7	84.2	87.1
Resource Savings	235	252	298	14.5	11.0	8.2
Energy Savings	199	198	281	12.2	8.7	7.8
Material Savings	17	16	17	1.1	0.7	0.5
Other Savings						
Capacity Expansion	404	804	1403	24.9	35.2	38.8
Product Quality	114	101	166	7.0	4.4	4.6
Product Variety	101	127	295	6.2	5.6	8.2
Transport and Com.	71	72	0	4.4	0.0	0.0
Labor Safety	40	65	0	2.5	2.9	0.0
Waste Treatments	79	136	196	4.9	6.0	5.4
Others	300	365	794	18.5	16.0	22.0
Non-Production Purpose	282	361	467	17.3	15.8	12.9

Source: Ministry of Metallurgical Industry. 1986. Statistics of Iron and Steel Industry of China, 1986. Beijing: Economic Information and Agency, p. 139.

Note: Transport and Com. = Transportation, Postal Services, and Telecommunications.

open-hearth furnaces can supply, and the new BOFs China added in 1977 are very small. This plant is thus a logical site for a large BOF.

China's iron and steel industry gave high priority to increasing product variety and improving product quality in the 1980s. China's steel-finishing capacity consists primarily of large blooming and structural mills and mainly produces semi-manufactures, such as sections and bars. It cannot satisfy rapidly growing demand for sheet steel, especially cold-rolled metal and surface-treated sheet, tube and pipe, and alloy steel. The demand for thin-rolled sheet, for example, has skyrocketed as China's output of vehicles and consumer durables, such as washing machines and refrigerators, takes off. Consequently, China has to import large amounts of finished steel products. In 1984, for example, China imported an estimated 4 million tonnes of steel sheet, in addition to an estimated 2 million tonnes of thicker plates. This compares to domestic production of 4-5 million tonnes of sheet and strip, and 7-8 million tonnes of plate. China, therefore, placed a great emphasis on increasing its ability to produce a variety of high-quality steel products between 1981 and 1987.

There were two types of energy-conservation projects. The first type aimed at improving equipment and operation conditions. Some examples were (1) modification of burner tips and nozzles to allow more complete burning, (2) reduction of boiler or furnace capacity to match the capacity of other equipment, (3) retrofiting or replacing obsolete and most inefficient energy-consuming equipment, (4) heavy oil emulsification, (5) injection of coal powder into blast furnaces, (6) improved burden preparation of blast furnaces, (6) conversion of oil-fueled boilers/furnaces to coal-fired ones. The second type of project involved introduction of energy saving facilities, such as blast furnace top-pressure turbines, coke-oven gas recovery systems, converter-gas recovery facilities. Generally, energy-conservation projects were small or medium in size. The adoption of fundamental production process like modern blast furnace, EAF, and continuous caster, which had important energy-efficiency implications, were usually motivated by nonenergy considerations, such as output expansion and quality improvement, and were not classified as energy conservation projects.

Focus of Technical Renovation

Table 6-11 shows the allocation of technical renovation investment among different processes or functional areas of iron and steel production between 1981 and 1985.[16] As expected, a large amount of the investment went to raw material preparation and steel finishing, two major bottlenecks in China's iron and steel industry. About 14 percent of the total investment funds during 1981-1987 was spent on mining, ore dressing, and agglomeration, and 19 percent was spent on steel rolling and forging. Other major areas of investment were metal smelting (14 percent), which included ironmaking and steelmaking, and residential buildings (9 percent), which were considered as nonproductive investment.

Raw Material Preparation. The renovation activities in this area focused on increasing mining capabilities and improving material quality. Efforts were made to expand existing mines and to increase the amount of pelletized ore from the estimated level of less than 10 percent in the early 1980s.

Blast Furnaces. Most renovation projects in ironmaking involved enlarging existing BFs, construction of large modernized BFs to replace old, small ones, addition of automatic charging systems, and the gradual

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[16] We do not have data for 1986 and 1987.

TABLE 6-11

DISTRIBUTION OF TECHNICAL RENOVATION INVESTMENT IN CHINA'S IRON AND STEEL INDUSTRY, 1981-1985

	1981	1982	1983	1984	1985	81-85
	Amount (Million RMB in Current Prices)					
Total Investment	1639	1876	2072	2645	3961	12193
	Distribution (Percent of the Total)					
All Investment	100.0	100.0	100.0	100.0	100.0	100.0
Mining & Ore Dressing	14.2	13.2	11.9	11.0	10.8	11.9
Agglomeration	2.4	2.9	2.5	2.1	2.1	2.3
Metal Smelting	10.7	11.8	12.6	16.4	17.3	14.6
Rolling and Forging	21.0	19.3	15.5	18.6	18.5	18.5
Ferroalloy	1.0	1.3	1.3	1.4	1.9	1.5
Coke, R & C Products	3.4	4.9	5.0	4.5	4.4	4.5
Comp. Util. & Env. P.	7.1	6.3	7.2	7.2	5.1	6.4
Maintenance & Power	7.9	6.9	6.9	6.4	6.5	6.8
Transportation	3.8	4.0	4.9	4.7	5.0	4.6
Residential Buildings	0.0	10.7	11.3	16.4	6.6	9.3
Others	28.6	18.8	20.8	11.3	21.8	19.8

Source: Ministry of Metallurgical Industry. 1986. Statistics of Iron and Steel Industry of China, 1986. Beijing: Economic Information and Agency, p. 118

Note: Coke, R & C Products = Coking, Refractory, and Carbon Products.
Comp. Util. & Env. P. = Comprehensive Utilization and Environmental Protection.

replacement of furnaces without bell-less tops with those that have bell-less tops. During our field visit in China in 1991, we came across several instances of:

- enlarging the size of existing blast furnaces,
- improving the technical parameters such as blast temperature, stoves and charging system, and
- introducing and increasing the use of powder coal injection.

Steelmaking Furnaces. The top priority here was to modify or phase out obsolete open-hearth furnaces and side-blown converters using turn-of-the century technology, which produced, respectively, some 31 percent and 7 percent of China's crude steel in 1981. Two methods were widely used to renovate OHF: one was to add oxygen lances to decrease heat time, and the other a variant of the BOF in which oxygen was blown in the bottom rather than the top of the furnace.

Another priority area was to increase BOF steel production by upgrading/stretching existing furnaces and constructing new ones. China had invested in some of the latest refinements to basic oxygen furnace technology. The Anshan, together with Shanghai's No. 5 mill, purchased from Sumitomo Metal (Japan) the know-how to install China's first BOF bottom argon-injection system in 1985, which decreased heat time and increased yield. Even the Baoshan Iron and Steel Company did not have this technology.

China also placed great emphasis on improving EAFs and expanding their production, which was crucial to China's drive to produce more and better alloy steel. Several special steel plants, for example, had installed argon-oxygen decarbonization (AOD) furnace to purify steel that emerges from the electric furnace.

Steel Finishing. Because steel finishing was one of the weakest areas in China's iron and steel technology, imported equipment and technology played a critical role in its renovation process. China imported a number of new or second-hand rolling facilities to upgrade old mills and to build entirely new mills. The emphasis was on introduction of modern control systems, such as controlled cooling, automatic gauge control, inline computers for process control, and computerization of operations, to increase yield and enhance product quality and variety.

China also invested heavily on continuous casting process, which makes it possible to caste semi-finished steel products directly out of a steel making furnace, without intermediate cooling and reheating steps. The process increases the yield from liquid steel to finished steel significantly (by about 8-10 per cent) and reduces the energy requirements per tonne of steel. It also improves steel quality and leads to possible linkages between steelmaking, and hot rolling in tandem.

Sources of Improved Technologies

China's iron and steel industry improved its production processes and facilities through a combination of domestic research and development and imports of key equipment and technical know how. The renovation of the hot rolling strip mill in Anshan Complex provides a good example. The original mill, designed and supplied by the Soviet Union in the 1950s, had a production capacity of 0.8 million tonne per year. With key control equipment and technical assistance from West Germany, Anshan upgraded the mill in the mid-1980s and increased its capacity to 2.5 million tonnes per year. The renovated mill had an online computer, an automatic gauge control from West Germany and a water curtain cooling system of its own design. Sometimes the technological import was critical to the success of the renovation project. The Benxi complex, for instance, designed and built a hot strip mill in the 1970s based on published materials from the West that did not discuss certain critical types of equipment and know-how. In order to make the mill run, the complex signed a contract with a German group in 1985 to fill the missing parts.

Many Chinese enterprises acquired foreign technologies by purchasing used equipment to reduce investment costs. Indeed, China received some great bargains, partly because of the restructuring and reorganization of the American and European steel industries. A good example was the agreement between Capital Iron and Steel and the Belgian giant Cockerill. Cockerill constructed a new wire-rod mill with 1.2 million tonnes per year capacity for its Walfield complex just before the world steel industry went into deep recession in the late 1970s and decided to shut it down in the early 1980s as a part of restructuring program. Capital Iron and Steel purchased the mill along with 2.5 million tonne per year of upstream steel-making capacity at a price of $28 million, which was about one-seventh of the construction costs Cockerill incurred. Overall, China was relatively successful in relocating foreign equipment and facilities. It took the Anshan complex, for example, less than 20 months to dismantle, transport, assemble, and recommission a 0.5 million tonne per year second-hand mill from the Fairless Works of U.S. Steel, which started operation in 1987.

Technical renovation projects, combined with improved technologies embodied in new production facilities from the basic construction projects, raised the technological level of China's iron and steel industry significantly. Several indicators in Table 6-12 illustrate the pace of technological progress during 1981-1987. In iron making, the utilization coefficient of blast furnaces increased by 21.8 percent from 1.47 to 1.79 tonne/m^3.day, and labor productivity rose by 34.3 percent. In steel making, the output share of out-dated OHF and side-blown converters declined by 8.7 percent and 5.1 percent, respectively. In steel finishing, continuous casting ratio increased from 7.1 percent to 12.9 percent. This technological progress was a major contributor to improved energy efficiency in China's iron and steel industry between 1981 and 1987.

CONCLUSION

China's iron and steel industry increased its energy efficiency significantly in the 1980s. Between 1981 and 1987, the industry reduced energy consumption per tonne of crude steel by an average annual rate of about 3 percent, saving more than 2 million tsce of energy a year. These energy savings came from three main sources: (1) the reduction in the iron/steel ratio, (2) improved energy management, and (3) technological progress. Quantifying the exact amount of saving from each source is difficult because they were overlapping activities and occurred simultaneously. For example, one way to reduce the iron/steel

TABLE 6-12

SOME INDICATORS OF TECHNOLOGICAL LEVEL OF CHINA'S IRON AND STEEL INDUSTRY, 1981 AND 1987

Indicator	Unit	1981	1987	change	%change
Ironmaking					
Util. Coefficient	tonne/m^3.day	1.47	1.79	0.3	21.8
Coke Ratio	kg/tonne	540	506	-34.0	-6.3
Labor Productivity	tonne/person.year	1225	1645	420.0	34.3
Steemaking					
Output By Process					
OHF	%	31.4	22.7	-8.7	-27.7
EAF	%	18.4	20.4	2.0	10.7
BOF	%	50.1	56.9	6.7	13.5
T-B Converter	%	43.0	54.9	11.9	27.7
S-B Converter	%	7.1	2.0	-5.1	-71.8
Util. Coefficient					
OHF	tonne/m^2.day	8.3	11.5	3.2	39.0
EAF	tonne/10^{6}VA.day	16.0	17.2	1.2	7.1
T-B Converter	tonne/tonne.day	16.3	20.6	4.3	26.5
Steel Finishing					
C. C. Ratio	%	7.1	12.9	5.8	81.7
Yield	%	75.0	77.9	2.9	3.9
Product Complexity	%	29.7	39.2	9.5	32.0

Source: Ministry of Metallurgical Industry. 1989. The Yearbook of Iron and Steel Industry of China, 1989. Beijing: China Metallurgical Industry Press, pp. 188-205.

ratio was to change the production process from OHF to EAF. Introduction of new equipment and process was often accompanied by changes in operation as well. Some energy-efficient measures, such as better control of the air-fuel ratio in reheating furnaces, may require installation of additional equipment (e.g., a computer).

It is possible, however, to make a rough estimate of the relative contribution of the three sources. One such estimate has been done by researchers from MMI and the Energy Research Institute (ERI) of the State Planning Committee. Based on data from 1981 to 1985, the researchers conclude that about 46-50 percent of the energy saving came from improved management, 27-29 percent from the reduction in the iron/steel ratio, and 23-25 percent from technological progress. These numbers probably overstate the importance of the reduction in iron/steel ratio and the improved management and underestimate the contribution of technological changes, especially when 1986 and 1987 are included. First, most iron and steel reduction occurred prior to 1984 and had, in fact, increased slightly since that year. Second, one major reason for the reduction in iron/steel ratio was the increase in steel yield due to improved technology and the expansion in EAF capacity as a result of technical renovation. Third, there is some evidence that while improved management played the dominant role in the early 1980s, technological changes became increasingly important since the mid-1980s because most low-cost management measures had been implemented by then.

We can make some adjustment of the numbers estimated by MMI and ERI researchers to arrive at a more reasonable estimate. Let us begin with lower-bound values for the improved management (46 percent) and iron/steel ratio (27 percent). If we assume that the contribution of the management measures are over-estimated by 5 percent and that of the iron/steel ratio, by 10 percent, the adjusted numbers for them will be 44 percent and 24 percent, respectively. The remaining 32 percent of the energy savings can be attributed to technological progress. The new distribution then becomes: 44 percent from improved management, 32 percent from technological progress, and 24 percent from the reduction in the iron/steel ratio. This gives us some idea on the order-of-magnitude of the relative contribution of the three sources to energy-efficiency improvements between 1981 and 1987.

Four factors largely explain the remarkable success of energy conservation activities in China's iron and steel industry in the 1980s. First, the original energy efficiency of the industry was very low due primarily to poor management, obsolete technologies, and irrational product/enterprise structure. There were large potentials for energy saving, many of which could be realized just by tightening-up energy use or cutting-down apparent waste without major capital investment. This is one reason why improved energy management played such an important role in the energy-efficiency improvement in the 1980s.

Second, energy-conservation activities were linked to greater efforts to improve overall economic efficiency and to modernize the industry. This is important because energy costs are just one of many factors managers consider in choosing production technologies and factor inputs. Our analyses indicate that much of the energy-efficiency improvement was not the result of direct efforts to reduce energy consumption, but of indirectly pursuing other economic goals, such as capacity expansion, improved product quality and variety, and increased yield of materials. For example, the structural readjustment program implemented by MMI was part of a larger effort of "readjusting, restructuring, consolidating, and improving" the national economy. Many energy-efficient operations were adopted because they not only saved energy, but also increased equipment utilization and enhanced productivity. The primary motivations for many technical renovation projects were product expansion and improved product quality and variety, but these projects often had side benefits with respect to energy efficiency.

Third, MMI did not just set energy-conservation requirements. It also helped enterprises to meet those requirements through such activities as organizing energy-conservation services, providing technical assistance, promoting cost-effective energy saving technologies, and facilitating technology transfer and information exchanges among enterprises. Most managers would agree that improved energy efficiency is desirable. What they want to know is how this can be achieved in the most cost-effective fashion without negatively affecting other, often more important, objectives of the company, such as profitability and product quality. Access to information and technologies, therefore, is a key to the success of an energy-conservation program.

Finally, there were several favorable macroeconomic and technological conditions for energy conservation. As the real GDP grew at an average rate of about 10 percent a year, the demand for steel products in China was rising rapidly. Growing demand induced the iron and steel industry to expand existing facilities and/or build entirely new facilities, which provided many opportunities to introduce energy-saving technologies. Furthermore, China's steel industry upgraded its technologies in the 1980s primarily by technology transfer from advanced plants to less-efficient ones and by adopting technological advances already pioneered abroad. The stagnation and restructuring of the steel industry in developed countries in the 1980s allowed China to import second-hand equipment or facilities at relatively low costs. Energy-conservation activities in China's iron and steel industry between 1981 and 1987, partly by design and partly by coincidence, appeared to be the right projects implemented in the right place at the right time.

CHAPTER 7

SUMMARY AND CONCLUSION

"To live is to transform energy" (Hooker et al., 1984, p. 3). Energy plays a critical role in the modern society. It is a necessity in our daily life, helping cook our food, lighting our houses, powering our appliances, keeping us warm in the winter and cool in the summer, and fueling our vehicles. It is also a fundamental input to the economy, essential for growing crops, mining ores, manufacturing products, transporting output, constructing facilities, and delivering services (OTA, 1990). Almost everything a consumer buys in the formal market nowadays requires, directly or indirectly, some energy to produce (Slesser, 1978).

The consumption of energy, however, has costs as well. These include the capital, labor, and natural resources devoted to obtaining energy--and hence not available for other purposes--and the negative environmental and sociopolitical impacts of energy supply and use (Holdren, 1992). Many analysts believe that the costs of supplying and consuming energy have been increasing since the 1970s and that the world is embarked on a transition to costlier energy, as pointed out by Holdren (1992, p. 1).

> Civilization is not running out of energy resources in any absolute sense, nor running out of technological options for transforming energy resources into the forms our patterns of energy use require. What is running out, rather, is the capacity to expand energy supply at low cost--a capacity which was fundamental to the growth of material wealth in today's industrial nations and which had been the basis of expectations that today's less developed countries would be able to follow a similar path to prosperity.

One way to cope with higher energy costs is energy conservation--improving energy efficiency and reducing the amount of energy required to provide goods and services. Technological advancements and management innovations have generated large potentials for energy-efficiency improvements in both industrialized and developing countries. It is difficult, however, to determine how much of these potentials will be or can be actually realized and how soon because there are many economic, institutional, informational, and technological barriers to energy efficiency. Energy conservation, often viewed as an easy "soft path," is, in fact, a difficult and complex path. It involves all sectors of the economy and requires a strong societal commitment (Polenske and Lin, 1993).

Assessing energy-conservation experiences in the past will help us to understand how far energy efficiency can be pushed and where the push needs to be the hardest (Schipper and Meyers, 1992, p. 337). In this study, we examined energy-use changes and energy-conservation activities in China in the 1980s. China has reduced energy intensity of its economy significantly since the late 1980s. Between 1981 and 1987, for example, China's real GDP (in 1981 constant producer prices) increased by 84 percent from 481 billion RMB to 886 billion RMB. This increase in final economic output was accompanied by a far less-than-proportional increase in energy inputs. Total primary energy consumption in China grew by only 43 percent from 611 million tsce to 874 million tsce during the same period. As a result, the energy intensity of China's economy, measured in terms of energy-to-GDP ratio, declined by 22 percent from 1270 gsce/RMB in 1981 to 986 gsce/RMB in 1987. The purpose of this study is to examine how this decline was achieved and determine major sources of energy savings.

The decline in China's energy intensity in the 1980s was an interesting phenomenon to study because it was in contrast with the overall trend towards higher energy intensity in many developing countries at similar stages of economic development. The result of this study should be useful for policymakers in assessing energy consequences of alternative development strategies and in designing energy-conservation policies in developing countries. It should also improve our understanding of China's energy uses, which is important for global energy demand projections and environmental modeling. China is the world's third largest commercial energy consumer and a major air polluter. Driven by the large and rapidly growing economy, China's energy consumption and its associated environmental pollution are likely to increase significantly in the next few decades. According to one estimate, China may account for as much as one-third of the global increase in commercial energy consumption between 1990 and 2020 (Manne and Schrattenhlzer, 1989). China's energy future will profoundly influence the world's energy system during the next century.

We studied China's energy-use changes from 1981 to 1987 within the general framework of a structural-decomposition analysis (SDA). We viewed the amount of energy required in the economy as a function of final demand (what final goods and services people consume) and production technology (how those goods and services are produced). Energy consumption of China's economy, for example, will increase if consumers purchase more final goods and services or if they shift their spending pattern from less energy-intensive products, such as services, to more energy-intensive ones, such as durable manufacturing goods, everything else being equal. This increase, however, may be moderated or counterbalanced by the introduction of alternative production technologies that reduce the amount of energy input used to produce final goods and services. The SDA was placed into a broad context of China's economic-reform program and changes in macroeconomic policies in the 1980s and was complemented with a case study of energy-efficiency improvements in the iron and steel industry. There are many methods and models available for examining energy-use changes, each with strengths and weaknesses. The question, therefore, is not which method or model is the best one, but which one sheds the most light on which problem. We believe that one key to a good energy-policy analysis is to match approaches to the task at hand and to mix different methods and models as needed.

SUMMARY OF RESEARCH FINDINGS

Before summarizing our findings, we need to point out two important caveats associated with this effort to analyze China's energy-use changes from 1981 to 1987. First, although we were using probably the best available energy input-output tables for our SDA modeling, the quality of China's energy and economic data for the study period, on which the tables were based, were generally poor. The data limitations may cause inaccuracies or even errors in our analyses. Thus, the numbers we present here should be interpreted as an indication of a general pattern of energy-use changes rather than as an exact estimate of different contributing components. Second, we can only conduct the SDA at a highly aggregated 18-sector level because of lack of data. This level of aggregation is too high to capture some important changes in specific industries and specific production processes. We must take this into consideration when we discuss the changes in the production technology and final-demand pattern and distribution.

With those caveats in mind, we summarize, in Table 7-1, the results from our SDA modeling of China's energy-use changes. Between 1981 and 1987, China's total primary energy consumption increased by 263 million tsce or 43 percent. Final-demand shifts--the increase in the level of economic activities and shifts in spending mix towards more energy intensive products--were the major factor pushing the energy use upward. Everything else being equal, they would increase the energy consumption by 487 million tsce or 80 percent. This upward pressure on energy demand, however, was dampened by changes in production technology, which reduced energy requirements per unit of goods and services. Holding all other factors constant, production-technology changes would decrease the energy use by 224 million tsce or 37 percent.

The 487 million tsce energy-use increase (80 percent of the 1981 total energy consumption) associated with final-demand shifts was the result of offsetting factors. The growth in the GDP--the level of total final demand--caused energy use to increase by 515 million tsce or 84 percent from 1981 to 1987. The shift in spending pattern, that is, the mix of goods and services purchased by final-demand sectors, resulted in an additional 8 million tsce or 1 percent increase in energy use. These

TABLE 7-1

STRUCTURAL DECOMPOSITION ANALYSIS ON CHINA'S ENERGY-USE CHANGES FROM 1981 TO 1987

(million tonnes standard coal equivalent)

Source	Amount (million tsce)	Percent (% of the 1981 use)
Actual Change	263	43
Final-Demand Shift	487	80
Level Effect	515	84
Distribution Effect	-36	-6
Pattern Effect	8	1
Production-Tech. Change	-224	-37
Energy Inputs	-277	-45
Nonenergy Inputs	54	9

Source: SDA Modeling and Computations.
Note: Numbers may not add to totals or subtotals due to rounding.

increases were moderated by 36 million tsce or 6 percent decrease in energy use stemming from changing the distribution of the GDP among different final-demand sectors.

All of the energy saving attributable to production-technology changes came from energy-efficiency improvements or changes in the use of energy inputs. Holding all other factors constant, energy-efficiency improvements (energy-inputs component in Table 7-1) would reduce energy use by 277 million tsce or 45 percent from 1981 to 1987. The changes in the use of nonenergy inputs, however, led to a higher energy use and cut the energy saving from the efficiency improvements by 54 million tsce (9 percent of the 1981 total energy consumption). On balance, production-technology changes from 1981 to 1987 resulted in a total energy saving of 224 million tsce or 37 percent of the 1981 total energy consumption.

Many researchers who study China's energy-intensity changes in the 1980s distinguish between energy savings from structural changes or sectoral shifts and those due to energy-efficiency improvements. We can rearrange and add different components of the SDA to conform with this convention. The structural-change factor equals the sum of the energy-use changes associated with nonenergy-input changes and with final-demand distribution and pattern effects. The energy-efficiency factor is equivalent to changes in energy inputs. When measured this way, we find that all of the energy savings in China in 1987 relative to 1987 can be attributed to energy-efficiency improvements. The structural changes from 1981 to 1987 would result in a slight increase, rather than decrease, in China's energy intensity.

We identified three macroeconomic factors that appeared to be primarily responsible for the energy-efficiency increases in China's economy between 1981 and 1987: (1) energy-conservation programs, (2) improvements in macroeconomic performance, and (3) increases in energy prices. First, the improvements in energy efficiency were a result of China's energy-conservation programs. There has been a major shift in energy policy since 1979 from conventional complete devotion to increasing supply to the one placing equal emphasis on supply expansion and energy conservation with priority given to conservation in the short run. The government adopted a large number of administrative, financial, and economic measures in the 1980s to reduce energy waste and promote energy efficiency in the industrial sectors, especially energy-intensive heavy industries. Overall, those measures were highly successful and resulted in large energy savings, in part, because China had used energy very inefficiently. There were large potentials for energy saving, many of which could be realized just by tightening-up energy use or reducing apparent waste without major capital investment.

Second, the improvements in energy efficiency were also a by-product of China's rapid economic growth and part of the overall trend towards higher productivity in the 1980s, as a result of China's economic-reform program which reduces central planning and increases the role of the market mechanism and incentive structures in the economy. China's rapid economic growth in the 1980s was accompanied by an expansion in production capacities and addition of new equipment and facilities, which usually embodied better technology and had higher energy efficiencies than old existing capital equipment. More importantly, many measures that were aimed at increasing productivity and profitability also helped to save energy. For example, worker training to improve equipment operations enhanced both productivity and energy efficiency. The introduction of a modern, large-scale blast furnace resulted in an increase in production capacity as well as a decrease in the coke rate. When business firms shifted from making low value-added products to high value-added ones, they not only increased profits, but also reduced energy per unit of output.

Third, the improvements in energy efficiency were an enterprise's rational response to energy-price increases. The Chinese government raised planned energy prices substantially in the 1980s. The government also introduced a dual-price system into the energy sector, which allows energy products to be exchanged at two different prices: a state-set price, for the amount produced under central planning, and a higher free-market price, for above-plan-output. These energy-price increases provided some incentives for enterprises to reduce energy waste and improve efficiency of energy utilization. We argue, however, that the incentives were limited because despite the energy-price increases, energy expenditures comprised a very small percentage of the total production cost in most sectors in the 1980s and were not that important in the overall scheme of production.

We conducted a case study of energy-efficiency improvements in the iron and steel industry, one of the largest energy consumers in China, to complement our macro-level SDA of production-technology changes and to determine what enterprises actually did to reduce energy-input requirements. We found that energy-efficiency gains achieved by iron and steel enterprises came from three main sources: (1) improved energy management, (2) technological progress, and, to a lesser extent, (3) a reduction in iron/steel ratio. We also found that very often the improvements in energy management and the introduction of energy-saving technologies were not the result of direct efforts to reduce energy consumption or costs, but of indirectly pursuing other economic goals like capacity expansion, improved product quality and variety, and increased yield of materials. For example, many energy-efficient operations were adopted because they not only saved energy but also increased equipment utilization and enhanced productivity. The primary motivations for many technical-renovation projects were product expansion and improved product quality and variety, but these projects often had side benefits on energy efficiency. Indeed, one main reason for the remarkable success of energy-conservation activities in China's iron and steel industry in the 1980s was that those activities were pursued jointly with other economic objectives and linked to greater efforts to improve overall economic efficiency and modernize the industry.

POLICY IMPLICATIONS

A key lesson from our study of China's energy-use changes between 1981 and 1987 is that energy problems are closely connected to broader issues of social and economic development. The energy intensity of an economy is not just a function of energy prices or a result of energy-cost minimization calculus. Rather, it is the cumulative product of millions of decisions made by consumers on how much and where to spend their money and by producers on how to combine energy and other inputs to provide the goods and services that consumers demand. Those decisions affect the level and mix of different types of economic activities, which ultimately determine the energy requirement of the economy and the nation's aggregate demand for energy.

This has four principal implications for energy-conservation policies. First, policymakers should not pursue energy efficiency in isolation from other economic objectives. Energy is just one factor of production, and energy costs, which rarely comprise more than 5 percent of total production costs, are only one of many factors managers consider in choosing production technologies and factor inputs. Energy conservation measures, for example, may not be undertaken if managers believe that the measures are likely to interfere with production or reduce profitability. In promoting energy conservation, policymakers, therefore, need to look not only at cost impacts but also at other motivations for technological and managerial changes, such as expanding production, increasing productivity, improving product quality, enhancing flexibility, and so on. They need to discover the synergism between energy efficiency and those other economic objectives, strengthen the synergism when possible, and link energy-conservation activities with greater efforts to improve overall economic efficiency.

Second, in designing energy-conservation strategies, policymakers should explore not only conservation opportunities in direct consumption of energy products but also indirect energy savings from a more efficient use of nonenergy products. We estimated that only 10 percent of the demand-related energy use increases in China between 1981 and 1987 can be attributable to the purchases of energy by final customers and the other 90 percent was due to the purchases of nonenergy products. In fact, the main factor increasing energy consumption in China's economy from 1981 to 1987 was the expenditures on light-industry goods and construction projects, not the direct purchases of energy products. This underscores the importance of going beyond energy products in promoting energy conservation. Some activities that have no apparent relationship to energy, such as recycling of scrap, conservation of nonenergy products, and increased product durability, may have an enormous impact on energy consumption. "An even better solution [for saving energy] than using energy efficiently is not using it at all" (Ross and Steinmeyer, 1990, p. 89).

Third, policymakers should recognize that not all energy-saving opportunities are equal and that the energy-efficiency increases in some sectors are more important than those in others. Through intersectoral input-output linkages, the energy-efficiency improvements of any one production sector will be multiplied across the entire economy by reducing the indirect energy requirements of those sectors that use the sector's product as inputs, thus generating energy savings that are greater than those obtained from each sector in isolation. Because of the differences in intersectoral linkages, the same magnitude of energy-efficiency improvements in different sectors may have a very different impact on total energy consumption of the macroeconomy. To achieve a maximum return to energy-conservation efforts, policymakers should give priority to those sectors whose energy-efficiency improvements, through interindustry linkages, will result in the largest total energy savings. In fact, one reason for the success of China's energy-conservation programs in the 1980s was that those programs focused mainly on heavy industry, which generated large energy-savings multiplier effects.

Finally, there is no single, one-size-fits-all answer to the question of how to achieve energy efficiency. The potential for and barriers to energy-efficiency improvements vary widely from sector to sector and may change over time. Furthermore, the adoption and operation of energy technologies are constrained by macroeconomic and resource conditions and are embedded within an institutional context, which provides both incentives and disincentives for energy-use decisionmakers. An effective strategy, therefore, must be based on diagnosis--understanding the context of energy-use decisionmaking, identifying causes of energy inefficiency or wastes, and then carefully designing strategies to overcome those causes. To some extent, building an energy-conservation strategy is like the process of healing.

> Unlike the faith-healer, whose cures are believed to be comprehensively beneficial, the expert healer . . . must identify what he is dealing with: he must size up the situation, distinguish one illness from another and recognize what its susceptibilities are likely to be. He looks for causes and tries to treat them (Miller, 1978, p. 58).

Diagnosis is not performed just once. It is a continuous process, repeated when energy, economic, and institutional conditions change, used as a device to monitor effectiveness of energy-conservation measures that are implemented, and serves as a basis for shifts in the direction and emphasis of the energy conservation strategy.

AGENDA FOR FUTURE RESEARCH

We have emphasized throughout this research that there are many methods and models available for examining energy-use changes, each with strengths and weaknesses, and an SDA is just one of them. Like taking the picture from different angles and distance, the SDA modeling allows us to see some aspects of energy-use changes that we would never had noticed from other approaches. It also, however, blocks our view on some other aspects of the relationship between energy use and economic activities, which may be very clear from other angles and distances. Furthermore, the breadth and depth of our SDA was limited because of poor data and insufficient information. In order to obtain a complete picture of energy-economy dynamics in China, we need, therefore, to expand our analyses by using more and better data and by complementing the SDA with other types of studies, such as econometric modeling, behavior studies, and institutional analyses. Here, we suggest two areas for immediate future research.

> 1. **SDA of Energy-Use Changes from 1987 to 1992.** The Balance Division of the State Statistical Bureau of China (SSB) is currently compiling the national 1992 input-output table, which is scheduled to be completed in early 1995. The 1992 table will adopt the same accounting convention (System of National Accounts) and have the same industrial classification system (over 100 production sectors) as the 1987 input-output table. The compilation of the 1992 table, combined with the expanded prices and energy data collected by SSB in recent years, will allow analysts to implement the SDA model for the period from 1987 to 1992 at a rather disaggregated level of industrial classification.
>
> 2. **Case Studies of Energy-Efficiency Improvements.** Because most of the energy savings between 1981 and 1987 came from energy-efficiency improvements, it is necessary to conduct more case studies of energy-use changes in individual production sectors, like the one we did on the iron and steel industry, to assess the working of energy-conservation programs and examine what enterprises actually do to conserve energy. The case studies should cover at least the following questions: (1) What are the primary reasons or motivations for energy conservation? (2) What measures does the industry take to conserve energy? (3) How effective are each of the energy-conservation measures? (4) How do those measures affect output, production costs, product quality, and productivity?

There are many other ways in which this research can be extended. In fact, extensions are possible for each component of final-demand shifts and production-technology changes and for each of the individual final-demand categories and production sectors. For example, we can perform a close analysis of investment and household-consumption behavior and examine their relationships with energy consumption. We can study the energy implications of changes in the level and composition of the imports and exports. We can also apply a production-function approach to identify underlying determinants of the input structure for China's economy as a whole and/or for individual production sectors, which will shed light on changes in energy-input requirements.

Obviously, much more empirical work needs to be done before the relationship between energy consumption and economic development in China can be fully understood. This research is just one step in what may be a thousand-mile journey. We hope that our study has improved the empirical and methodological foundation upon which to conduct further research and will contribute to the formation and implementation of a sustainable energy strategy in China, whose economy is one of the largest and fastest-growing in the world.

APPENDIX 1

CHINA ENERGY INPUT-OUTPUT TRANSACTIONS TABLE, 1981

		Intermediate Demand									
	Producing Sectors	1	2	3	*	4	5	6	7	8	9
	(1000 tonnes of standard coal equivalent)										
1	Coal	10089	561	36	0	85684	11295	60996	4153	34687	12492
2	Petroleum	943	10276	209	0	24313	11316	7786	1038	5290	17311
3	Natural Gas	0	2328	4668	0	80	0	1045	45	4319	1773
*	Hydropower	0	0	0	0	26677	0	0	0	0	0
4	Electricity	2178	1029	37	0	5663	3461	3260	2278	3764	3497
	(million RMB in 1981 producer prices)										
5	Agriculture	140	158	13	0	20	33768	67	28	30	2267
6	Iron and Steel	570	548	57	0	54	171	8828	193	99	104
7	Nonferrous Metals	27	31	1	0	10	5	638	4478	56	317
8	Chemical Fertilizers	0	0	0	0	0	13340	0	0	1110	158
9	Heavy Chemicals	335	870	14	0	19	3822	139	191	438	5951
10	Cement	120	92	11	0	5	16	25	22	2	2
11	Construction Materials	134	193	15	0	10	21	481	151	29	26
12	Heavy Machinery	1241	719	65	0	512	395	2029	420	94	106
13	Light Industry	1821	726	65	0	97	5794	726	885	1293	2452
14	Construction	0	0	0	0	0	0	0	0	0	0
15	Freight & Communication	256	618	9	0	625	902	1667	253	313	570
16	Passenger Transport	31	15	1	0	29	275	26	20	16	55
17	Commerce	215	1574	45	0	493	1466	477	401	363	815
18	Services	154	83	9	0	73	1793	312	150	99	388
	Value Added	9607	14720	692	0	13375	148347	11072	3530	3912	10495
	Total Inputs	16649	26826	1066	0	19310	211921	30696	12472	12523	26460

APPENDIX 1 (continued)

	Producing Sectors	Intermediate Demand									
		10	11	12	13	14	15	16	17	18	Subtotal (1-18)
	(1000 tonnes of standard coal equivalent)										
1	Coal	23106	17639	21637	48231	2710	12640	2302	3753	7956	359966
2	Petroleum	1023	2737	3893	11034	2469	10580	1862	503	6379	118962
3	Natural Gas	10	70	638	838	665	80	13	0	80	16652
*	Hydropower	0	0	0	0	0	0	0	0	0	26677
4	Electricity	746	658	2845	5071	573	304	54	235	907	36559
	(million RMB in 1981 producer prices)										
5	Agriculture	43	601	804	68646	3670	10	0	1328	869	112463
6	Iron and Steel	762	42	9064	5498	6394	165	35	48	371	33005
7	Nonferrous Metals	2	18	3402	3376	103	18	1	7	24	12516
8	Chemical Fertilizers	0	3	0	3	4	0	0	1	0	14618
9	Heavy Chemicals	59	530	2021	10782	1057	211	46	94	449	27028
10	Cement	785	41	21	35	7787	13	0	98	0	9076
11	Construction Materials	21	189	329	509	10367	29	20	212	1348	14083
12	Heavy Machinery	545	710	13760	5351	4445	923	689	1317	5277	38598
13	Light Industry	1013	1586	8694	84258	12269	570	200	12671	15058	150179
14	Construction	0	0	0	0	0	0	0	0	0	0
15	Freight & Communication	435	592	1081	3447	2878	471	35	625	1489	16265
16	Passenger Transport	28	55	323	370	89	58	27	279	1810	3505
17	Commerce	49	81	1630	4946	1253	832	73	1304	1623	17641
18	Services	201	353	2022	3589	342	973	982	5127	18097	34747
	Value Added	3193	7557	29477	97960	22385	15660	4285	25849	58607	480722
	Total Inputs	9059	14427	76858	296939	75761	23400	7499	50455	108676	1020996

APPENDIX 1 (continued)

		Final Demand									Gross Output
	Producing Sectors	19	20	21	22	23	24	25	26	27	
	(1000 tonnes of standard coal equivalent)										
1	Coal	37545	48809	0	0	-5794	4890	-1379	0	84072	444037
2	Petroleum	1516	154	0	0	-263	25254	-1019	0	25643	144604
3	Natural Gas	0	293	0	0	0	0	0	0	293	16944
*	Hydropower	0	0	0	0	0	0	0	0	0	26677
4	Electricity	659	791	0	0	0	0	0	0	1450	38009
	(million RMB in 1981 producer prices)										
5	Agriculture	81642	15216	277	2519	5377	2558	-9245	1115	99458	211921
6	Iron and Steel	0	0	0	0	-67	642	-2890	6	-2309	30696
7	Nonferrous Metals	0	0	0	0	52	491	-592	6	-44	12472
8	Chemical Fertilizers	0	0	0	0	45	0	-2145	5	-2095	12523
9	Heavy Chemicals	12	18	68	0	62	963	-1713	21	-568	26460
10	Cement	0	0	0	0	15	69	-103	2	-17	9059
11	Construction Materials	12	35	57	0	14	293	-70	4	345	14427
12	Heavy Machinery	93	144	46	43109	1762	2995	-9984	94	38260	76858
13	Light Industry	55882	54464	4814	2532	22916	15684	-9892	360	146761	296939
14	Construction	0	0	0	74361	0	0	0	1400	75761	75761
15	Freight & Communication	1068	1173	16	602	267	4064	-2	-54	7135	23400
16	Passenger Transport	1915	1463	0	0	0	780	-102	-64	3994	7499
17	Commerce	9729	10265	1254	1695	1925	7900	0	46	32814	50455
18	Services	17219	16843	39084	0	0	2762	-1995	15	73929	108676

Source: Division of Operation Research and Management Sciences, Institute of Systems Science, Chinese Academy of Sciences; and State Statistical Bureau of China. 1990. China Energy Statistical Yearbook, 1989. Beijing: China Energy Statistical Press, p. 230.

Note: Final demand sectors 19-27 are as follows: 19. Rural Consumption; 20. Urban Consumption; 21. Social Consumption; 22. Capital Investment; 23. Inventory Change; 24. Exports; 25. Imports; 26. Others; 27. Final Demand Total (19-26).

* The hydropower sector is a hypothetical sector introduced by the author to trace the changes in hydropower-input requirements.

APPENDIX 2

CHINA ENERGY INPUT-OUTPUT TRANSACTIONS TABLE, 1987

		Intermediate Demand									
	Producing Sectors	1	2	3	*	4	5	6	7	8	9
	(1000 tonnes of standard coal equivalent)										
1	Coal	17542	1003	68	0	144454	16800	92721	6496	41178	16295
2	Petroleum	1920	21009	323	0	18791	12893	6449	1446	6247	20173
3	Natural Gas	146	1131	5546	0	545	0	958	40	3885	2200
*	Hydropower	0	0	0	0	39698	0	0	0	0	0
4	Electricity	3257	1897	82	0	8726	4419	5704	3119	3635	4176
	(million RMB in 1981 producer prices)										
5	Agriculture	199	3	0	0	10	48915	54	89	27	3231
6	Iron and Steel	521	427	31	0	135	105	14784	343	193	322
7	Nonferrous Metals	27	9	0	0	22	9	1038	9934	72	642
8	Chemical Fertilizers	0	0	0	0	0	21980	0	0	913	362
9	Heavy Chemicals	629	669	38	0	225	3028	932	893	1435	17833
10	Cement	214	111	10	0	64	117	108	67	37	54
11	Construction Materials	163	168	9	0	83	107	1590	360	348	488
12	Heavy Machinery	3159	2502	160	0	1395	2868	5817	1393	1222	2172
13	Light Industry	1792	449	29	0	764	20306	1593	968	2960	8888
14	Construction	0	0	0	0	0	0	0	0	0	0
15	Freight & Communication	340	1006	10	0	556	3352	1094	385	349	1005
16	Passenger Transport	46	22	2	0	43	407	38	29	23	82
17	Commerce	629	874	18	0	563	2848	1801	1054	662	2357
18	Services	470	255	28	0	222	5474	951	457	303	1185
	Value Added	14160	24528	382	0	20895	219270	15304	6555	6412	24080
	Total Inputs	26813	43923	798	0	33893	332201	53646	25180	19570	67847

APPENDIX 2 (continued)

		Intermediate Demand									Subtotal
	Producing Sectors	10	11	12	13	14	15	16	17	18	(1-18)
	(1000 tonnes of standard coal equivalent)										
1	Coal	40871	35627	25986	70452	3352	13601	2457	5981	12385	547271
2	Petroleum	1840	4969	4800	10992	5638	17984	3552	876	7067	147969
3	Natural Gas	36	243	549	788	1144	53	13	0	173	17450
*	Hydropower	0	0	0	0	0	0	0	0	0	39698
4	Electricity	2281	1867	4542	9944	718	836	107	603	1832	57747
	(million RMB in 1981 producer prices)										
5	Agriculture	37	479	595	92251	840	5	0	6431	1667	154833
6	Iron and Steel	1299	591	20701	3775	18904	258	57	280	607	63335
7	Nonferrous Metals	38	288	8677	3436	759	31	7	130	179	25299
8	Chemical Fertilizers	0	11	0	5	12	0	0	3	13	23299
9	Heavy Chemicals	495	2677	12110	24482	4876	1694	187	344	1838	74386
10	Cement	1635	321	280	199	20361	75	14	511	1065	25243
11	Construction Materials	1040	2407	3334	2255	19515	120	27	807	1816	34637
12	Heavy Machinery	2261	2733	64343	21783	29977	4038	1323	2472	10126	159743
13	Light Industry	3710	5390	12599	172649	19016	1661	419	21384	31570	306149
14	Construction	0	0	0	0	0	0	0	0	0	0
15	Freight & Communication	451	570	2581	10142	4282	443	100	866	4268	31801
16	Passenger Transport	42	81	479	548	132	87	39	413	2681	5194
17	Commerce	786	1197	7685	23125	6099	919	164	2786	3637	57204
18	Services	613	1078	6175	10960	1044	2970	862	15655	11901	60605
	Value Added	7353	12308	91052	226027	37643	30376	6596	33439	109408	885788
	Total Inputs	23980	35367	237340	599100	167405	49649	11112	87429	186284	2001535

APPENDIX 2 (continued)

		Final Demand									
	Producing Sectors	20	21	22	23	24	25	26	27	28	Gross Output
	(1000 tonnes of standard coal equivalent)										
1	Coal	53094	64986	0	0	-11379	10260	-1386	0	115575	662845
2	Petroleum	1820	318	0	0	1360	44641	-4475	0	43664	191632
3	Natural Gas	0	1024	0	0	0	0	0	0	1024	18474
*	Hydropower	0	0	0	0	0	0	0	0	0	39698
4	Electricity	1526	1995	0	0	0	5	-159	0	3367	61114
	(million RMB in 1981 producer prices)										
5	Agriculture	112246	42341	505	6814	8512	13284	-7774	1443	177369	332201
6	Iron and Steel	0	0	0	0	927	2930	-12952	-594	-9689	53646
7	Nonferrous Metals	0	0	0	0	-48	2047	-1919	-199	-118	25180
8	Chemical Fertilizers	0	0	0	0	503	43	-3989	-286	-3729	19570
9	Heavy Chemicals	93	149	232	0	867	4175	-10286	-1771	-6539	67847
10	Cement	0	0	0	0	-416	19	-222	-644	-1263	23980
11	Construction Materials	472	179	51	0	-251	2245	-1022	-943	730	35367
12	Heavy Machinery	1987	1036	66	97680	14646	19665	-59405	1922	77597	237340
13	Light Industry	113489	112427	10239	2211	18819	73237	-40479	3009	292950	599100
14	Construction	0	0	0	167405	0	0	0	0	167405	167405
15	Freight & Communication	5112	3755	45	1765	1061	11040	-4834	-96	17848	49649
16	Passenger Transport	2838	2168	0	0	0	1156	-151	-94	5918	11112
17	Commerce	13536	8731	7856	3589	2757	9788	-16123	91	30224	87429
18	Services	20510	25475	78186	0	0	5291	-3821	39	125679	186284

Source: Division of Operation Research and Management Sciences, Institute of Systems Science, Chinese Academy of Sciences; and State Statistical Bureau of China. 1990. China Energy Statistical Yearbook, 1989. Beijing: China Energy Statistical Press, p. 242.

Note: Final demand sectors 19-27 are as follows: 19. Rural Consumption; 20. Urban Consumption; 21. Social Consumption; 22. Capital Investment; 23. Inventory Change; 24. Exports; 25. Imports; 26. Others; 27. Final Demand Total (19-26).

* The hydropower sector is a hypothetical sector introduced by the author to trace the changes in hydropower-input requirements.

APPENDIX 3

DIRECT INPUT COEFFICIENTS TABLE OF CHINA, 1981

(direct input per unit of gross output)

	Producing Sectors	Purchasing Sectors									
		1	2	3	*	4	5	6	7	8	9
		kgsce/kgsce					kgsce/RMB				
1	Coal	0.0227	0.0039	0.0021	0.0000	2.2543	0.0533	1.9871	0.3330	2.7699	0.4721
2	Petroleum	0.0021	0.0711	0.0123	0.0000	0.6397	0.0534	0.2536	0.0832	0.4224	0.6542
3	Natural Gas	0.0000	0.0161	0.2755	0.0000	0.0021	0.0000	0.0341	0.0036	0.3448	0.0670
*	Hydropower	0.0000	0.0000	0.0000	0.0000	0.7019	0.0000	0.0000	0.0000	0.0000	0.0000
4	Electricity	0.0049	0.0071	0.0022	0.0000	0.1490	0.0163	0.1062	0.1826	0.3006	0.1321
		RMB/kgsce					RMB/RMB				
5	Agriculture	0.0003	0.0011	0.0007	0.0000	0.0005	0.1593	0.0022	0.0023	0.0024	0.0857
6	Iron and Steel	0.0013	0.0038	0.0034	0.0000	0.0014	0.0008	0.2876	0.0155	0.0079	0.0039
7	Nonferrous Metals	0.0001	0.0002	0.0001	0.0000	0.0003	0.0000	0.0208	0.3590	0.0045	0.0120
8	Chemical Fertilizers	0.0000	0.0000	0.0000	0.0000	0.0000	0.0629	0.0000	0.0000	0.0886	0.0060
9	Heavy Chemicals	0.0008	0.0060	0.0008	0.0000	0.0005	0.0180	0.0045	0.0153	0.0350	0.2249
10	Cement	0.0003	0.0006	0.0007	0.0000	0.0001	0.0001	0.0008	0.0017	0.0002	0.0001
11	Construction Materials	0.0003	0.0013	0.0009	0.0000	0.0003	0.0001	0.0157	0.0121	0.0023	0.0010
12	Heavy Machinery	0.0028	0.0050	0.0038	0.0000	0.0135	0.0019	0.0661	0.0336	0.0075	0.0040
13	Light Industry	0.0041	0.0050	0.0039	0.0000	0.0026	0.0273	0.0237	0.0710	0.1032	0.0927
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0006	0.0043	0.0005	0.0000	0.0164	0.0043	0.0543	0.0203	0.0250	0.0216
16	Passenger Transport	0.0001	0.0001	0.0001	0.0000	0.0008	0.0013	0.0008	0.0016	0.0012	0.0021
17	Commerce	0.0005	0.0109	0.0027	0.0000	0.0130	0.0069	0.0155	0.0322	0.0290	0.0308
18	Services	0.0003	0.0006	0.0005	0.0000	0.0019	0.0085	0.0102	0.0120	0.0079	0.0147
	Value Added	0.0216	0.1018	0.0408	0.0000	0.3519	0.7000	0.3607	0.2831	0.3124	0.3966
	Total Inputs	0.0375	0.1855	0.0629	0.0000	0.5080	1.0000	1.0000	1.0000	1.0000	1.0000

APPENDIX 3 (continued)

	Producing Sectors	Purchasing Sectors									
		10	11	12	13	14	15	16	17	18	All Sectors
					kgsce/RMB						
1	Coal	2.5507	1.2226	0.2815	0.1624	0.0358	0.5402	0.3070	0.0744	0.0732	0.3526
2	Petroleum	0.1129	0.1897	0.0506	0.0372	0.0326	0.4521	0.2483	0.0100	0.0587	0.1165
3	Natural Gas	0.0011	0.0048	0.0083	0.0028	0.0088	0.0034	0.0018	0.0000	0.0007	0.0163
*	Hydropower	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0261
4	Electricity	0.0823	0.0456	0.0370	0.0171	0.0076	0.0130	0.0072	0.0047	0.0083	0.0358
					RMB/RMB						
5	Agriculture	0.0048	0.0417	0.0105	0.2312	0.0484	0.0004	0.0000	0.0263	0.0080	0.1102
6	Iron and Steel	0.0841	0.0029	0.1179	0.0185	0.0844	0.0071	0.0046	0.0010	0.0034	0.0323
7	Nonferrous Metals	0.0002	0.0013	0.0443	0.0114	0.0014	0.0008	0.0001	0.0001	0.0002	0.0123
8	Chemical Fertilizers	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0143
9	Heavy Chemicals	0.0065	0.0367	0.0263	0.0363	0.0139	0.0090	0.0061	0.0019	0.0041	0.0265
10	Cement	0.0867	0.0028	0.0003	0.0001	0.1028	0.0006	0.0000	0.0019	0.0000	0.0089
11	Construction Materials	0.0023	0.0131	0.0043	0.0017	0.1368	0.0012	0.0027	0.0042	0.0124	0.0138
12	Heavy Machinery	0.0602	0.0492	0.1790	0.0180	0.0587	0.0394	0.0919	0.0261	0.0486	0.0378
13	Light Industry	0.1118	0.1099	0.1131	0.2838	0.1619	0.0244	0.0266	0.2511	0.1386	0.1471
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0480	0.0411	0.0141	0.0116	0.0380	0.0201	0.0046	0.0124	0.0137	0.0159
16	Passenger Transport	0.0031	0.0038	0.0042	0.0012	0.0012	0.0025	0.0035	0.0055	0.0167	0.0034
17	Commerce	0.0054	0.0056	0.0212	0.0167	0.0165	0.0356	0.0098	0.0258	0.0149	0.0173
18	Services	0.0222	0.0245	0.0263	0.0121	0.0045	0.0416	0.1310	0.1016	0.1665	0.0340
	Value Added	0.3524	0.5238	0.2835	0.3299	0.2955	0.6692	0.5714	0.5123	0.5393	0.4708
	Total Inputs	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Source: Calculated from Appendix 1 as the direct input from a given sector divided by the gross output of the sector that is purchasing the input.

Note: kgsce = kilogram of standard coal equivalent.

APPENDIX 4

DIRECT INPUT COEFFICIENTS TABLE OF CHINA, 1987

(direct input per unit of gross output)

	Producing Sectors	Purchasing Sectors									
		1	2	3	*	4	5	6	7	8	9
		kgsce/kgsce					kgsce/RMB				
1	Coal	0.0265	0.0052	0.0037	0.0000	2.3637	0.0506	1.7284	0.2580	2.1041	0.2402
2	Petroleum	0.0029	0.1096	0.0175	0.0000	0.3075	0.0388	0.1202	0.0574	0.3192	0.2973
3	Natural Gas	0.0002	0.0059	0.3002	0.0000	0.0089	0.0000	0.0179	0.0016	0.1985	0.0324
*	Hydropower	0.0000	0.0000	0.0000	0.0000	0.6496	0.0000	0.0000	0.0000	0.0000	0.0000
4	Electricity	0.0049	0.0099	0.0045	0.0000	0.1428	0.0133	0.1063	0.1239	0.1858	0.0616
		RMB/kgsce					RMB/RMB				
5	Agriculture	0.0003	0.0000	0.0000	0.0000	0.0002	0.1472	0.0010	0.0035	0.0014	0.0476
6	Iron and Steel	0.0008	0.0022	0.0017	0.0000	0.0022	0.0003	0.2756	0.0136	0.0099	0.0047
7	Nonferrous Metals	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0193	0.3945	0.0037	0.0095
8	Chemical Fertilizers	0.0000	0.0000	0.0000	0.0000	0.0000	0.0662	0.0000	0.0000	0.0467	0.0053
9	Heavy Chemicals	0.0009	0.0035	0.0021	0.0000	0.0037	0.0091	0.0174	0.0355	0.0733	0.2628
10	Cement	0.0003	0.0006	0.0006	0.0000	0.0011	0.0004	0.0020	0.0027	0.0019	0.0008
11	Construction Materials	0.0002	0.0009	0.0005	0.0000	0.0014	0.0003	0.0296	0.0143	0.0178	0.0072
12	Heavy Machinery	0.0048	0.0131	0.0086	0.0000	0.0228	0.0086	0.1084	0.0553	0.0624	0.0320
13	Light Industry	0.0027	0.0023	0.0015	0.0000	0.0125	0.0611	0.0297	0.0385	0.1512	0.1310
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0005	0.0052	0.0006	0.0000	0.0091	0.0101	0.0204	0.0153	0.0178	0.0148
16	Passenger Transport	0.0001	0.0001	0.0001	0.0000	0.0007	0.0012	0.0007	0.0012	0.0012	0.0012
17	Commerce	0.0009	0.0046	0.0010	0.0000	0.0092	0.0086	0.0336	0.0418	0.0338	0.0347
18	Services	0.0007	0.0013	0.0015	0.0000	0.0036	0.0165	0.0177	0.0182	0.0155	0.0175
	Value Added	0.0214	0.1280	0.0207	0.0000	0.3419	0.6601	0.2853	0.2603	0.3277	0.3549
	Total Inputs	0.0405	0.2292	0.0432	0.0000	0.5546	1.0000	1.0000	1.0000	1.0000	1.0000

APPENDIX 4 (continued)

	Producing Sectors	Purchasing Sectors 10	11	12	13	14	15	16	17	18	All Sectors
						kgsce/RMB					
1	Coal	1.7044	1.0073	0.1095	0.1176	0.0200	0.2739	0.2212	0.0684	0.0665	0.2734
2	Petroleum	0.0767	0.1405	0.0202	0.0183	0.0337	0.3622	0.3196	0.0100	0.0433	0.0739
3	Natural Gas	0.0015	0.0069	0.0023	0.0013	0.0068	0.0011	0.0012	0.0000	0.0009	0.0087
*	Hydropower	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0198
4	Electricity	0.0951	0.0528	0.0191	0.0166	0.0043	0.0168	0.0096	0.0069	0.0098	0.0289
						RMB/RMB					
5	Agriculture	0.0015	0.0135	0.0025	0.1540	0.0050	0.0001	0.0000	0.0736	0.0089	0.0774
6	Iron and Steel	0.0542	0.0167	0.0872	0.0063	0.1129	0.0052	0.0051	0.0032	0.0033	0.0316
7	Nonferrous Metals	0.0016	0.0081	0.0366	0.0057	0.0045	0.0006	0.0006	0.0015	0.0010	0.0126
8	Chemical Fertilizers	0.0000	0.0003	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0116
9	Heavy Chemicals	0.0206	0.0757	0.0510	0.0409	0.0291	0.0341	0.0168	0.0039	0.0099	0.0372
10	Cement	0.0682	0.0091	0.0012	0.0003	0.1216	0.0015	0.0013	0.0058	0.0057	0.0126
11	Construction Materials	0.0433	0.0680	0.0140	0.0038	0.1166	0.0024	0.0025	0.0092	0.0098	0.0173
12	Heavy Machinery	0.0943	0.0773	0.2711	0.0364	0.1791	0.0813	0.1190	0.0283	0.0544	0.0798
13	Light Industry	0.1547	0.1524	0.0531	0.2882	0.1136	0.0335	0.0377	0.2446	0.1695	0.1530
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0188	0.0161	0.0109	0.0169	0.0256	0.0089	0.0090	0.0099	0.0229	0.0159
16	Passenger Transport	0.0017	0.0023	0.0020	0.0009	0.0008	0.0017	0.0035	0.0047	0.0144	0.0026
17	Commerce	0.0328	0.0338	0.0324	0.0386	0.0364	0.0185	0.0148	0.0319	0.0195	0.0286
18	Services	0.0256	0.0305	0.0260	0.0183	0.0062	0.0598	0.0776	0.1791	0.0639	0.0303
	Value Added	0.3066	0.3480	0.3836	0.3773	0.2249	0.6118	0.5936	0.3825	0.5873	0.4426
	Total Inputs	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Source: Calculated from Appendix 2 as the direct input from a given sector divided by the gross output of the sector that is purchasing the input.

Note: kgsce = kilogram of standard coal equivalent.

APPENDIX 5

TOTAL INPUT REQUIREMENTS TABLE OF CHINA, 1981

(direct and indirect input per unit of final demand)

	Producing Sectors	Purchasing Sectors									
		1	2	3	*	4	5	6	7	8	9
		kgsce/kgsce					kgsce/RMB				
1	Coal	1.0538	0.0790	0.0524	0.0000	2.9073	0.5389	3.7366	1.7680	4.4603	1.4978
2	Petroleum	0.0115	1.1031	0.0314	0.0000	0.8822	0.2017	0.6809	0.5307	0.9593	1.1916
3	Natural Gas	0.0008	0.0265	1.3821	0.0000	0.0273	0.0495	0.0925	0.0348	0.5600	0.1641
*	Hydropower	0.0053	0.0101	0.0050	1.0000	0.8498	0.0486	0.1707	0.2713	0.3228	0.1804
4	Electricity	0.0076	0.0144	0.0072	0.0000	1.2108	0.0693	0.2432	0.3866	0.4599	0.2571
		RMB/kgsce					RMB/RMB				
5	Agriculture	0.0030	0.0084	0.0056	0.0000	0.0215	1.2182	0.0559	0.0844	0.0895	0.2096
6	Iron and Steel	0.0030	0.0086	0.0088	0.0000	0.0218	0.0098	1.4479	0.0664	0.0478	0.0335
7	Nonferrous Metals	0.0007	0.0019	0.0014	0.0000	0.0060	0.0043	0.0619	1.5754	0.0206	0.0341
8	Chemical Fertilizers	0.0002	0.0006	0.0004	0.0000	0.0016	0.0844	0.0041	0.0062	1.1040	0.0231
9	Heavy Chemicals	0.0018	0.0104	0.0031	0.0000	0.0160	0.0392	0.0354	0.0571	0.0808	1.3225
10	Cement	0.0003	0.0009	0.0011	0.0000	0.0018	0.0006	0.0034	0.0044	0.0030	0.0019
11	Construction Materials	0.0005	0.0019	0.0016	0.0000	0.0035	0.0016	0.0278	0.0237	0.0084	0.0062
12	Heavy Machinery	0.0045	0.0098	0.0086	0.0000	0.0424	0.0138	0.1551	0.1018	0.0602	0.0425
13	Light Industry	0.0082	0.0186	0.0132	0.0000	0.0541	0.0829	0.1473	0.2440	0.2568	0.2494
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0013	0.0066	0.0022	0.0000	0.0298	0.0131	0.0985	0.0551	0.0540	0.0491
16	Passenger Transport	0.0002	0.0004	0.0003	0.0000	0.0020	0.0025	0.0042	0.0055	0.0042	0.0054
17	Commerce	0.0012	0.0141	0.0052	0.0000	0.0319	0.0188	0.0501	0.0770	0.0664	0.0714
18	Services	0.0011	0.0040	0.0025	0.0000	0.0135	0.0196	0.0420	0.0480	0.0350	0.0459

APPENDIX 5 (continued)

	Producing Sectors	Purchasing Sectors								
		10	11	12	13	14	15	16	17	18
					kgsce/RMB					
1	Coal	3.8161	1.7587	1.3407	0.7568	1.3021	0.8100	0.6039	0.4202	0.4186
2	Petroleum	0.4124	0.4006	0.3382	0.2583	0.3122	0.5779	0.3631	0.1319	0.1860
3	Natural Gas	0.0289	0.0307	0.0448	0.0372	0.0429	0.0241	0.0184	0.0152	0.0154
*	Hydropower	0.1266	0.0716	0.0974	0.0599	0.0667	0.0300	0.0274	0.0287	0.0301
4	Electricity	0.1803	0.1021	0.1388	0.0854	0.0950	0.0427	0.0391	0.0409	0.0429
					RMB/RMB					
5	Agriculture	0.0877	0.1225	0.1034	0.4170	0.1710	0.0333	0.0400	0.1554	0.0953
6	Iron and Steel	0.1691	0.0324	0.2252	0.0525	0.1691	0.0296	0.0370	0.0261	0.0313
7	Nonferrous Metals	0.0209	0.0149	0.1013	0.0334	0.0244	0.0094	0.0137	0.0136	0.0135
8	Chemical Fertilizers	0.0063	0.0091	0.0076	0.0294	0.0123	0.0025	0.0029	0.0110	0.0068
9	Heavy Chemicals	0.0383	0.0713	0.0677	0.0865	0.0573	0.0260	0.0245	0.0319	0.0290
10	Cement	1.0968	0.0042	0.0017	0.0009	0.1141	0.0015	0.0007	0.0026	0.0005
11	Construction Materials	0.0093	1.0167	0.0129	0.0056	0.1448	0.0045	0.0073	0.0083	0.0176
12	Heavy Machinery	0.1288	0.0874	1.2654	0.0511	0.1272	0.0679	0.1363	0.0601	0.0910
13	Light Industry	0.2595	0.2219	0.2760	1.4713	0.3451	0.0931	0.1167	0.4232	0.2807
14	Construction	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0785	0.0566	0.0449	0.0306	0.0734	1.0308	0.0169	0.0265	0.0280
16	Passenger Transport	0.0064	0.0062	0.0080	0.0040	0.0048	0.0047	1.0076	0.0094	0.0217
17	Commerce	0.0315	0.0256	0.0515	0.0411	0.0428	0.0512	0.0255	1.0439	0.0324
18	Services	0.0523	0.0473	0.0618	0.0382	0.0376	0.0642	0.1707	0.1416	1.2186

Source: Calculated from Appendix 3 by inverting the (I-A) matrix, where A is the intermediate-input portion of the direct input coefficients matrix.

Note: kgsce = kilogram of standard coal equivalent.

APPENDIX 6

TOTAL INPUT REQUIREMENTS TABLE OF CHINA, 1987

(direct and indirect input per unit of final demand)

	Producing Sectors	Purchasing Sectors 1	2	3	*	4	5	6	7	8	9
		kgsce/kgsce					kgsce/RMB				
1	Coal	1.0545	0.0757	0.0548	0.0000	2.9981	0.4449	3.3062	1.4219	3.2703	0.9119
2	Petroleum	0.0085	1.1387	0.0378	0.0000	0.4507	0.1343	0.3670	0.3049	0.6011	0.5754
3	Natural Gas	0.0008	0.0107	1.4302	0.0000	0.0225	0.0285	0.0508	0.0207	0.3197	0.0793
*	Hydropower	0.0047	0.0111	0.0071	1.0000	0.7791	0.0337	0.1525	0.1859	0.1913	0.0919
4	Electricity	0.0073	0.0170	0.0109	0.0000	1.1994	0.0519	0.2347	0.2862	0.2945	0.1415
		RMB/kgsce					RMB/RMB				
5	Agriculture	0.0021	0.0040	0.0027	0.0000	0.0168	1.2063	0.0511	0.0637	0.0835	0.1493
6	Iron and Steel	0.0024	0.0073	0.0065	0.0000	0.0195	0.0109	1.4271	0.0639	0.0507	0.0334
7	Nonferrous Metals	0.0008	0.0022	0.0018	0.0000	0.0076	0.0062	0.0677	1.6707	0.0264	0.0348
8	Chemical Fertilizers	0.0002	0.0003	0.0002	0.0000	0.0013	0.0840	0.0041	0.0051	1.0556	0.0182
9	Heavy Chemicals	0.0027	0.0092	0.0070	0.0000	0.0242	0.0395	0.0851	0.1210	0.1569	1.4005
10	Cement	0.0004	0.0009	0.0010	0.0000	0.0033	0.0016	0.0071	0.0080	0.0061	0.0038
11	Construction Materials	0.0006	0.0021	0.0016	0.0000	0.0060	0.0052	0.0559	0.0360	0.0315	0.0189
12	Heavy Machinery	0.0087	0.0259	0.0214	0.0000	0.0793	0.0476	0.2887	0.1975	0.1875	0.1265
13	Light Industry	0.0071	0.0139	0.0102	0.0000	0.0633	0.1563	0.1850	0.2131	0.3498	0.3445
14	Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0011	0.0074	0.0020	0.0000	0.0188	0.0206	0.0479	0.0440	0.0422	0.0388
16	Passenger Transport	0.0002	0.0004	0.0004	0.0000	0.0018	0.0027	0.0041	0.0049	0.0042	0.0042
17	Commerce	0.0021	0.0081	0.0037	0.0000	0.0248	0.0265	0.0849	0.1041	0.0789	0.0807
18	Services	0.0019	0.0053	0.0045	0.0000	0.0187	0.0357	0.0682	0.0739	0.0597	0.0618

APPENDIX 6 (continued)

	Producing Sectors	Purchasing Sectors								
		10	11	12	13	14	15	16	17	18
					kgsce/RMB					
1	Coal	2.7509	1.7000	0.8884	0.5363	1.2302	0.5489	0.4932	0.4144	0.3499
2	Petroleum	0.2645	0.3227	0.1793	0.1411	0.2362	0.4793	0.4272	0.1062	0.1285
3	Natural Gas	0.0189	0.0280	0.0211	0.0172	0.0306	0.0122	0.0114	0.0102	0.0090
*	Hydropower	0.1197	0.0790	0.0631	0.0414	0.0666	0.0318	0.0267	0.0287	0.0256
4	Electricity	0.1844	0.1216	0.0971	0.0637	0.1025	0.0489	0.0412	0.0442	0.0394
					RMB/RMB					
5	Agriculture	0.0817	0.0974	0.0591	0.2876	0.0892	0.0309	0.0319	0.1832	0.0759
6	Iron and Steel	0.1196	0.0578	0.1837	0.0311	0.2225	0.0309	0.0371	0.0259	0.0257
7	Nonferrous Metals	0.0270	0.0342	0.0987	0.0246	0.0452	0.0140	0.0172	0.0160	0.0143
8	Chemical Fertilizers	0.0062	0.0080	0.0049	0.0206	0.0070	0.0026	0.0025	0.0131	0.0056
9	Heavy Chemicals	0.0874	0.1566	0.1319	0.1054	0.1203	0.0722	0.0535	0.0522	0.0490
10	Cement	1.0770	0.0133	0.0046	0.0025	0.1351	0.0035	0.0034	0.0091	0.0080
11	Construction Materials	0.0630	1.0842	0.0337	0.0125	0.1497	0.0094	0.0105	0.0190	0.0174
12	Heavy Machinery	0.2316	0.1884	1.4539	0.1139	0.3711	0.1530	0.2061	0.1066	0.1232
13	Light Industry	0.3566	0.3474	0.2124	1.5142	0.3498	0.1191	0.1301	0.4696	0.3148
14	Construction	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
15	Freight & Communication	0.0423	0.0373	0.0330	0.0371	0.0543	1.0209	0.0217	0.0305	0.0367
16	Passenger Transport	0.0050	0.0054	0.0054	0.0036	0.0046	0.0039	1.0061	0.0095	0.0170
17	Commerce	0.0781	0.0754	0.0794	0.0777	0.0946	0.0395	0.0377	1.0683	0.0461
18	Services	0.0721	0.0737	0.0738	0.0601	0.0651	0.0842	0.1045	0.2260	1.0949

Source: Calculated from Appendix 4 by inverting the (I-A) matrix, where A is the intermediate-input portion of the direct input coefficients matrix.

Note: kgsce = kilogram of standard coal equivalent.

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