65

Energy Prices and Energy Intensity in China:

A Structural Decomposition Analysis and Econometric Study

by

Xiaoyu Shi

M. S. in Human Geography
Peking University
Beijing, China (2002)

B.S. in Economic Geography and Regional Planning
Shanxi University
Taiyuan, Shanxi, China (1999)

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degree of

Master in City Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2005

Signature of Author ____
Department of Urban Studies and Planning
August 9, 2005

Certified by ____
Professor Karen R. Polenske
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by ____
Professor Langley Keyes
Chair, MCP Committee
Department of Urban Studies and Planning

Table of Contents

Main Body

Chapter 1: Introduction

Chapter 2: Methodology and Data

Chapter 3: Decomposition of Energy Consumption

Chapter 4: Hypothesis Testing

Chapter 5: Summary and Conclusion

Energy Prices and Energy Intensity in China: A Structural Decomposition Analysis and Econometric Study

by

Xiaoyu Shi

Submitted to the Department of Urban Studies and Planning
On August 8, 2005 in partial fulfillment of the
requirements for the Degree of Master in
City Planning

Abstract:

Since the start of its economic reforms in 1978, China's energy prices relative to other prices have increased. At the same time, its energy intensity, i.e., physical energy consumption per unit of Gross Domestic Product (GDP), has declined dramatically, by about 70%, in spite of increases in energy consumption. Is this just a coincidence? Or does a systematic relationship exist between energy prices and energy intensity?

In this study, I examine whether and how China's energy price changes affect its energy intensity trend during 1980-2002 at a macro level. I conduct the research using two complementary economic models (the input-output-based structural decomposition analysis and econometric regression models) and a decomposition method of own-price elasticity of energy intensity. Findings include a negative own-price elasticity of energy intensity, a price-inducement effect on energy-efficiency improvement, and a greater sensitivity, in terms of the reaction of energy intensity towards changes in energy prices, of the industry sector, compared to the overall economy.

Analysts can use these results as a starting point for China's energy use and carbon emission forecasts, which they traditionally conduct in China without accounting for energy intensity and energy prices. In addition, policy implications may initiate new thinking about energy policies that are needed to conserve China's energy resources and reduce carbon emissions.

Thesis Supervisor: Karen R. Polenske
Title: Professor of Regional Political Economy and Planning
Thesis reader: Ernest R. Berndt
Title: Louis E Seley Professor of Applied Economics

Acknowledgement

During my master's program, I received much generous help and support. I am in great debt to many professors, professionals, friends, and my family.

First of all, I express my sincere acknowledgments to Professor Karen R. Polenske at the Department of Urban Studies and Planning (DUSP) at the Massachusetts Institute of Technology (MIT), my thesis and academic advisor. Karen kindly encouraged and supervised me all through the whole process. Her talents and brilliant insights kept me on the right track. Besides the thesis issues, she is always considerate and cares for students. Without her support, at least financially, I do not think that I had a chance to finish my study at MIT. However, this little section is just not enough for me to enumerate everything about her "inputs" in me. What I got from Karen is much beyond what a typical academic and thesis supervisor provides in these days. I believe that her advise on my academic, professional, and personal development have and will continue to have a far-reaching impact on me. The second professor I want to express my deepest gratitude to is my thesis reader Professor Ernest R. Berndt from the Sloan School of Management at MIT. However, he is, in fact, also my "technical supervisor and director," especially on the econometric modeling, not only a thesis reader. His technical supervision and comments were always insightful, thought-provoking, and encouraging. It is no doubt that he devoted a lot of his valuable time to my thesis. Without his generosity and aptitude, the completion of my thesis would be very different.

Second, Professor Chen Xikang generously provided me with four comparable China's input-output tables and energy-flow matrices, which took him and his colleagues years to assemble. Dr. Lin Xinnuan (James) from Merrill Lynch and Professor Yang Cuihong very kindly guided me on some input-output nuances.

Third, I am also grateful to all the following persons. DUSP Ph.D. student Hongliang Zhang actively discussed with me many technical and mathematical aspects of this thesis. Professor John deMonchaux at DUSP reviewed my thesis draft and provided insightful and strategic comments and suggestions. Another DUSP Ph.D. student Rajendra Kumar reviewed the major part of my thesis and provided valuable comments. Robert Irwin and his colleagues from the Writing Center at MIT helped me with many of the English issues while I was writing, especially Mr. Irwin who helped me develop some of the arguments. At the last step toward the submission of my thesis, my friend and mentor, Kasia Austin-Barnes from Austin-Barnes Foundation offered me warmly and unforgettable support, which helped me work with ease.

Fourth, but not least, I want to thank many "outside persons", including those involved in the initial topic discussion phase, for their valuable information and delight involvement. They are from China's government agencies, civic organizations, and academic and research institutes. They include Professor Shen Fengman from the Northeastern University in China, Mr. He Jianyu and Zhang Gengtian from China's National

Development and Reform Commission, Professor Zhang Yongfa from the Taiyuan University of Technology, Mr. Zhao Jianping from Shanxi Provincial Chemical Design Institute, Mr. Liu Deshun from China Academy of Macroeconomic Research, and Mr. Huang Jingan from China Iron and Steel Association. Also, I appreciate my friends of Cao Liou, Diao Mi, Li Xin, Li Yaodong, Li Yu, Tan Zhijun, Yang Jiawen, Zhang Yabei and others, most of whom are from MIT, for their various support.

In addition to all the persons I mentioned earlier, I am in deepest gratitude to my parents and my brother for their long-time trust, encouragement, support, and love. I believe that they agree that the completion of my thesis is one of the best ways for me to show my deep appreciation to them.

Finally, I appreciate the funding support from Grant #2737251 from the Center for Energy and Environmental Policy Research (CEEPR) at MIT for sponsoring the final work on my thesis. I also thank DUSP for the tuition support and the Alliance for Global Sustainability for their partial stipend grant and funds, which supported my study since I entered MIT in January 2003.

Figures:

Tables:

Appendices

Notes on Abbreviations:

Btu	British thermal unit
CAS	China Academy of Sciences
CEG	China Energy Group at University of California, Berkeley
CEIN	China Economic Information Network
CPI	Consumer Price Index
EIA	Energy Information Administration, U.S.
ISS	Institute of Systems Science (at CAS)
kg	Kilogram
kgsce	Kilogram standard coal equivalent
kwh	Kilowatt hour
Mtce	Million tonnes of standard coal equivalent
NBSC	National Bureau of Statistics of China (NBSC)
OLS	Ordinary Least Square
R&D	Research and Development
RMB	RenMinBi (China's currency)
sce	Standard coal equivalent
SDA	Structural Decomposition Analysis
SIEF	Shaanxi Institute of Economics and Finance

Chapter 1

Introduction

1.1 Background

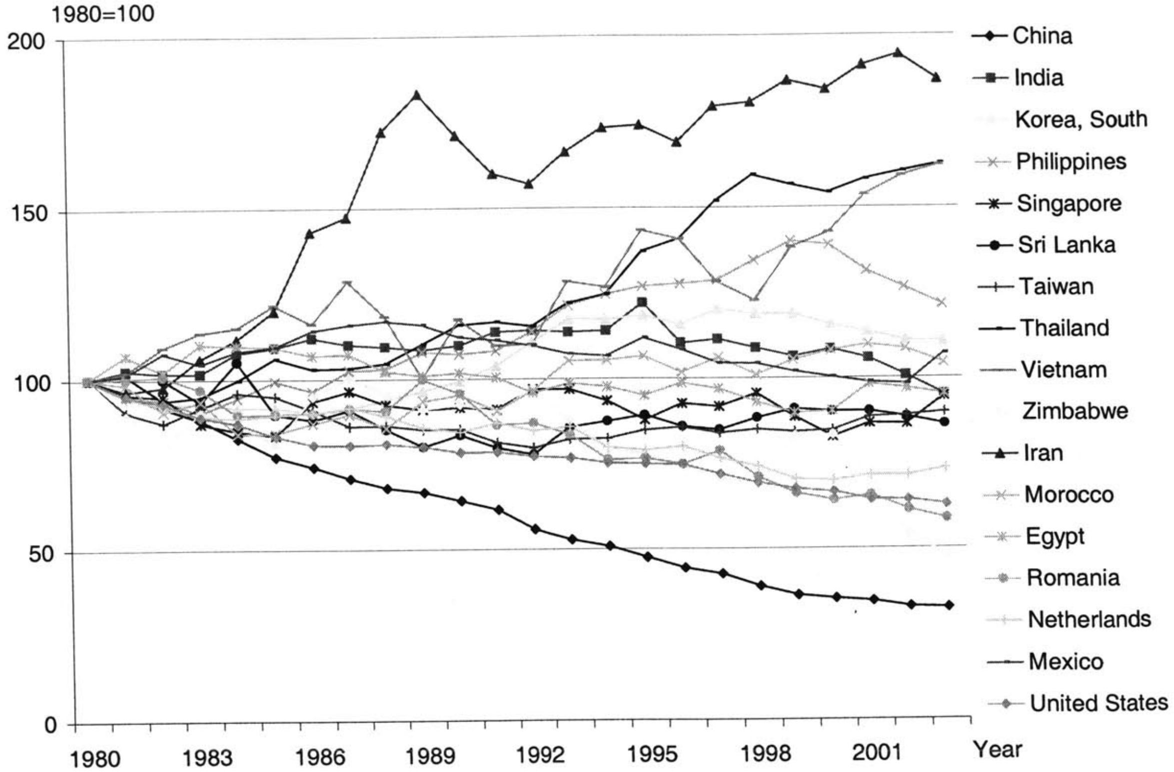
As a developing country, the People's Republic of China (China) has increased its real Gross Domestic Product (GDP) annually by 9.3% (SSB, 2003) since the late 1970s, a remarkable feat. However, its energy consumption has a slower rate of increase; furthermore, China's primary energy consumption decreased in the latter half of the 1990s. Thus, by 2000, China's energy intensity, defined as the ratio of real energy consumption in physical terms to real GDP, declined by approximately 70%. (Fisher-Vanden, et al., 2004)

In terms of energy prices, China has gradually built a market-determined pricing system as the central government has eliminated many of its controls on energy pricing since the early 1990s, although the reform's extensiveness and intensity varied by energy type. Relative energy prices increased generally over time, with some fluctuation in the late 1990s. After the significant new energy price reforms in 1993, real prices for coal (and other energy products) rose in China at a far higher rate than those for other industrial products. By 1999, there were no significant differences in the energy prices faced by state-owned enterprises and foreign-invested firms. Oil supply remains under state control with prices higher than parity on a per Btu (British Thermal Unit) basis, but it has been linked to the global market prices since 1998 through pegging its domestic price to Singapore's. Electricity prices also rose throughout the country since the late 1970s with some short-term fluctuations in recent years. The state-set price of natural gas for most customers was adjusted significantly upwards in 1997. (Sinton et al., 1999, and Fisher-Vanden, et al., 2004)

1.2 Theory and Arguments about Energy Intensity

Empirically, China's energy-intensity dramatic decline is a unique phenomenon in the developing world, in contrast to most developing countries' experiences. (Lin, 1996; Zhang, 2003; Figure 1.1) China is one of the few countries at a relatively early stage of industrialization in which energy demand has consistently–and over many years–grown significantly less rapidly than GDP. (Sinton et al., 1998) Theoretically, China's energy-intensity decline contradicts traditional economic development theory, which claims that in the industrialization stage, an increase of the energy-intensive manufacturing industries and a decline of the less-energy-intensive agricultural industries will lead to an increase of energy intensity of total output. (Dunkerley et al., 1981; Moroney, 1988)

Figure 1.1: Energy Intensities of Selected Developing and Developed Countries



Source: US Energy Information Administration (EIA), 2005

Beginning in the 1990s, analysts have tried to account for this unique phenomenon through different empirical studies. Most of them, including Sinton and Levine (1994), Lin and Polenske (1995), Garbaccio et al. (1999), and Zhang (2003), argue that energy-efficiency improvement is the primary factor explaining the decline of China's energy intensity. However, Smil (1990) and Kambara (1992) argue that structural shifts away from more energy-intensive industrial subsectors to less energy-intensive ones is the major causal factor. Others, Sinton (2000) and Fisher-Vanden et al., (2004) provide a multifactor explanation. They stress the importance of other factors, such as environmental and energy-efficiency policies, research and development expenditures, and ownership reform in enterprise sectors. However, few analysts except Fisher-

Vanden et al. (2004) incorporate energy prices into their analytical framework. Fisher-Vanden et al. show a negative elasticity of energy intensity with respect to energy prices, which composes part of their study results on China's energy-intensity decline. However, they base their study only on firm-level data during an extremely short and special time period (1997-1999), in which energy consumption and prices went down, and examine only large and medium firms, which usually have a lower direct energy demand per unit of output than small firms, at least in the cokemaking sector in China. (Polenske, forthcoming)

Is this just a coincidence, or is there any systematic relationship between energy prices and energy intensity at the macro level? Have energy-price increases been among the factors triggering the energy-intensity decline in China? Although many analysts have tried to understand China's dramatic energy-intensity decline, very few of them have correlated energy prices with energy intensity or energy efficiency. Generally, at an aggregate level, analysts neglect price measures in their macroeconomic modeling. Analysts' neglect of the price factor may be explained by the following two factors. First, China had a government-controlled pricing system in the energy sector before 1993. Second, debates about why energy intensity has been falling have centered mainly on the relative roles of technological change within individual sectors and structural change between sectors (Garbaccio, et al., 1999); however, prices also have their effect on energy intensity. Consistent with Fisher-Vanden et al. (2004), recent macroeconomic studies on energy intensities of some OECD countries (Kaufmann, 2004; Miketa, 2001; Verbruggen, 2003) show the "inducement effect" of energy prices on energy intensity and efficiency improvements, i.e., how price increases reduced the energy intensity and lead to energy-efficiency improvements.

Without price as an explanatory variable, this type of interpretation of China's energy-intensity decline may be misleading. Specifically, omission of the important price variable may lead forecasts of energy use, energy security, and carbon emissions to be built upon an invalid assumption that China's energy intensity will decline over time for reasons unrelated to energy prices. It also may lead policy makers to create some inappropriate energy and technology policies targeted at energy conservation and carbon-emission control in China. Hence, I will conduct a systematic investigation of energy prices and energy intensity. I will use a set of economic models, making use of the input-output techniques and econometric models, and adapting them to bridge the gap between them.

1.3 Hypothesis and Questions

As stated earlier, China's energy intensity and energy prices have generally experienced opposite growth trends over the last two decades, one decreasing and the other increasing. Studies show that energy intensity had a negative elasticity with respect to energy prices in some Organization for Economic Co-operation and Development countries (Miketa, 2001; Verbruggen, 2003; Kaufmann, 2004). However, energy prices are omitted in the analytical framework in most studies on China's energy intensity. Hence, in this study I include both energy prices and energy intensity together in the analytical framework and look at the effect, if any, of China's energy price changes on its energy intensity. I hypothesize that China's energy intensity is negatively related to energy prices and further test and extend Fisher-Vanden et al.'s study at an aggregate level. Specifically, I examine the following questions empirically:

1. Did the overall economy react to energy-price changes, or, in other words, did energy-price changes induce the decrease of energy intensity in China?
2. Did the impact of energy prices on energy intensity apply in the industry sector? Was the industry sector more sensitive to energy-price changes than the overall economy and adjust its energy intensity more when it faced the same amount of energy price changes?
3. How did energy-price changes affect energy-intensity improvements in China through technological changes and structural shifts? What were the relationships of prices to both energy-efficiency improvements and structural shifts, respectively?

1.4 Summary

Along with energy intensity declines, China's energy prices were affected by the central-government regulation, but they increased generally in the past two decades. Yet, analysts except for Fisher-Vanden et al. (2004) omit the factor of energy prices in their analytical frameworks and models of energy consumption and intensity. Although one of their results show the negative impacts of energy prices on energy intensity, Fisher-Vanden et al. (2004) based their study on a short and special period of time and a limited set of energy-intensive sectors, such as the steel and iron industry, and large and medium-sized enterprises.

However, at a broader level, the opposite trends of China's energy intensity and energy prices over the last two decades may have some internal relationship across both enterprise sizes and economic sectors. In terms of energy intensity, China may possess the same features over time as some other countries: energy intensity is negatively related to energy prices, i.e., as prices increase, the intensity decreases. The negative correlation between energy prices and energy intensity seems easy to understand. However, in practice, most forecasts of energy use, energy security, and carbon emissions are built upon an assumption of an autonomous energy-intensity decline, which is independent of energy prices. Empirical studies of the energy-price effect on energy intensity are few. (Kaufmann, 2004)

Chapter 2

Methodology and Data

Analysts have used different quantitative models to explore this energy intensity issue in China. These economic models include structural decomposition analysis (SDA), shift-share analysis, a vector error-correction model, Divisia-decomposition method, Laspeyres-decomposition approach, and multivariable regression. I follow the quantitative tradition of the analysis on energy intensity, but build my study on two complementary models, combining accounting and behavioral models. I assume that energy-consumption savings and the consequent energy-intensity changes can be decomposed into the effects of technological changes, or, in other words, energy-efficiency changes, and of structural shifts. I also assume that the energy efficiency and structural shifts have different effects on the relationship between energy intensity and energy prices.

2.1 Structural Decomposition

Given the limitations of different research methodologies and my study objectives, I first use a comprehensive SDA model to decompose energy-consumption savings into two effects: technological-change effects and final demand-shift effects. This model provides a comprehensive view of economic interdependence.

The SDA model is mathematically derived from the input-output model, whose structure is expressed as:

$$AX + Y = X \tag{1}$$

where X = matrix of gross output of every sector;
Y = matrix of final demands for all the sectors; and
A = matrix of direct input coefficients, which shows the inputs required to produce one unit of gross output.

Starting from the conventional monetary input-output tables, I incorporate into them physical energy flows in comparable thermal units across different energy types. Then, I can use the hybrid energy input-output tables, which are preferable to the ones from the conversion approach[1] because the latter introduce inconsistencies in accounting for energy consumption and often need to be adjusted to satisfy energy-conservation conditions (Miller and Blair, 1985; Lin 1996).

Within the framework of the energy input-output tables, the overall energy consumption is the sum of a composition of two parts, that is, direct energy consumption by final users and intermediate energy consumption by intermediate producing sectors. Through the intermediate transactions, I can trace the energy consumption back to those incumbent in the inputs of any energy or non-energy product before the product goes to the final demand, including the production process and transportation process in supply-chain analyses. This hybrid table thus gives me fairly complete information on the origin of final-consumer products or how production processes use energy directly and indirectly. Then, after some mathematical transformations, I can use the SDA

---

[1] "Analysts using the output-conversion approach first compute energy requirements in terms of output values and then convert those values into physical energy units using output-to-energy ratios". (Lin, 1996)

model to decompose energy-use change into two components: one due to the final-demand shift and the other due to production-technology change.

$$\begin{aligned} \Delta E &= FR[Y - YR] + e[Y - YR]n && \text{(final-demand shift)} \\ &\quad + [F - FR]\,Y && \text{(production-technology adjustment)} \end{aligned} \tag{2}$$

where $F = e[(I-A)^{-1} - I]$;

A is the direct coefficient from hybrid energy input-output tables;
e is a matrix consisting of ones and zeros, with ones in the diagonal locations corresponding to the upper left quadrant of energy sectors within the whole matrix, and zeros in all other elements of the matrix. The e matrix selects the energy rows from the input-output tables;
FR is the F matrix of the reference year;
Y is the vector of final demand;
YR is the vector of the final demand in the reference year; and
n is a matrix consisting of ones and zeros, with ones in the diagonal locations corresponding to those columns that are neither imports, exports, nor inventory changes, and zeros in all other elements of the matrix. It excludes energy imports, exports, and inventory changes from the calculation of direct energy consumption.

Using this formula, I can answer the question of how much more/less energy would have been required in current year (for example, 1987) if the reference year's (for example, 1981) production technology had still been used to satisfy the current (1987) final demand.[2] Then, I can examine the main question concerning energy intensity changes which I discuss in more detail later, the question which is how much of energy intensity changes is due to technological changes. Finally, I examine how energy-price changes and energy-intensity changes are related to production-technology improvements.

---

[2] If the question is how much less/more energy would be used in reference year (1981), for example 1981, if the current production technology, for example 1987's, had been available to deliver reference year's, i.e. 1981's, final demand, the formula subject to use is as follows.

$$\begin{aligned} \Delta E &= F[Y - YR] + e[Y - YR]n && \text{(final-demand shift)} \\ &\quad + [F - FR]\,YR && \text{(production-technology adjustment)} \end{aligned}$$

Furthermore, I can use the SDA model to decompose direct and intermediate energy consumption into more detail, as follows.

Table 2.1: Structural Decomposition of Energy-Use Changes

Factor	*Equation*□
Final-Demand Shift	$F[Y - Y_R] + e[Y - Y_R]n$
Level Effect	$F_R M_R D_R(L - L_R) + eM_R D_R(L - L_R)n$
Distribution Effect	$F_R M_R(D - D_R)L + eM_R(D - D_R)Ln$
Pattern Effect	$F_R(M - M_R)DL + e(M - M_R)DLn$
Production-Technology Adjustment	$[F - F_R]Y$
Energy Inputs	$eG(A^E - A_R^E]G_R Y$
Nonenergy Inputs	$eG(A^N - A_R^N]\ G_R Y$

Where $F = e[(I-A)^{-1} - I]$;
e is a matrix, consisting of ones and zeroes, with ones in the row locations corresponding to energy sectors and zeroes in all other elements of the matrix, which is used to select the energy rows from the input-output table;
I is an identity matrix;
A is the matrix of technological coefficients;
Y is the vector of final demand (i.e., gross domestic product);
R subscript signifies the corresponding measures for the reference year;
n is a matrix consisting of ones and zeroes, with ones in the diagonal locations corresponding to those columns that are not imports, exports, and inventory changes and zeroes in all other elements of the matrix. It excludes energy imports, exports, and inventory changes from calculation of direct energy consumption;
G = (I-A)-1;
M is the matrix of spending mix of individual final demand sectors;
D is a diagonal matrix with the sectoral distribution of total final demand on the diagonal;
L is a diagonal matrix with the overall total final demand level on the diagonal;
E superscript indexes the direct use of energy inputs like coal, oil, and electricity; and
N superscript indexes the non-energy sectors.

Source: Lin (1996)

Although it is a comparative static model and has some other limitations, the SDA model provides a comprehensive accounting framework to examine some energy-consumption and energy-intensity issues. The SDA model integrates energy data into an input-output accounting framework and provides a unified macro framework for describing the relationships between energy, other factor inputs, and other final products, and consequently, the relations between energy and the economy (Lin, 1996). Hudson and Jorgenson (1978) have pointed out that since the output of the energy producing industries is largely utilized by other non-energy industries rather than by final consumers, the matrix of interindustry transactions, representing flows of commodities including energy among industrial sectors, is a natural focal point for the study of the impact of energy policy.

First, I use the SDA model to describe the economy as a system of interdependent activities. The model enables me to "trace the effect of a particular final-product consuming decision back through to the product's producer, to the companies that supply intermediate inputs to the producer, and all the way back to the raw-material processors".(Lin, 1996) Second, together with some transformation, I can use the decomposition approach to measure the price effects on energy intensity from both technological-change and final-demand shift perspectives, among which the latter reflects the shifts of producing sectors. Third, I can use the model to study price effects on different subcomponents of final demand and production technology.

2.2 Econometric Model

In a static or comparative static input-output model, the transactions between different economic sectors are provided. Specifically, with the SDA model, an analyst can trace the demand/consumption changes of energy induced by the changes of final demand and decompose total energy consumption change into two subcomponents, which are the effects of final demand shift and production technology adjustment. The hybrid energy input-output tables and the SDA model provide a powerful tool to capture all the energy components of any final product. However, both of them are only accounting, not behavioral, methods. The dynamic aspect of the interaction between demand and energy prices, which is conceptualized as the price elasticity, cannot be measured in the SDA model. An analyst cannot capture the substitution effect due to the price changes. Econometric models provide a tool for the incorporation of behavioral and technological responses of production and consumption to alternative energy prices. Analysts can use them to determine the impact of energy prices on the demand for energy, non-energy intermediate goods, capital services, and labor services. (Hudson and Jorgenson, 1978) Consequently, I henceforth use econometric models to quantify the relationship between energy intensity and energy prices.

In this study, I use two econometric regression models to examine the correlation between energy prices and energy intensity and energy efficiency in China, primarily over time. They are from econometric studies on energy-demand. I revise the functional specification of one of them to describe the energy prices and energy-intensity relationship. Specifically, the two models are a dynamic partial adjustment model and a dynamic optimization model on energy consumption (Berndt and Field, 1981), both of which provide the starting point for the functional specifications for the price- elasticity analysis on energy intensity.

The two models are effective and data-manageable in China at a microeconomic level. I assume there are only two kinds of variable inputs, energy and non-energy inputs and two kinds of semi-fixed inputs of capital and skilled labor. Hence, for the purposes of this study, I use the functional specifications from a single-equation partial adjustment model and a well-defined dynamic optimization model, as follows.

$$E_t = \alpha + \beta EP_t + \delta MP_t + \phi GDP_t + (1-\omega)E_{t-1} + \varepsilon \qquad (3)$$

$$EI_t = \alpha + \beta T + \lambda EP_t + \phi MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \varepsilon \qquad (4)$$

where E_t is the actual amount of energy consumption at time t;
E_{t-1} is the energy consumption at time t-1;
GDP_t is gross domestic product or value added at time t;
EI_t is the energy intensity at time t;
EP_t is the aggregate energy price at time t;
MP_t is the price for non-energy intermediate materials at time t;
K_{t-1} is the number of total capital assets at time t-1;
SL_{t-1} is the amount of skilled labor at time t-1(K and SL are two quasi-fixed inputs);
T is a time counter variable from 1 to T; and
ε is a error term.

Both models conform to the Marshallian framework about energy consumption implicitly by lagging the dependent variable or incorporating a dynamic economic-optimization process of costs of adjustment for the quasi-fixed factors. Although the second model is more complex and provides a richer and clearer economic interpretation of the energy-substitution process, analysts still use and prefer the first one in some cases due to the tradeoff of data availability and model complexity (Berndt and Field, 1981). In this study, I use both to investigate questions about energy intensity and energy prices. What is more, because of its simplicity and flexibility, I use the first partial-adjustment model more than the second explicit dynamic-optimization model.

Because the log specification is convenient for measuring elasticities, I choose the log-specification as the functional format for the partial-adjustment model. I also choose it because log specification provides a convenient and sound basis for the transformation from the partial-adjustment model of energy demand to a model of energy intensity. Dividing by GDP on both sides of the distribution equation,[3] I obtain the energy intensity on the left side as the dependent variable, instead of the energy demand. Then I follow the point that the partial adjustment model of energy demand and incorporate a lagged energy intensity variable in the functional specification. At this point, I have the following two models to analyze the questions presented earlier.

$$\ln EI_t = \alpha + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + (1-\omega)\ln EI_{t-1} + \varepsilon \tag{5}$$

$$EI_t = \alpha + \beta T + \lambda EP_t + \varphi MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \varepsilon \tag{4}$$

Equation 5 is from the log-linear partial adjustment model of energy demand without the restrictions of long-run constant returns to scale and of factor demand theory that input demand functions are homogeneous of degree zero in factor prices. In this functional specification, ω is the proportional adjustment rate within the range of 0 and 1. 1/ω is the duration of time for full adjustment. The short-run own-price elasticity is β and the long-run energy own-price elasticity of energy intensity is equal to β divided by ω. Both

---

[3] The distribution equation refers to the partial adjustment equation, but net of the addition of the lagged energy consumption variable.

elasticities are expected to be negative, meaning that holding everything else constant, when relative energy prices increase, energy-intensity declines. In the case of constant personal income, consumers decrease their consumption of energy through behavior adjustment or new investment, for example, shifting from private transportation to public transit for commuting, when facing higher energy prices. The energy intensities for these consumers accordingly decrease. Similarly, the corresponding energy-intensity elasticities with respect to prices of non-energy inputs are δ and δ divided by ω in the long and short run. I expect both elasticities to be positive. When the prices of non-energy inputs increase, the energy intensity increases, holding everything else constant.

However, from the Equation 3 based functional specification[4] to (5), the coefficient of lnGDP changes from φ to (φ-1), which implies that the coefficient of LnGDP in Equation 5, λ, may be negative, depending on the GDP elasticity of energy demand in the specification (1). According to economic theory, we expect that the energy demand has a positive elasticity with respect to GDP, but it may, in fact, be either inelastic or elastic. When the energy demand increase is more than proportional to the increase in GDP, energy demand is elastic with respect to GDP; otherwise, when it is less than proportional, energy demand is inelastic. U.S. manufacturing has a positive output elasticity of energy demand, but it is inelastic from 0.1 to 0.36. (Berndt and Field, 1981, Ch. 12) When the energy-demand elasticity with respect to GDP is less than 1, the coefficient of lnGDP in Equation 5, that is, the energy-intensity elasticity with respect to GDP, is negative. Otherwise, it is positive. The short-run and long-run elasticities of

---

[4] This specification is based on Equation 3 but with the lagged dependent variable removed. The partial adjustment concept will be utilized later in the newly formed energy intensity model.

energy intensity with respect to output are λ or (φ-1) and λ or (φ-1) divided by ω, respectively.

Equation (4) is employed by C. J. Morrison and E. R. Berndt. It is the short-run energy-output demand equation from the dynamic-optimization model. The short-run energy intensity (energy input-output coefficient) is affected by prices of the variable inputs of energy and non-energy intermediate materials, output quantity, stocks of the quasi-fixed inputs K and SL, and the state of technology. The short-run own-price elasticity of energy intensity is $\varepsilon_{EEI}^{SR} = \varepsilon_{EEC}^{SR} = (EP/EI)*\lambda$.[5] I expect negative coefficient estimates for normalized energy prices, capital assets over GDP, and skilled labor over GDP, according to the Berndt, Fuss, and Waverman's studies on the energy consumption of the U.S. manufacturing. In their work, energy and capital assets, as well as energy and skilled labor, were complements. (Berndt and Field, 1981)

In terms of error terms in the two functional specifications, it is hard to define their properties. They may have heteroskedasticity, autocorrelation, and autocorrelation with a lagged dependent variable, given the fact that I examine the topic on energy prices and energy intensity in time series and China has been experiencing dramatic policy and market changes. The null hypotheses will provide an answer.

---

[5] I derived the short-run own-price elasticity of energy intensity as follows: similar to the derivation of the short-run own-price elasticity of energy consumption of $\varepsilon_{EEC}^{SR} = (\mathrm{EP/E}) * \mathrm{GDP} * \lambda$, I hold capital assets, skilled labor, and prices of non-energy intermediate materials constant in the short run, the own-price elasticity of energy intensity is: $\varepsilon_{EEI}^{SR} = \Delta EI/\Delta EP*(EP/EI) = (EP/E)*GDP*\lambda = \varepsilon_{EEC}^{SR}$.

In this study, as I mentioned earlier, I obtained all the data from published statistical or census books.[6] The 1980-2002 time series for modeling of the overall economy and the industry sector are annual (Appendices A and B). I calculate all money values at 1979 constant prices. For all price indices, I also use 1979 as the base year. Because the data series of energy intensity, GDP, and prices are highly trended, I include T, the time-counter variable in the partial-adjustment model to detrend the time-series data. In the functional specification of the dynamic-optimization model of energy consumption, T not only stands for the technology, it also functions to detrend the data series in the regression. After I modify the partial-adjustment model, the models are:

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \gamma \ln EI_{t-1} + \varepsilon \qquad (6)$$

$$EI_t = \alpha + \beta T + \lambda EP_t + \gamma MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \varepsilon \qquad (4)$$

As mentioned earlier, some analysts, such as Smil (1990) and Kambara (1992) argue that China's energy-intensity decline is mainly due to industrial structural shifts. It may be one factor bringing down the energy intensity. In order to measure the energy price effect on energy intensity properly, I first need to purge the effect of structural shift on energy intensity. I incorporate a new independent variable, the structural shift, in the partial-adjustment model. Structural shift measures the value-added share of several energy-intensive sectors among all sectors. To obtain the appropriate energy-intensive sectors, I process the selection at a two-digital industry classification level (Appendix G).

---

[6] Books include the *China Energy Databook* by China Energy Group at the University of California, Berkeley, the annual *China Statistical Yearbook*, *China Labor Statistical Yearbook*, *China Population Statistical Yearbook*, *China Census Booklet 1982* (Zhongguo 1982 nian ren kou pu cha zi liao), and *China Science and Technology Statistical Data Book*. In order to keep consistency in terms of sector classification, measurement coverage, and statistical method as much as possible, I mainly use data from various editions of the *China Statistical Yearbook*. I obtain some figures for several data series from other data sources when they are not available in the *China Statistical Yearbook*, for example, the skilled labor amount in 1982.

Second, because some analysts argue that energy-intensity declines in China are due to energy-efficiency improvements and the fact that technology improvement is usually significantly related to research and development (R&D) expenditures (Popp, 2002), I incorporate another variable, namely, of R&D expenditures, in the partial-adjustment model to purge its effect on energy intensity. I calculate the measure based on the R&D expenditure ratio to GDP for some years.[7] RD is R&D expenditures in the functional specifications.

Finally, to allow for the fact that China's Central Government has gradually removed its control on energy prices since late 1992, I add a dummy variable of policy change, MKT, to the two basic models. This enables me (a) to measure if the energy-pricing policy change alters energy intensity in China, holding other factors constant, and (b) to capture the energy-price change effect on energy intensity, controlling for the effect of the policy change. I assign 0 to MKT for the years before 1993 and 1 for the other years. I expect a negative coefficient estimate of this dummy variable because this policy change in energy pricing should have the same impact on energy intensity in terms of the direction as energy price changes, if any. Consumers may realize that this energy-pricing change towards a market-oriented one would stay forever and take it into account as they budget their energy expenditures. It turns out that the energy intensity

---

[7] I gathered the expenditure data for the overall economy from 1987 to 2002 in China S&T Statistics Data Books. I assume that the ratios from 1980 to 1986 are constant and are the average of those in the late 1980s. However, only for 2000 is the R&D expenditures ratio for industry sector available. I use the R&D expenditures of the overall economy to represent those of the industry sector, implicitly assuming that the structures of R&D expenditures by sectors do not change over time.

may be more economical in the context of the new market-oriented energy pricing system. Although the own-price elasticity of energy intensity does not change, consumers lower their energy intensity more in the new energy pricing system than in the previous controlled pricing system.

In addition, I compose an interaction term of MKTEP from the dummy variable and the variable of energy prices, in a log form or regular form, depending on the functional specifications in each of the particular models. I use this regressor to examine whether the energy-price effect on energy intensity depends on whether or not the central government controls energy pricing. For the interaction term, I expect a negative coefficient estimate. A negative coefficient estimate of the interaction term means that consumers have a larger own-price elasticity of energy intensity in absolute value in the new market-oriented energy pricing system than that in the controlled pricing system. Facing the same amount of energy price increase, consumers decrease their energy intensity more in the market-oriented pricing system than they do in the controlled system.

In summary, the functional specifications that are helpful in hypothesis testing and empirical studies are[8]:

$$EI_t = \alpha + \beta T + \lambda EP_t + \gamma MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \varepsilon \tag{4}$$

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \gamma \ln EI_{t-1} + \varepsilon \tag{6}$$

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \eta \ln SS_t + \gamma \ln EI_{t-1} + \varepsilon \tag{7}$$

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \eta \ln RD_t + \gamma \ln EI_{t-1} + \varepsilon \tag{8}$$

---

[8] The absence of Equation 5 in this set of equations is because it is produced for the derivation of Equation 6.

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \varepsilon \ln SS_t + \eta \ln RD_t + \gamma \ln EI_{t-1} + \varepsilon \tag{9}$$

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \varepsilon MKT + \gamma \ln EI_{t-1} + \varepsilon \tag{10}$$

$$\ln EI_t = \alpha + \theta T + \beta \ln EP_t + \delta \ln MP_t + \lambda \ln GDP_t + \varepsilon MKTEP + \gamma \ln EI_t + \varepsilon \tag{11}$$

$$EI_t = \alpha + \beta T + \lambda EP_t + \gamma MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \delta MKT + \varepsilon \tag{12}$$

$$EI_t = \alpha + \beta T + \lambda EP_t + \gamma MP_t + \rho K_{t-1} / GDP_t + \omega SL_{t-1} / GDP_t + \delta MKTEP + \varepsilon \tag{13}$$

Equations 4 and 6 are the two basic models: the partial adjustment model and the dynamic-optimization model. Equations 7 through 11 are extended partial models, and Equations 12-13 are extended dynamic models. However, the applicability of the functional specifications is still subject to null hypothesis testing, especially that of the partial-adjustment model.

2.3 Decomposition of Own-Price Elasticity

The econometric models discussed in Section 2.2 provide a way to measure generally the dynamic relationship between energy prices and energy intensity. However, energy intensity is not an indivisible unit and its changes could be caused by two fundamentally different factors: final-demand shifts and real energy-efficiency improvements (production-technology improvements). In order to measure the potentially different effects of energy-price changes on these two energy-intensity change components, I decompose the own-price elasticity of energy intensity. Conceptually, I think that part of the own-price elasticity change of energy intensity is due to efficiency improvements and the remaining part is due to the structural shifts. I start by introducing the decomposition of energy consumption changes and energy-intensity changes into the partial-adjustment model.

First, I examine the energy-intensity changes.

$$\begin{aligned} EI_t &= E_t / GDP_t = (E_{t-1} + \Delta E) / GDP_t \\ &= E_{t-1} / [GDP_{t-1}(1+g)] + \Delta E / GDP_t \\ &= EI_{t-1}[1 - g/(1+g)] + (\Delta E^{shift} + \Delta E^{improvement}) / GDP_t \\ &= EI_{t-1} - EI_{t-1} g/(1+g) + \Delta E^{shift} / GDP_t + \Delta E^{improvement} / GDP_t \end{aligned} \tag{14}$$

where g is the growth rate of GDP;

ΔE^{shift} is the energy consumption changes due to the final-demand shift effects;
$\Delta E^{improvement}$ is the energy consumption changes due the technology-improvement effects, which, together with ΔE^{shift}, is from the SDA modeling;
E_t is the energy consumption at time t;
EI_t is energy intensity at time t;
GDP_t is the gross domestic product at time t.

Subtracting EI_{t-1} from both sides of the above equation,

$$\begin{aligned} \Delta EI &= EI_t - EI_{t-1} \\ &= -EI_{t-1} g/(1+g) + \Delta E^{shift} / GDP_t + \Delta E^{improvement} / GDP_t \end{aligned} \tag{15}$$

To this point, I decompose energy intensity changes into final demand shift effect, production technology adjustment effect, and an undefined component of $-EI_{t-1} g/(1+g)$, which is related to the previous period's energy intensity and growth rate, which will be clarified after some transformations. Assuming that there is neither a structural shift effect nor a technology-improvement effect on energy consumption change, energy consumption grows at the same rate as GDP. In other words, controlling for the effects of structural shifts and production-technology adjustments on energy consumption, energy consumption grows at the same rate of g with GDP.

$E_t = E_{t-1}(1+g)$, that is, $\Delta E^{growth} = E_{t-1} g$ (16)

ΔE^{growth} is the pure growth effect of energy consumption, net of structural shift and technological improvement. Then, we have:

$$\begin{aligned}\Delta EI &= -EI_{t-1}g/(1+g)+\Delta E^{shift}/GDP_t+\Delta E^{improvement}/GDP_t \\ &= -E_{t-1}g/[GDP_{t-1}(1+g)]+\Delta E^{shift}/GDP_t+\Delta E^{improvement}/GDP_t \\ &= -\Delta E^{growth}/GDP_t+\Delta E^{shift}/GDP_t+\Delta E^{improvement}/GDP_t \\ &= (-\Delta E^{growth}+\Delta E^{shift}+\Delta E^{improvement})/GDP_t\end{aligned} \tag{17}$$

Hence, the energy-intensity change is the joint result, with GDP at the current level, of three components of the energy-consumption changes: those due to the pure final demand growth, final demand shift, and technological improvement. However, this decomposition is not mutually exclusive. Pure final demand growth is the final demand growth, net of structural change. Final demand shift includes both structural shift and final demand growth. Hence, I can integrate these two components of energy-intensity change into the structural-shift effect on energy intensity, that is, the final demand shift effect on energy intensity net of demand expansion. Mathematically, the relationship of structural-shift effect on energy consumption with pure final demand growth and final demand shift effects is as follows:

$$\Delta E^{structural} = -\Delta E^{growth} + \Delta E^{shift} \tag{18}$$

Then, the energy-intensity change is the sum of two subcomponents: the structural-shift effect and the technology-improvement effect.

$$\Delta EI = \Delta E^{structural}/GDP_t + \Delta E^{improvement}/GDP_t = \Delta EI^{structural} + \Delta EI^{improvement} \tag{19}$$

Second, I incorporate the decomposed energy-intensity changes into the dynamic-optimization model.

$$EI_t = \alpha + \beta T + \lambda EP_t + \phi MP_t + \rho K_{t-1}/GDP_t + \omega SL_{t-1}/GDP_t + \varepsilon \tag{4}$$

Lagging Equation (4) by one period, I have:

$$EI_{t-1} = \alpha + \beta(T-1) + \lambda EP_{t-1} + \gamma MP_{t-1} + \rho K_{t-2} / GDP_{t-1} + \omega SL_{t-2} / GDP_{t-1} + \varepsilon_{t-1} \tag{20}$$

The first difference (4)-(20) is:

$$\begin{aligned}\Delta EI = EI_t - EI_{t-1} = \beta + \lambda(EP_t - EP_{t-1}) + \gamma(MP_t - MP_{t-1}) + \rho(K_{t-1} / GDP_t - K_{t-2} / GDP_{t-1}) \\ + \omega(SL_{t-1} / GDP_t - SL_{t-2} / GDP_{t-1}) + \varepsilon - \varepsilon_{t-1}\end{aligned} \tag{21}$$

Incorporating Equation 19 into 21, I have

$$\begin{aligned}\Delta EI^{structural} + \Delta EI^{improvement} = \beta + \lambda(EP_t - EP_{t-1}) + \gamma(MP_t - MP_{t-1}) + \rho(K_{t-1} / GDP_t - K_{t-2} / GDP_{t-1}) \\ + \omega(SL_{t-1} / GDP_t - SL_{t-2} / GDP_{t-1})\varepsilon - \varepsilon_{t-1}\end{aligned} \tag{22}$$

The above equation means that the overall energy-intensity change has a similar functional specification on the right-hand side as the overall energy intensity in terms of incorporated measures and their mathematical relationship, while the dependent and independent variables are not levels at a given time, but changes between two periods. Furthermore, I assume that both of the two models of energy-intensity changes due to structural shifts and technological improvements have the same functional specification as the overall energy-intensity change.

$$\begin{aligned}\Delta EI^{structual} = \beta_1 + \lambda_1(EP_t - EP_{t-1}) + \gamma_1(MP_t - MP_{t-1}) + \rho_1(K_{t-1} / GDP_t - K_{t-2} / GDP_{t-1}) \\ + \omega_1(SL_{t-1} / GDP_t - SL_{t-2} / GDP_{t-1})\end{aligned} \tag{23}$$

$$\begin{aligned}\Delta EI^{improvement} = \beta_2 + \lambda_2(EP_t - EP_{t-1}) + \gamma_2(MP_t - MP_{t-1}) + \rho_2(K_{t-1} / GDP_t - K_{t-2} / GDP_{t-1}) \\ + \omega_2(SL_{t-1} / GDP_t - SL_{t-2} / GDP_{t-1})\end{aligned} \tag{24}$$

(23)+(24),

$$\begin{aligned}&\Delta EI^{structural} + \Delta EI^{improvement} \\ &\quad = \beta_1 + \beta_2 + (\lambda_1 + \lambda_2)\Delta EP + (\gamma_1 + \gamma_2)\Delta MP + (\rho_1 + \rho_2)\Delta(K / GDP) + (\omega_1 + \omega_2)\Delta(SL / GDP)\end{aligned} \tag{25}$$

Finally, I have

$$\lambda = \lambda_1 + \lambda_2 \tag{26}$$

Therefore, the own-price elasticity of energy intensity is decomposed into two portions: the portion due to efficiency improvements, and the portion due to structural shifts of final demand.[9] Similarly, at the three-component level of energy-consumption changes, the first component is the pure final demand growth effect, the second is the final demand shift effect, and the third is the technological improvement effect, as in Equation 17 above. I decompose the own-price elasticity of energy intensity into the corresponding three portions. In this study, I mainly discuss the two-portion method because the three-portion method is jointly exhaustive but not mutually exclusive, and also because the structural shift and technological improvement effects on energy intensity are always debated in the previous studies on China's energy intensity.

Similarly, I can incorporate the decomposed energy-intensity changes into the partial adjustment model of Equation 6. I decompose the energy intensity modeling as follows:[10]

---

[9] The structural shift here refers to the structural shift of final demand, instead of the structural shift among different production sectors, to which economic analysts normally refer. The structural-shift effect is the final-demand shift effect net of pure growth effect. Under the SDA modeling framework, it is similar in concept to the sum of the final-demand distribution and pattern effects, that is, the final-demand effect net of final-demand level effect.

[10] Given that the energy intensity decreases by less than 11%, we have:

$$\begin{aligned}\ln(EI_t / EI_{t-1}) &= \ln(1 + \Delta EI / EI_{t-1}) = \ln(1 + \Delta EI^{structural} / EI_{t-1} + \Delta EI^{improvement} / EI_{t-1}) \\ &= \ln(1 + \Delta EI^{structural}\% + \Delta EI^{improvement}\%) \\ &\cong \Delta EI^{structural}\% + \Delta EI^{improvement}\%\end{aligned}$$

where $\Delta EI^{structural}\%$ is the percent change of energy intensity due to the structural-shift effects;
$\Delta EI^{improvement}\%$ is the percent change of energy intensity due to the production-technology-improvement effects.

$$\begin{aligned}&\Delta EI^{structural}\% + \Delta EI^{improvement}\% \\ &\quad = \delta_1 + \beta_1 \ln(EP_t / EP_{t-1}) + \delta_1 \ln(MP_t / MP_{t-1}) + \lambda_1 \ln(GDP_t / GDP_{t-1}) + \gamma_1 \ln(EI_{t-1} / EI_{t-2}) \\ &\quad\quad + \delta_2 + \beta_2 \ln(EP_t / EP_{t-1}) + \delta_2 \ln(MP_t / MP_{t-1}) + \lambda_2 \ln(GDP_t / GDP_{t-1}) + \gamma_2 \ln(EI_{t-1} / EI_{t-2}) \\ &\quad = \delta + \beta \ln(EP_t / EP_{t-1}) + \delta \ln(MP_t / MP_{t-1}) + \lambda \ln(GDP_t / GDP_{t-1}) + \gamma \ln(EI_{t-1} / EI_{t-2})\end{aligned} \tag{27}$$

and $\beta = \beta_1 + \beta_2$ (28)

As stated earlier, I expect a negative short-run own-price elasticity of energy intensity of λ in Equations 4 and 26 and β in Equations 6 and 28, which means that at least one of the decomposed coefficients in the two-portion approach is negative. Ideally, the short-run own-price elasticity of energy intensity due to efficiency improvements of λ_1 and β_1 is negative. This means that the increase of energy prices induces production-technology improvements and hence energy-efficiency improvements. Consequently, the energy intensity declines with energy-efficiency improvements. In short, energy prices are negatively related to energy intensity through their induced effect on energy efficiency. Popp's study on U.S. patents (2002) shows that energy prices have strongly significant positive effects on innovations in energy-saving technology.

2.4 Data Sources and Limitations

I use data sets of China's national input-output tables, energy-flow data, energy-price indexes, and other macroeconomic data. Professor Chen Xikang, Chinese Academy of Sciences (CAS), provided me a time-series of comparable input-output tables with the same 18-sector classification in 1990 producer prices. They are for the years of 1981, 1987, 1992, and 1995, a total of four years. He also provided energy flows of coal, crude oil, refined oil, natural gas, and electricity in physical units in the corresponding industrial classification and for the same years with those monetary flows in the input-output tables. His provision of these data made the SDA analysis in this study possible. Unfortunately, there are no national input-output tables in constant prices for the recent years. Due to this limitation, I had to limit my decomposition-econometric study to the years from 1980 to 1995.

These tables and energy-flow data are the research results of the Joint Research Team of the Institute of Systems Science (ISS), CAS, and Shaanxi Institute of Economics and Finance (SIEF). They constructed the 1981 table in this set of tables on the basis of the 1981 table for 26 sectors, which was compiled according to the Material Production System (MPS), following the Russian practice, rather than the System of National Accounts (SNA), by the Forecasting Center of the State Planning Commission of China and the State Statistical Bureau of China (Polenske and Chen, 1991). They reconstructed the remaining tables as follows:

1. The 1987 table on the basis of the 1987 table of 117 sectors, which was compiled by the Department of Balances of National Economy of the State Statistical Bureau and Office of the National Input-Output Survey.
2. The 1992 table on the basis of the 1992 table of 118 sectors, compiled by the Department of Balances of National Economy of the State Statistical Bureau.
3. The 1990 table by using improved RAS methods (a technique for balancing tables with fixed row and column totals), 1990 statistical data, and the 1987 direct input coefficients.

4. The 1995 table by using the same methodology as for the 1990 table. (Guo, 2000)

In all these tables, there are four energy sectors: coal, oil, natural gas, and electricity. Both the energy production sectors and non-energy production sectors are summarized in Table 2.2. Within this sectoral classification, energy-intensive sectors are presented at a more disaggregated level than the rest of the economy. Eight final demand users are also presented in Table 2.2 as follows.

Table 2.2: Eighteen Production Sectors and Seven Final-Demand Sectors in SDA Models

Code	Sector
Production Sectors	
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 and Telecommunication
16	Commerce
17	Passenger Transport
18	Services
Final Demand Users/Sectors	
19	Urban Residents
20	Rural Residents
21	Social Consumers
22	Fixed Assets Formation
23	Change in Stock
24	Export
25	Import
26	Others

Source: Input-output tables in constant producer prices, Joint Team of ISS and SIEF.

In terms of the coke-flow data, I gather them from the energy consumption by sectors and energy/coke balance tables in series of China's Statistical Yearbooks and China Energy Statistical Yearbooks. The allocation of these coke-flow data in the hybrid input-output tables is relatively rough, but based on the industrial classifications of the input-output tables (Appendix I) and the China Standard Industrial Classification Code. Up to this point, the energy-flow matrix shows the flows of six different energy products being consumed by all eighteen production-sectors and by eight categories of final demand in the input-output tables. The six energy products are coal, coke, crude oil, refined oil, natural gas, and electricity, covering significant parts of primary energy and secondary energy, respectively.

After gathering all the energy-flow data in their individual physical units, I convert these energy data in physical units into thermal units, that is, standard coal equivalent (SCE), according to their average net caloric values or lower heating values, using conversion factors given in Table 2.3. Lastly, I aggregate them into four categories, that is, coal, oil, natural gas, and electricity, based on the conversion efficiency (Table 2.4) and input-output relationship, which make them fit into the four energy sectors in the input-output tables. In the oil and coal sector, respectively, the self-consumption of energy is calculated using the following formula:

Self-consumed energy = total crude oil/coal
- sum(crude oil/coal used by other sectors)
- sum(oil products/coke used by other sectors)/conversion efficiency

Table 2.3: Conversion Factors to Standard Coal Equivalent

			1981	1987	1992	1995
Coal	kgsce/kg	0.71				
Coke	kgsce/kg	0.97				
Crude Oil	kgsce/kg	1.43				
Refined Oil	kgsce/kg		1.447	1.449	1.452	1.454
Natural Gas	kgsce/m3	1.33				
Electricity	kgsce/kwh		4.07	4.02	3.89	3.96

Source: China Statistical Yearbook (CSYB) and the calculation of the author
Note: The conversion factors for refined oil are the weighted averages of four major refined oil products of fuel oil, gasoline, kerosene, and diesel for any given year.

Table 2.4: Conversion Efficiency (%)

	Oil Refinery	Coking
1981	99.1	90.9
1987	98.8	90.5
1992	96.8	92.7
1995	97.7	92.0

Source: China Energy Statistical Yearbook

Then, all the monetary values of energy outlays of coal, oil, natural gas, and electricity in the input-output tables are replaced by their thermal values. Thus, the hybrid input-output tables are constructed and all energy products are primary energy except electricity, but not all commercial primary energy are included. I incorporate a hypothetical hydropower and nuclear power sector into the hybrid input-output tables following the approach used by Lin (1996) 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. The hydropower and/or nuclear sector sell all its output to the electricity sector for power generation and get all of its input from the earth, not from other intermediate sectors. Each of these hybrid input-output tables has the same number of purchasing and producing intermediate sectors.

Energy prices for econometric modeling are in index form and are at a highly aggregated level. The general energy price index (Figure 4.1) is the weighted average of energy prices of the three primary energy types, weighted by their individual energy consumption in physical quantities from the published *China Statistical Yearbook*. Other data, such as the GDP, the fixed assets, technical personnel, etc., are from various statistical books published by the National Statistical Bureau of China, and are processed according to certain assumptions and empirical study practices.[11]

I present the original time-series data sets of China's overall economy and its industry sectors for econometric modeling in Appendices A and B,[12] respectively, and their descriptive statistics in Appendices C and D. In addition, the simple correlation matrices of the regressors are in Appendices E and F.

Although the data I use for the analysis of China's energy prices and energy intensity are generally reliable, there are some limitations, primarily of three kinds. First, the hybrid input-output tables are at a rather high level of sectoral aggregation. Some of the final demand shift effect at a finer level of sectoral classification on energy savings may be accounted for as the effect of technological changes. (Lin, 1996) The price-technology effect on energy intensity may be upwardly biased. Second, the SDA analysis is not annual, due to the lesser frequency of input-output table compilation in

---

[11] The process and the resulting date are compiled in appendices.

[12] One of the difficulties of data collection is the inconsistency of statistical items. Although most of my data are from various editions of *China Statistical Yearbook*, the statistical content changes frequently.

China. I assume a constant pattern, that is, the relative importance expressed as a ratio, of production technology adjustment effect and final demand shift effect on energy savings. The decomposed own-price elasticity of energy intensity may be biased either upward or downward. Third, some of the data in one time series have to rely on some other assumptions due to the gradual reform of China's statistical system. The different fine level and the inconsistency of industry classification between different years of those statistical data bring about more difficulties. They produce some measurement errors for econometric modeling.

2.5 Summary

In order to assess the hypothesis of the negative relationship between China's energy intensity and energy prices empirically, I utilize the structural-decomposition model, an input-output-based model, and two econometric models, which I obtained from econometric energy-demand studies. The two models are complementary. I connect them through the decomposition of energy-consumption savings. First, I use econometric models to measure the price elasticity of overall energy intensity. Second, I decompose energy-intensity changes into the two portions of the structural shift and production-technology improvement effects, assuming that energy consumption grows at the same rate as GDP when there is no structural shift and technological improvement. I derive the effects on energy intensity of structural shifts and energy-efficiency improvements using SDA analysis, in which I decompose energy-consumption changes into final-demand shift effects and production-technology improvement effects. Third, I use the decomposed energy-intensity changes to measure the own-price elasticity of energy intensity due to structural shifts and also due to energy-efficiency improvements in econometric models.

In this study, as I mentioned earlier, I obtained all the data for econometric studies from published statistical or census books. The 1980-2002 time series for modeling of the overall economy and the industry sector are annual (Appendices A and B). Four Input-output tables in 1990 constant prices and energy-flow data of coal, crude oil, refined oil, natural gas, and electricity are for 1981, 1987, 1992, and 1995, were provided by Professor Chen Xikang, Chinese Academy of Sciences. Coke-flow data are basically from various editions of *China Statistical Yearbook and China Energy Statistical Yearbook.*

Chapter 3

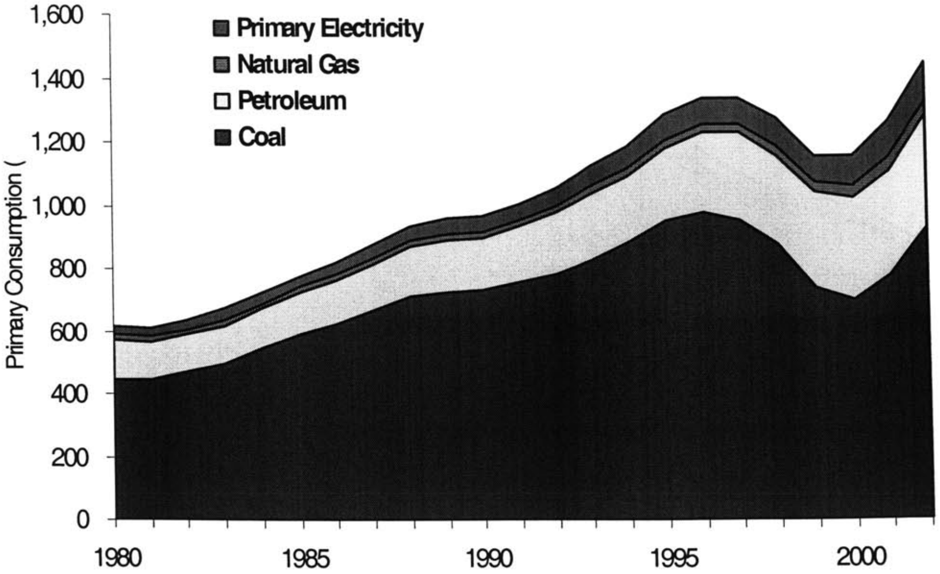
Decomposition of Energy Consumption

3.1 Energy Consumption and Energy Intensity

Since late 1978 when China implemented a “reform and open door” policy, its economy and energy consumption have been growing rapidly. During the years 1978–2002, the gross domestic product (GDP) increased by 9.3% (CSYB, 2003) annually, but the energy consumption rises at a lower rate of 4%. The growth of China’s GDP outpaces that of the energy consumption, indicating the decreasing of energy intensity.

Generally speaking, China’s total energy consumption has been increasing from 602.8 Mtce (Million tones of coal equivalent) in 1980 to 1,480 Mtce in 2002. The consumption has therefore more than doubled. The four types of primary energy: coal, petroleum, natural gas, and hydro-power (primary electricity), account for 72.2%, 20.7%, 3.1% and 3.4%, respectively, in 1980 and for 66.1%, 23.4%, 2.7%, and 7.8% respectively, in 2002. China has been shifting its energy consumption from coal to petroleum and hydro-power, but coal consumption still dominates the energy market. China’s energy consumption experienced a dip after a continuous increase in the 1980s and early 1990s, which was mainly caused by the reduction in industry demand. (Figure 3.1)

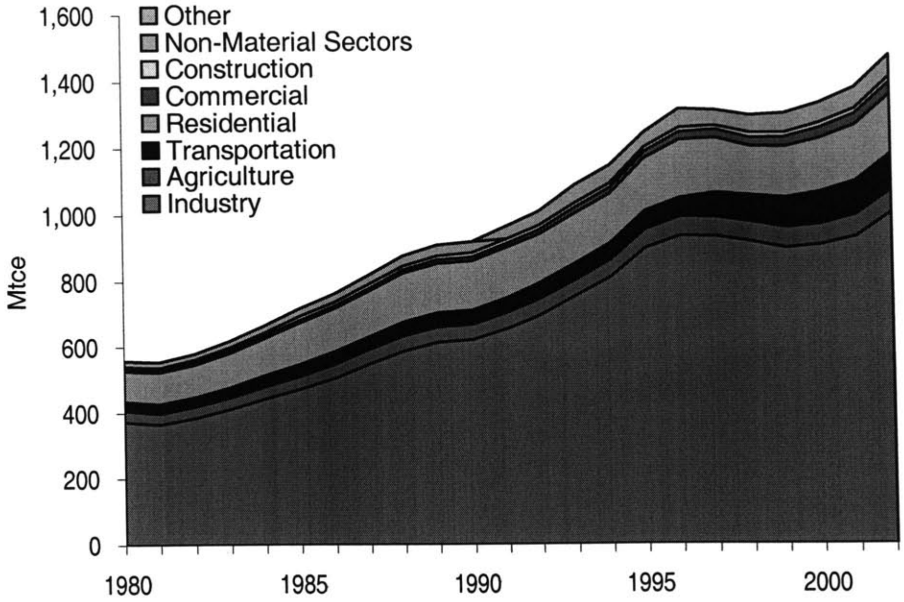
Figure 3.1: Primary Energy Consumption by Type



Source: China Energy Group (CEG), 2004, China Energy Databook 6.0

Among all the consumers by economic sectors, the industry sector is the largest and dominates energy consumption in China. Energy consumption in the industry sector accounts for about 67% over the entire investigated period, and most of the changes in total energy consumption arose from that sector. (Figure 3.2) The CEG's revised data show that the energy consumption decline in industry sector was greater than the decline of overall energy consumption by 23.8 Mtce. The increase in energy consumption from 1996 to 1999 occurred mainly in the transportation sector, whose energy consumption increased by 32.6 Mtce (CEG, 2004). The industry sector dominates energy consumption in China. In this context, I will explore the hypothesis that energy intensity was negatively correlated with energy prices in China for the overall economy as well as for the industry sector in Chapter 4.

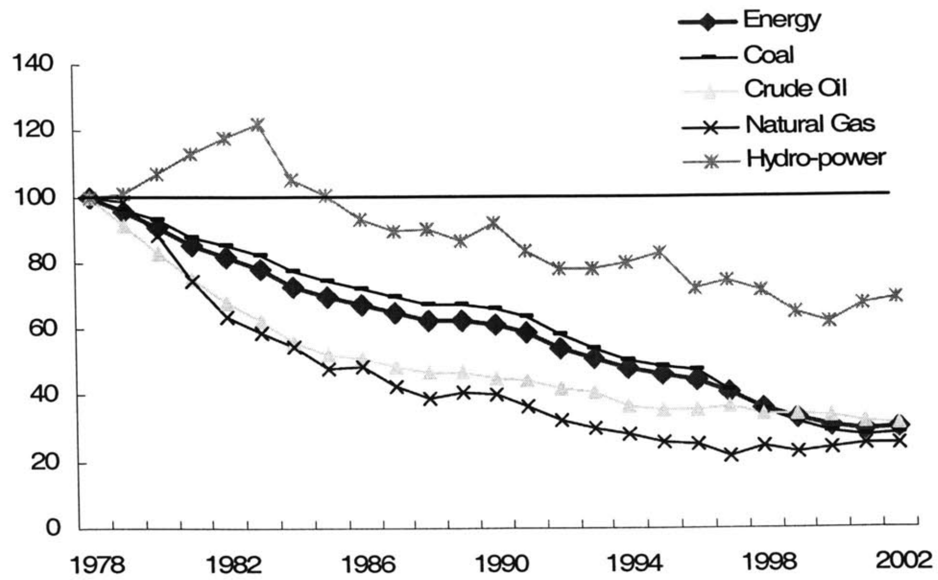
Figure 3.2: Energy End Use by Sector



Source: CEG, 2004, China Energy Databook 6.0

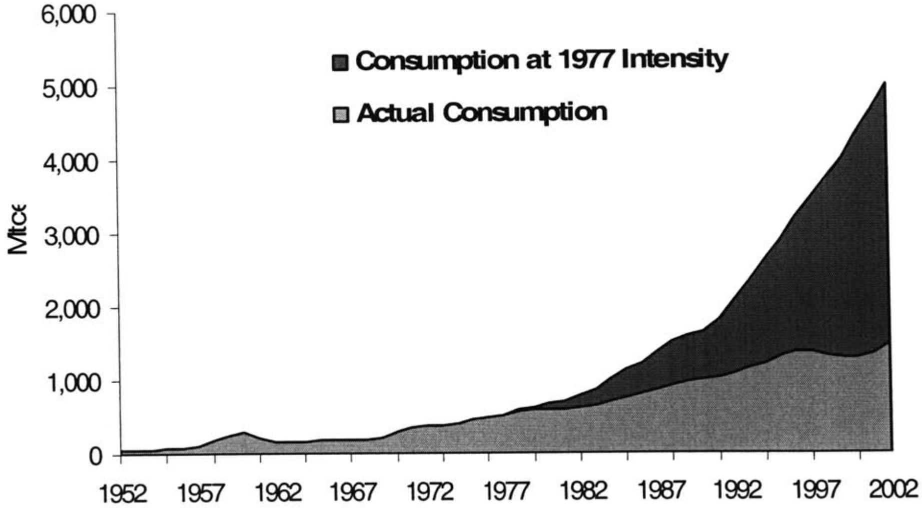
The fact that China's GDP outpaced its energy consumption indicates that China's overall energy-intensity declined over time (Figure 3.3). The overall energy intensity in 2002, which was 460 kilogram standard coal equivalents (kgsce) per thousand RenMinBi (RMB) Yuan, was 70% less than the one in 1978. This phenomenon has been in contrast to the overall trend toward higher energy intensity in many developing countries at similar stages of economic development (Lin, 1996; Zhang 2003). CEG's database shows that if China's energy intensity had been stabilized at its 1977 level, China's energy consumption would have been more than three times its current consumption level (Figure 3.4). Energy-intensity declines contributed to the energy savings and helped energy consumption growing at a slower pace than GDP. In this sense, China experienced energy savings. In fact, the declining energy intensity has a valuable meaning to China's energy conservation, energy security, and environmental protection as well.

Figure 3.3: China Energy Intensity Index (1978=100)



Source: CSYB 2003

Figure 3.4: Primary Commercial Energy Consumption: Actual Use and Use Predicted by 1977 Energy Intensity



Source: CEG, 2004, China Energy Databook 6.0

3.2 Energy Effects of Final-Demand Shifts

Concerning the energy-saving process, however, there may be two different factors driving it: final-demand shifts and production-technology adjustments. In the following two sections, I will use the SDA analysis to explore how much each of the two factors affected energy consumption in China during each of the three periods when comparable data are available (1981-1987, 1987-1992, and 1992-1995).

In this section, I examine the energy effect of final-demand shifts, which have important energy consequences directly and indirectly. In order to identify the final-demand shift effect on energy consumption change, I assume, within any examined period, that production technology remains constant and stays at the level of the start of that period.

For example, I assume production technology to be that of 1981 for the period from 1981 to 1987. With this assumption, I am able to investigate how much more/less energy would have been required at the end of any period (1987) if the production technology of the start of the period (1981) had still been used to satisfy the final demand of the end of the period (1987).

Using the SDA model, I conduct a series of matrix computations to decompose energy consumption changes based on the hybrid input-output tables discussed earlier. The resulting final-demand shift effects on energy consumption not only include the direct energy use changes by final consumers, but also changes in intermediate or indirect energy use implied by changes in the demand for both energy and non-energy products resulting from three types of final demand changes: level, distribution (across final users), and pattern (i.e., the spending pattern across different goods and services of final users). (Lin, 1996) In the SDA formula, these two parts of direct and indirect energy use changes due to final-demand shifts are illustrated as e[Y-YR]n and FR[Y-YR].

As the decomposition results (Table 3.2) show, most of the energy consumption changes are due to final-demand shifts, which have increased energy consumption in China. In the 1981-1987 period, if China had used 1981 technology to deliver 1987 final demand, China's final-demand shift would, in total, have raised its energy consumption by 506.6 million tonnes, of which 92.0% would be due to the indirect energy effect of final-final demand shifts. In the 1987-1992 and 1992-1995 periods, these two figures are 432.8 million tonnes (99.1%), and 461.4 million tonnes (99.2%), respectively. In

China, it is primarily the changes in non-energy consumption of final consumers that have raised the total energy consumption in China, but indirectly.

Table 3.1: Decomposition of China Energy-Consumption Changes (Mtce)

	Energy use changes ΔE	Final demand shift			Production-technology change
		FR[Y - YR]	e[Y– YR]n	subtotal	[F - FR] Y
1987-1981	267.9	466.2	40.4	506.6	-238.7
1992-1987	222.1	428.8	4.0	432.8	-210.7
1995-1992	218.0	457.7	3.7	4614	-243.4

Source: the SDA modeling
Note: The difference between the results of SDA modeling and the results from published energy data from CSYB is due to allocation errors.

Although final demand is a heterogeneous group, and spending by different groups depends on widely different factors and may develop along divergent paths (OTA, 1990), I do not explore the final-demand shift effects in more detail, that is, for changes in the level, distribution, and pattern effects. Instead, I assume there is a pure growth effect of GDP on energy consumption and convert the decomposition from final-demand shift effects and production-technology-adjustment effects to final-demand's structural-shift effect and production-technology-adjustment effects. I do not explore energy consumption changes in the level, pattern, and distribution framework, because my main purposes are to examine the relationship of energy prices and energy intensity and to differentiate the price-technology effect and price-structure effect.

However, several points concerning the final-demand-shifts effect on energy consumption changes are worth pointing out. Among all the seven final users (imports and exports are combined into one user-international trade) in the input-output accounts, the demand shift of residential consumers, especially urban residential consumers, is the second largest factor raising the energy consumption after the fixed-asset formation shifts (Table 3. 3). It is especially the shifts in non-energy product consumption of residential users that have played a significant role in the increase of energy consumption in China. International trade is the factor that saved energy for China indirectly through product-demand shifts; the indirect effect of imports on energy savings was larger than that of exports on energy consumption increases.

Table 3.2: The Indirect Energy-Consumption Effects of Final Demand Shifts

	Rural Residential Consumption	Urban Residential Consumption	Social Consumption	Fixed Assets Formation	Stock Changes	International trade	Others	Sub-total
Mtce								
1981-1987	118.1	108.9	35.4	271.7	29.7	-81.3	-16.2	466.2
1987-1992	78.5	107.2	46.4	177.4	17.3	-14.4	16.4	428.8
1992-1995	76.9	119.9	11.4	253.0	38.1	-36.2	-5.5	457.7
%								
1981-1987	25.3	23.4	7.6	58.3	6.4	-17.5	-3.5	100.0
1987-1992	18.3	25.0	10.8	41.4	4.0	-3.3	3.8	100.0
1992-1995	16.8	26.2	2.5	55.3	8.3	-7.9	-1.2	100.0

Source: SDA modeling and calculations

3.3 Energy Effects of Technological Improvements

Besides the final-demand shift, production-technology improvement is the other factor that impacts energy consumption level. I use a production-input mix to describe production technology for a particular product sector, which refers to a column of direct input or technical coefficients of that product sector in input-output models. The technical coefficients for a particular sector are obtained by dividing each element in the column of that sector by the total output for that sector. (Polenske and Fournier, 1993) Thus, what a given production-input mix actually shows is the underlying structural relationship of the average production technology of a sector, that is, the relationship between the output of a given sector and its required inputs. (Lin, 1996) A systematic tabulation of production-input mixes of all production sectors of an economy provides a concise and detailed description of the technological structure of the economy at a given time. (Leontief, 1958)

Hence, in the SDA model, technology is at the sectoral level and is defined widely. The production-technology changes are at least the aggregation of five separate (but overlapping) kinds of activities (Lin, 1996): (1) changes in production facilities, such as, the introduction of electric furnace for steel production; (2) changes in management practice and operations of production facilities; (3) changes in the quality of inputs; (4) changes in capacity utilization and/or scale of production; (5) changes in the types of quality of goods and services produced within a sector (product mix), which are not included in the production structural shift because the structural -shift is defined at the sector level.

Production-technology adjustments alter the input requirement of direct energy inputs and also other non-energy intermediate inputs. Direct energy-input coefficients not only varied significantly across the eighteen production sectors of China's economy, but also varied over time. (Appendices A-D) Consequently, the direct and indirect energy-input requirements also changed. (Appendices E-H) When we examine the energy effect of production-technology changes within a period, for example, within the 1981-1987 period, what we are really asking is: "how much would total energy consumption change if China had had to produce the 1987 final output according to the 1981, rather than 1987, structural relationships of production technologies?" (Lin, 1996)

Compared to the increasing effects of final-demand shifts, China's production-technology adjustment had negative effects on energy consumption, helping China saving energy in the 1980s and early 1990s. (Table 3.2) The improvement of production technology in 1987 over that of 1981 helped China save 238.63 million tonnes of primary energy in the process of delivering 1987 final demand. In other words, if the production technology had not improved from its 1981 level to the 1987 level, China would have consumed, in addition to the final-demand effect, 238.63 million tonnes more energy than it consumed in 1981 in order to meet all the 1987 realized final demand. Similarly, for the 1987-1992 and 1992-1995 periods, the figures are 210.75 and 243.42 million tonnes, respectively. Thus, the ratios between the final-demand-shift effect and the production-technology-improvement effect are 2.12: -1, 2.05: -1, and 1.9:-1 for the 1981-1987, 1987-1992, and 1992-1995 periods, respectively. Within any time period, production-technology improvements significantly decreased the energy consumption, but these effects on energy consumption are not as large as those of final-demand shifts. Over time, the production-technology effect on energy consumption was larger in the late 1980s than the early 1980s and also larger in the early 1990s than in the 1980s.

Table 3.3: The Indirect Energy-Consumption Effects of Production-Technology Improvements by Energy Type (Mtce)

	1981-1987	1987-1992	1992-1995
Coal	-13517	-15983	-19204
Petroleum	-8088	-2842	-4713
Natural Gas	-1423	-738	-886
Electricity	-3643	-2603	-3328
Toatal	-23866	-21072	-24342

Source: SDA modeling and calculations

3.4 Summary

The energy-intensity decline in China is a complex phenomenon and has led China's energy consumption to grow at a slower rate than China's economic output. However, concerning the question what is the major factor explaining the energy-intensity decline in China, analysts have different opinions. Structural shifts (producing and consuming) and real energy efficiency changes are the primary debates. The analysis on energy consumption changes provides some clues on it. In this paper, I use the SDA model to uncover the myth of energy savings in China as discussed in Chapter 2: Methodology and Data. To do so, I collect and build four hybrid energy input-output tables. Using these tables, I decompose China's energy-consumption changes during three distinctive periods (1981-1987, 1987-1992, and 1992-1995) into two effects of final-demand shifts and production-technology adjustments, both of which may help China lower its energy consumption. I will use these findings on China's energy consumption to examine its energy intensity in the next section.

From the SDA modeling and calculations, I obtain the following findings on energy-consumption changes. First, China's final demand shifts and production-technology adjustments had opposite effects on its energy consumption. Final-demand shifts increased energy consumption, while technology improvements had decreased energy consumption, which helped China save energy. The production-technology adjustment was the major factor that explains the unexpected energy-consumption savings[13] and declining energy intensity in China although it had less impact on energy consumption than final-demand shifts, The ratios between energy- consumption effects of final-demand shifts and technology improvements are 2.09:-1, 1.99: -1, and 1.83:-1, respectively, for the three periods, 1981-1987, 1987-1992, and 1992-1995. This implies that in the case that China's energy intensity declined and economy grew, that is, final demand expanded, it is the production-technology-adjustment effect that exceeded the final-demand-shift effect and enabled China to expand its economy in an energy-saving manner. Energy intensity declined.

Second, for the three periods I examined, the indirect effect of final-demand shifts on energy consumption is larger than the direct effect of final-demand shifts and always raised energy consumption in China. Thus, the non-energy product consumption shifts of final users have a significant impact on energy consumption indirectly. International trade is the factor which saved energy for China indirectly through product demand shifts; the indirect effect of imports on energy savings was larger than that of exports on

---

[13] I define energy savings in the same way as most of the analysts do. When energy consumptions do not grow at the same pace as the GDP does, we think that energy are saved due to some changes in the economy, such as technology improvements. There would have been an extra amount of energy consumed by the economy if there had no such changes. In this sense, we have energy savings.

energy consumption increases. It implies that consumers' appetite in China in the past actually changed towards more energy intensive product, such as refrigerators and cars. [14]

These static comparative results help us to understand the phenomenon of energy savings and energy-intensity decreases in China from the accounting point of view. In the next chapter, I conduct a series of econometric studies in order to understand the relationship between energy intensity and energy prices from the dynamic and behavioral point of view, first reviewing energy prices in China.

---

[14] This energy intensity of a product refers to a broader concept, not limited to the direct energy requirement of consuming the product, but refers to a concept in which energy intensity includes the energy consumption during the production process. It measures direct and indirect energy consumption per unit of output.

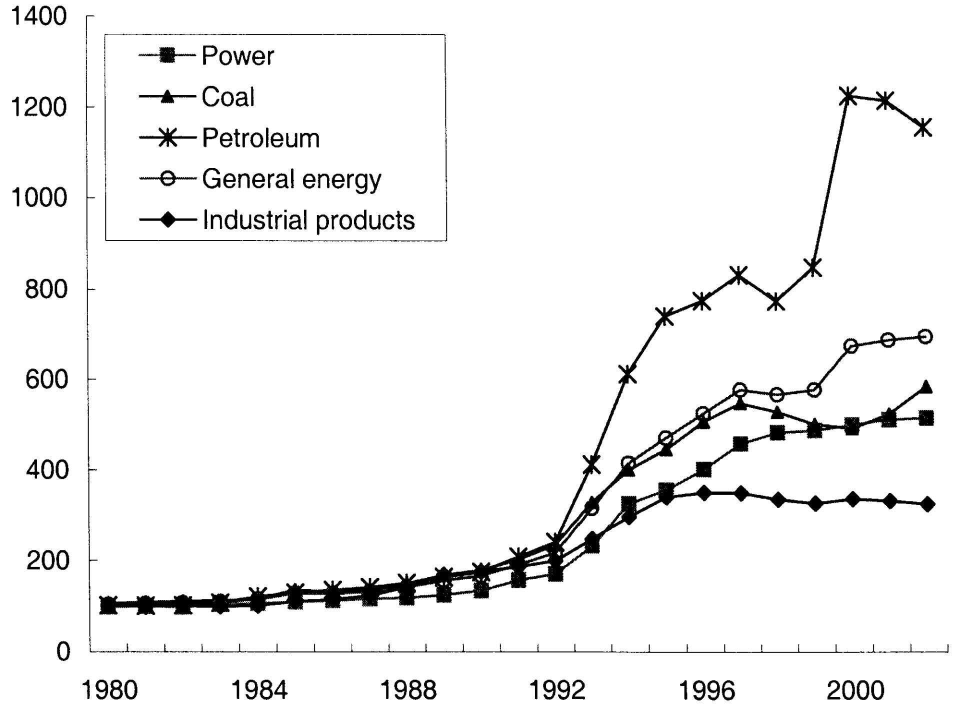
Chapter 4

Hypothesis Testing

4.1 Energy Prices in General

Together with the decline in energy intensity, China's energy prices and its pricing system have also been changing. Since the deregulation of energy pricing by the central government began to be implemented in late 1992, China has gradually built a market-determined pricing system. Although the reform's extensiveness and intensity varied by energy types, China's energy prices did change, mainly increasing. As the price indices show (Figure 4.1), energy prices and energy prices relative to prices of general industrial products generally increased over time with some fluctuations in the late 1990s. In particular, after significant energy-pricing-system reforms, real prices for coal and other energy products rose at a far higher rate than those for other industrial products. The price increases changed the situation that existed prior to the pricing-system reform, when coal prices were usually lower than the world prices and even lower than the production costs of coal (Changle, Yan, Zhilin, and Zhao, 2003).

Figure 4.1: Price Indices by Energy Type



Source: CSYB 2003
Note: Aggregate (general) energy prices are calculated by the weighted average of four types of primary energy and three energy price indices. Coal consumption is the weight to the price index of the coal industry, hydro-power consumption is the one to that of the electricity industry, and crude oil as well as natural gas consumptions are the weights to that of the petroleum industry. The differences of hydro-power prices and thermal power prices are assumed zero. The year of 1979 is the base year.

4.2 General Relationship in the Overall Economy and the Industry Sector

Such increasing energy prices may have played a role in the process of the energy-intensity decline in China during the last two decades. In order to test this hypothesis, I examine the overall national economy and the industry sector. For both of them, I employ the same analytical logic and implement the statistical tests and inferences in the same process as follows, using ordinary least squares (OLS).

First, I examine the attributes of the error terms in the two basic models without the regressors of structural shift, R&D expenditures, the policy-change dummy variable, or the interaction term. Although the functional specifications have been defined and have included the energy-intensity lag regressor in the partial- adjustment model according to energy demand theory and previous empirical studies, China's practice may have its own properties. I start with the test of heteroskedasticity and autocorrelation of each of the two basic models, respectively, at both the overall economy and the industry-sector levels.

White-tests[15] show that the null hypothesis of homoskedasticity about the overall national economy can be rejected, while that of the industry sector cannot be rejected at the 0.05 significance level. I use the White-robust standard error method to calculate the standard errors of the parameters in the models for the overall economy. Durbin-Watson tests for the overall economy and the industry sector are all in the ambiguous region with their individual degrees of freedom. I further compute the parameter estimates and their standard errors of the first-order autocorrelation regressors for each of the four combinations of the partial-adjustment model and the dynamic optimization model as well as the overall economy and the industry sector. None of null hypotheses of the zero autocorrelation parameter estimates can be rejected at the 0.05 significance level. However, the null hypothesis of a lagged dependent variable can be rejected in the dynamic optimization model of the industry sector at the 0.05 significance level. The

---

[15] White-test is used to diagnose the property of the error term of a regression to ensure whether it has heteroskedasticity or homoskedasticity.

remaining three basic regressions keep the lagged dependent variable as a regressor. For these remaining three, I further examine the null hypothesis of first-order autocorrelation when there is a lagged dependent variable among the regressors using the Durbin-m tests. The tests show that I can reject the null hypothesis that there is no autocorrelation in the context of lagged dependent variable in the partial-adjustment model of the industry sector at the 0.05 significance level, but not in the models of the overall economy. The summary of null hypothesis results is in Table 4.1.

Table 4.1: Results of the Null hypotheses Tests for Error Terms

	Null Hypotheses	The Overall Economy	The Industry Sector
Partial Adjustment Model	Homoskedasticity	---	++
	D-W test	Ambiguous	Ambiguous
	No autocorrelation	---	---
	Lagged dependent	++	++
	No autocorrelation (Lagged dependent)	++	---
Dynamic Optimization Model	Homoskedasticity	---	++
	D-W test	Ambiguous	Ambiguous
	No autocorrelation	---	---
	Lagged dependent	++	---
	No autocorrelation (Lagged dependent)	_ ++	

Note: --- means reject the null hypothesis; ++ stands for the fact that I cannot reject the null hypothesis.

Second, I run the regressions on China's time-series data according to the functional specifications in Chapter 2 (Methodology and Data) and the null hypothesis testing results about error terms in the first step. The results are summarized in Tables 4.2 and 4.3.

Table 4.2: Results of Null Hypothesis Testing and Regressions: China's Overall Economy

		Partial Adjustment Model						Dynamic Model		
	Common variables	Lnep, Inmp, InGDP, T, Inei(-1)						ep, mp, t, st(-1), sl(-1), ei(-1)		
	Added variables		Mkt	mktep	Inss	Inrd	Inss, Inrd		Mkt	mktep
1980-2002	ep	-.1(.87).39	-.17(1.1).28	-.17(1.1).28	-.1(.59).56	-.07(.63).54	-.06(.4).69	-.008(2.).04	-.00008(0)1	-.00005(.0)1
	mp	.1(.9).38	.04(.3).7	.04(.34).7	.11(.97).35	.08(.75).46	.07(.7).49	.008(.89).4	.02(1.5).15	.02(1.3).21
	GDP	-.27(1.4).18	-.33(1.8).1	-.33(1.8).1	-.36(1.4).18	-.32(1.5).16	-.44(2.1).06			
	T	.00(.3).76	.01(.6).54	.01(.6).5	.01(.45).66	.01(.6).55	.02(.87).4	-.08(1.0).32	-.15(1.6).14	-.13(1.4).18
	ei(-1)*	.57(1.3)3.9	.58(1.5)	58(1.5)	.55(1.0)	.52(1.2)	.5(1.1)	.78(4.2)3.8	.69(3.5)	.71(3.6)
	ar(1)*	.6(1.1)3.74	.6(1.0)	.6(1.0)	.65(.96)	.65(.96)	.7(1.45)	10.1		
	mkt		.04(1.1).16						-.55(1.1).29	
	mktep			.008(1).28						-.003(.78).5
	Inss				.12(.68).51		.14(1.03).32			
	Inrd					-.05(.38).7	-.07(.62).54			
	st(-1)							1.3(.92).37	-.03(.02).98	.58(.32).75
	sl(-1)							-7.3(1.6).14	-7.3(1.7).12	-7.7(1.7).11
	e'e (F)	.0098(499)	.0094(413)	.0094(414)	.0094(412)	.0095(407)	.0091(347)	.5909(609)	.5348(538)	.5607(513)
	D-W*	1.1(.96, 1.8)						.99(.86, 2)		
	white-test*	2.74(.047)						3.6(.02)		
	e(-1)*	2.75(.02)	.					1.16(.26)		

To be continued on the next page.

		Partial Adjustment Model						Dynamic Model		
	Common variables	Lnep, lnmp, lnGDP, T, lnei(-1)						ep, mp, t, st(-1), sl(-1), ei(-1)		
	Added variables		Mkt	mktep	lnss	lnrd	lnss, lnrd		Mkt	mktep
1980-1992	ep	-.1(2.2).1						-.009(.58).6		
	mp	.08(2.5).07						.007(1.).37		
	GDP	-.69(12).00								
	T	.001(2).11						-.3(3.5).02		
	ei(-1)	-.41(3.3).03						-.12(.51).63		
	ar(1)	-.33(1.4).23								
	lnss									
	lnrd									
	st(-1)							23.(3.5).02		
	sl(-1)							.69(.13).89		
	e'e (F)	.00008(1167)						.1009(190)		
1993-2002	ep	-.46(1.7).19						-.002(.23).8		
	mp	.67(1.4).26						-.02(.49).66		
	GDP	5.3(1.5).23								
	T	-.32(1.1).33						-1.1(3.3).05		
	ei(-1)	.46(.8).48								
	ar(1)	.78(8.5).00								
	lnss									
	lnrd									
	st(-1)							6.2(1.4).25		
	sl(-1)							-65(3.7).03		
	e'e (F)	.0031(62)						.1537(93)		
Chow-test		F=(.0098-(.00008+.0031))/(.00008+.0031)*9/7=2.676 n=23, k=7, j=2, (7,9)--3.68(.05); 2.72(.1)						F=(.5909- n=23, k=7, j=2 --3.68(.05); 2.72(.1);		

Source: the author

Notes: 1. In the portion of partial adjustment model, regressors are in log specification; while in the portion of the dynamic economic-optimization model, regressors are not.

2. Generally, there are three set of figures for each cell, separated by a pair of parentheses. They are coefficient estimate, t-value, and probability, respectively. However, for e'e (F) rows, the first and second figures are the error sum of squares and the F-value of each regression, respectively.

3. Rows with * signify that the cells in that row have results from null hypotheses about error terms' attributes, that is, homoskedasticity, autocorrelation, lagged dependent variable, and autocorrelation in the context of a lagged dependent variable as a regressor. In this case, sets of figures are also separated by a pair of parentheses. Specifically, in cells with three sets of figures about autocorrelation and lagged dependent variable, the first two are coefficient estimates and related statistical values, and the third one is the t-value of the null hypothesis tests about the error terms; while in cells with two sets of figures, they are the coefficient estimate and related statistical values, except the rows of D-W test, White-test, and e(-1), where the two figures are the test results of the statistical value and the probability.

Table 4.3: Results of Null Hypothesis Testing and Regressions: China's Industry Sector

		Partial Adjustment Model						Dynamic Model		
	Common variables	Lnep, lnmp, lnGDP, T, lnei(-1)						ep, mp, t, st(-1), sl(-1), ei(-1)		
	Added variables		Mkt	mktep	lnss	lnrd	lnss, lnrd		Mkt	mktep
1980-2002	ep	-.29(2.3).03	-.36(2.2).05	-.36(2.1).05	-.31(2.3).04	-.26(2,0).06	-.28(2.1).06	-.01(.7).49	-.02(1.6).14	-.005(.24).8
	mp	.2(1.4).19	.14(.74).47	.14(.73).48	.2(1.3).20	.15(.94).4	.14(.86).40	.01(.33).74	.04(1.4).18	.017(.6).56
	GDP	-.1(.58).57	-.19(.83).42	-.19(.83).42	-.11(.65).53	-.2(1.04).31	-.27(1.3).23			
	T	-.005(.29).8	.004(.18).9	.004(.19).8	-.004(.23).8	.01(.58).57	.02(.8).44	-.48(1.4).18	-.3(1.7).10	-.51(1.4).17
	ei(-1)*	.59(4.2)4.2	.56(3.8).00	.57(3.9).00	.56(3.3).00	.53(3.6).00	.45(2.4).03	0.33		
	ar(1)*	6.1						.84(8.7)8.74	.39(.89).38	.84(8.09).0
	mkt		.05(.6).56						-.86(.88).39	
	mktep			.01(.61).55						-.003(.6).55
	lnss				.113(.35).73		.26(.75).46			
	lnrd					-.1(1.02).32	-.13(1.2).25			
	st(-1)							4.2(2.4).03	.91(.66).52	3.9(2.2).05
	sl(-1)							4.9(.32).75	18(.88).39	4.1(.26).79
	e'e (F)	.0173(516)	.0169(413)	.0169(414)	.0171(407)	.0161(432)	.0155(360)	2.158(442)	2.213(343)	2.1(362)
	D-W*	.85(.9, 1.8)						1.697(.9, 2)		
	white-test	.75(.65)						1.08(.44)		
	e(-1)*	.63(.5)								

To be continued on the next page.

		Partial Adjustment Model						Dynamic Model		
	Common variables	Lnep, lnmp, lnGDP, T, lnei(-1)						ep, mp, t, st(-1), sl(-1), ei(-1)		
	Added variables		Mkt	mktep	lnss	lnrd	lnss, lnrd		Mkt	mktep
1980-1992	ep	-.18(2.6).04						.005(.22).83		
	mp	.01(.34).74						.002(.13).9		
	GDP	-.68(9.6).00								
	T	.03(6.1).00						-14(.06).95		
	ei(-1)	-.08(.59).57								
	ar(1)							.99(7.2).00		
	lnss									
	lnrd									
	st(-1)							5.8(6.7).00		
	sl(-1)							-1.5(.21).83		
	e'e (F)	.00026(478)						.1396(128)		
1993-2002	ep	-.16(.2).85						-.0001(.0).99		
	mp	-1.19(.67).54						-.07(.44).69		
	GDP	.58(1.3).36								
	T	-.17(2.8).05						-.02(.02).98		
	ei(-1)	-.4(.68).53								
	ar(1)							-.44(.78).49		
	lnss									
	lnrd									
	st(-1)							-6.6(1.8).18		
	sl(-1)							131(1.6).21		
	e'e (F)	.0061(70)						.4780(52)		
Chow-test		F=(.0173-(.00026+.0061))/ (.00026+.0061)*11/6=3.15 n=23, k=6, j=2, (6,11)—4.03(.05); 2.92(.1)						F=(2.1576-(.1396+.4780))/ n=23, k=7, j=2, (7,9) —3.68(.05); 2.72(.1)		

Source: the author

Notes: 1. In the portion of partial adjustment model, regressors are in log specification; while in the portion of the dynamic economic-optimization model, regressors are not.

2. Generally, there are three set of figures for each cell, separated by a pair of parentheses. They are coefficient estimate, t-value, and probability, respectively. However, for e'e (F) rows, the first and second figures are the error sum of squares and the F-value of each regression, respectively.

3. Rows with * signify that the cells in that row have results from null hypotheses about error terms' attributes, that is, homoskedasticity, autocorrelation, lagged dependent variable, and autocorrelation in the context of a lagged dependent variable as a regressor. In this case, sets of figures are also separated by a pair of parentheses. Specifically, in cells with three sets of figures about autocorrelation and lagged dependent variable, the first two are coefficient estimates and related statistical values, and the third one is the t-value of the null hypothesis tests about the error terms; while in cells with two sets of figures, they are the coefficient estimate and related statistical values, except the rows of D-W test, White-test, and e(-1), where the two figures are the test results of the statistical value and the probability.

According to the nine functional specifications and error-term tests, I conduct eighteen regressions for the overall economy and the industry sector, nine for each of them. Generally speaking, all eighteen regressions are statistically significant. Each of the regressions has an equation F-statistic value larger than the corresponding critical values at the 0.05 significance level. However, some of the individual parameters are not statistically significantly different from zero even at the 0.2 significance level.

As for my t-tests of the individual regressor, the results are not uniform and depend on the sector. I primarily discuss the parameters of energy prices. In the basic and extended partial adjustment models of the overall economy, the t-statistics of the parameter estimate of the log energy prices is less than its critical value at the 0.1 significance level, with 17 degrees of freedom, and we cannot reject its null hypothesis; while in the dynamic optimization model of the same overall economy, the t-statistic of energy prices is larger than their corresponding critical value even at the .05 significance level, and we can reject the null hypothesis of the zero parameter of energy prices. I prefer the results of the dynamic model because I use the energy-price index in the industry sector to approximate the prices for the overall economy. In China, energy prices were differentiated by the users. For example, residential consumers face different energy prices from the consumers in the industry sector. The dynamic model is more complex and includes two other important quasi-fixed assets, which control for the effect of other variables on energy intensity when measuring the effect of energy prices.

Turning to the industry sector, I find that the regressions also present as perplexing results as those of the overall economy, but the results of parameter null hypothesis testing are opposite. I can reject the null hypotheses about the zero parameter of the energy prices in the six partial-adjustment models, while I cannot reject them in the dynamic model. I think the results from partial-adjustment models are more reliable for the industry sector, because of the limited data availability, data assumptions, and the model features. I assume the fixed distribution of national skilled labor among sectors, which is problematic.

The other common regressor in the two basic models, the prices of non-energy materials, presents the same results: for the overall economy, its parameter estimates have a lower probability of being zero in the dynamic model than in the partial-adjustment model; estimates for the industry sectors have a lower probability of being zero in the partial adjustment models than in the dynamic models. Thus, I think that the dynamic model is more reliable for the overall economy, while the partial-adjustment model is preferable for the industry sector. Again, the main reason lies in the data availability and its corresponding measurement bias.

However, comparing the two basic models, I have the following uniform results for the overall economy and the industry sector. First, the energy price deregulation of the central government does not have a significant effect on energy intensity. The null hypotheses about the zero parameter of the policy change dummy variable with the post-deregulation as 1 as well as about the zero parameter of the interaction term cannot be rejected at a predetermined 0.1 significance level. This result is opposite to the expectation that after deregulation the economy would present a higher elasticity of energy intensity with respect to energy prices because energy prices before deregulation were lower than the production cost for a long time due to Chinese government's intervention in order to protect general growth. Although the policy change measures are not significant, I note that the rejection of the null hypotheses related to policy changes depends on the level of predetermined significance level and the sector (Tables 4.2 and 4.3).

Second, in terms of regressors of structural shifts and R&D expenditures, regressions result in positive estimates for the former and negative estimates for the latter, as expected. In addition, the own-price elasticity of energy intensity increases very slightly by 2-7% with the inclusion of structural shifts as a regressor in the partial adjustment model, while it decreases by about 10-25% with the inclusion of R&D expenditures. However, the effects of the structural shift and R&D expenditures on energy intensity are not statistically significant both in the overall economy and the industry sector even at a higher predetermined 0.2 significance level. The probabilities that these parameters are equal to zero are high, from 25% to 73%. This result differs from those of some previous analysts, who argue that the fact of structural shifts away from energy-intensive sectors to non-energy intensive sectors is the primary reason to the energy-intensity decline. However, given the simple assumption of the R&D expenditures in the industry sector, my results about the effects of R&D expenditures in the industry sector should be treated with caution.

Third, according to the results from the Chow-test, the null joint hypotheses about the stability of the parameters over time within each of the two economic sectors cannot be rejected at the 0.05 significance level. It is valid in both of the basic models for the overall economy and for the industry sector. Although the parameter signs of the energy prices, the prices of non-energy materials, etc., change from negative to positive or vice versa over the two sub time periods, the F-statistic values from the Chow-test are all less than the critical values at their individual degrees of freedom (Tables 4.2 and 4.3). This is consistent my test results of the non-rejected null hypothesis of the zero parameters of the policy change and the interaction term. There is less than a 5% chance that I am wrong in arguing that the economy's reaction to energy-price changes persisted over time in terms of energy intensity or arguing that the own-price elasticity of energy intensity persists over time.

Fourth, the overall economy and the industry sector are different in terms of the degree of the reactions to the energy-price changes in the process of using energy. Compared to the own-price elasticity of the energy intensity in the overall economy, the one in the industry sector is higher. The regressions show that the industry sector has a short-run own-price elasticity of energy intensity of -0.29 according to the partial-adjustment model, while the overall economy has that of -0.13 for the average year according to the dynamic optimization model, both of which are reasonable estimates. In the long-run, the own-price elasticity for the industry sector is -0.78.[16]

---

[16] For the overall economy, I cannot derive the long-run elasticity. Due to limited data, I prefer the dynamic economic-optimization model for the overall economy and apply only the short-run specification in this study on China's energy intensity.

Up to this point, I have examined the general relationship between energy intensity and energy prices. However, as mentioned in Section 2.3, the energy intensity at any given time can be decomposed into the three or four portions, which is, in the two-portion specification of energy intensity changes, composed of the energy intensity at the start of a period, the energy intensity effect of structural shifts, and the production-technology adjustments.. Correspondingly, we are further concerned with the relationship of the subcomponents of energy intensity with energy prices in China. To be specific, we are interested in the question: how did energy-price changes affect energy-intensity improvements in China through technological changes and structural shifts, or what is the relationship of prices to both energy-intensity changes due to real energy-efficiency improvements and structural shifts?

4.3 Energy Efficiency and Energy Prices

Production technology stands for the input requirements for a unit of production of a particular product sector. Usually, energy efficiency is defined as the energy requirement for a unit of production or product output per unit of energy input. Thus, any changes in technological coefficients for a particular product sector will lead to the changes in energy efficiency. In this sense, the energy-efficiency effect on energy consumption is the same as the technology-adjustment effect.[17] This measurement of

---

[17] Starting here, I use the term "energy-efficiency effects" to substitute for that of production-technology improvement effects.

the energy-efficiency effect on energy consumption reflects the managerial and technical features at a given time, as stated earlier.

SDA modeling provides an effective and reliable approach to decompose energy-consumption changes. However, the applied SDA modeling and calculations on China's energy consumption do not produce annual results, which are needed to decompose the own-price elasticity of energy intensity, due to the limited frequency of China's input-output accounts. In order to get the annual estimations of the effects of final-demand shifts and production-technology adjustment on energy consumption, I take the following steps. First, I compute the final-demand structural-shift effect, which is the final-demand shift effect net of the pure growth effect, for each of the three periods: 1981-1987, 1987-1992, and 1992-1995.[18] Second, I assume that within any period both the structural shifts and production-technology adjustments possess a simple linear growth trend in terms of their individual effects on energy consumption. This means that the relative significance of the effects of structural shifts and production-technology adjustments in energy consumption changes, which are net of pure growth effects, is constant. Third, I calculate the pure growth effects on energy consumption and energy-consumption changes net of the pure growth effect for each year from 1981 through 1995. Last, I apply the ratios of energy- consumption effects of structural shifts and

---

[18] This approach considers the exponential growth of GDP on energy consumption, that is, the exponential growth of the pure growth effect, in the estimation of the structural-shift effect on energy consumption and consequently energy intensity. Thus, this approach omits the overestimate of the structural-shift effects on energy consumption when I apply the alternative approach. For the alternative approach, I first annualize the two energy-consumption effects of final-demand shifts and production-technology improvements according to their individual importance among energy-consumption changes; then, I calculate the annual pure growth effect and final-demand's structural-shift effect.

production-technology improvements for the corresponding periods to the energy-consumption changes net of pure growth effect. I come up with the decomposition of the energy consumption changes net of pure growth effects at a yearly frequency from 1981 through 1995. My SDA modeling and the consequent calculations on energy-consumption changes determine that I will examine only the overall economy in the process of decomposition of the own-price elasticity of energy intensity.

Table 4.4 presents the resulting decomposition of energy-consumption changes net of the pure growth effect into structural-shift effects and production-technology adjustment effects. Consequently, Table 4.5 presents the decomposition of energy-intensity changes into two and three portions. In this section, I use the two-portion decomposition, mainly because the three-portion decomposition of energy intensity changes is not mutually exclusive, as stated earlier. However, the two-portion decomposition approach is mutually exclusive and collectively exhaustive. In addition, in this study, I mainly focus on the examination and differentiation of technology-related price effect and the overall price effect on energy intensity.

Table 4.4: Decomposition of Energy Consumption Changes, 1981-1995 (Mtce)

	Energy Consumption Changes	Effects		
		Pure Growth	Structural Shifts	Technology Improvement
1981	-8.3	31.7	-5.7	-34.3
1982	26.2	53.6	-3.9	-23.5
1983	39.7	67.6	-4.0	-23.9
1984	48.6	100.2	-7.4	-44.2
1985	57.8	95.5	-5.4	-32.4
1986	41.7	68.0	-3.7	-22.5
1987	57.8	93.6	-2.6	-33.2
1988	63.7	97.6	0.0	-33.9
1989	39.4	37.8	0.0	1.6
1990	17.7	37.2	0.0	-19.5
1991	50.8	90.7	0.0	-39.9
1992	53.9	147.8	2.1	-96.0
1993	68.2	147.3	3.6	-82.7
1994	67.4	146.9	3.6	-83.1
1995	84.4	128.9	2.0	-46.6

Source: SDA modeling and net-of-pure-growth-effect calculations

Table 4.5: Decomposition of Energy Intensity, 1981-1995 (kgsce/thousand RMB Yuan)

	Energy Intensity	Two-Portion Effects		Three-Portion Effects			
		Structural Shifts	Technology Improvement	Pure Growth	Final-Demand	Technology Improvement	Total
1981	1297.3	-12.4	-74.8	69.2	56.7	-74.8	-87.2
1982	1242.5	-7.8	-47.0	107.2	99.4	-47.0	-54.8
1983	1192.2	-7.2	-43.2	122.1	114.9	-43.2	-50.3
1984	1111.3	-11.5	-69.3	157.1	145.6	-69.3	-80.9
1985	1059.2	-7.4	-44.7	131.9	124.5	-44.7	-52.1
1986	1025.9	-4.8	-28.6	86.3	81.5	-28.6	-33.4
1987	985.2	-2.9	-37.7	106.4	103.5	-37.7	-40.6
1988	950.5	0.0	-34.7	99.8	99.7	-34.7	-34.7
1989	952.0	0.0	1.5	37.1	37.1	1.5	1.5
1990	933.6	0.0	-18.4	35.1	35.1	-18.4	-18.4
1991	899.0	0.0	-34.6	78.6	78.6	-34.6	-34.6
1992	827.8	1.6	-72.8	112.1	113.7	-72.8	-71.2
1993	775.0	2.4	-55.2	98.4	100.8	-55.2	-52.8
1994	727.9	2.2	-49.3	87.1	89.3	-49.3	-47.1
1995	704.0	1.1	-25.0	69.2	70.3	-25.0	-23.9

Source: Table 4.4 and energy-intensity-decomposition calculations.

Following the method proposed in Section 2.3, I utilize three empirical regressions of energy-intensity changes to examine the price-inducement effect on technology-related energy intensity, that is, real energy efficiency. Specifically, the three empirical regressions are: (1) total energy-intensity changes, (2) energy-intensity changes due to the real energy-efficiency movement effect, and (3) energy-intensity changes due to the structural-shift effect of final demand. I use the dynamic optimization model for this set of overall economy data since it is preferable for the overall economy according to the study in the last section.

The regression results show that the three energy-intensity models and their subcomponents are statistically significant at the 0.1 significance level.[19] In the model for the own-price elasticity of energy intensity due to the energy-efficiency improvement, the coefficient estimate of energy prices is statistically significant at the 0.05 significance level. The short-run own-price elasticity of energy intensity due to efficiency improvements is negative, around 0.19 in absolute value for mean efficiency effect on energy intensity, while the own-price elasticity for the overall economy over the same period is -0.25. Hence, using elasticity as the measure, I find that the technology-inducement effect of energy prices on energy intensity is the primary factor that represents the own-price effect on energy intensity. By contrast, I find that the coefficient estimate of energy prices in the modeling of energy intensity due to the structural shift is not statistically significant at the 0.1 significance level.

---

[19] To be exact, the regression on energy intensity changes due to the technology-improvement effect has an equation F-statistic value of .115 at the 6 and 8 degrees of freedom.

Table 4.6: Decomposition Regressions for the Overall Economy, 1981-1955[20]

	EI	EITS	EIT	EIS
C	7.39			
T	-0.27	-0.29	-0.28	-0.01
EP/CEP	-.0215(6.1).0	-.0187(2.9).02	-.0185(2.8).02	-0.0002(.17).87
MP/CMP	.0076(.85).4	0.0088(1).4	0.0086(.93).38	0.0001(.1).9
ST/CST	18.6(4.6).0	17.4(3.1).01	13.1(2.3).05	4.2 (5.2).0
SL/CSL	3.(1.2).3	1.8(.65).53	1.1 (.4).7	0.7(1.7).13

Note: Each set of three figures are respectively the coefficient estimate, t-statistic value, and probability of that coefficient to be zero.
Source: the author

Hence, energy-price increases induced technology improvement and contributed to the decline of energy intensity in China from 1981 to 1995. This suggests that increases in energy prices decreased energy consumption per unit of GDP and reduced pollution primarily by encouraging the development and application of new technologies (including management tools and programs), which makes pollution control less costly in the long run. However, one point should be noticed. The own-price elasticity of energy intensity due to energy-efficiency improvement/movement may be upward biased. The exactness of this finding relies on the decomposition of energy-consumption changes, on which the fineness of production industry classification in input-output tables has impacts. Lin (1996) points out that some of the final demand shift effect at a finer level of sectoral classification on energy savings may be accounted for by the effect of technological changes.

---

[20] The sum of each set of decomposed coefficient estimates is not equal to its corresponding estimate according to the original/non-decomposed energy intensity data. This is different from the idea case due the effect of error terms.

In my SDA modeling and calculations, I have extremely broad sectoral classifications with only 19 production sectors, instead of the 118 sectors in current prices of China's 1992 input-output table, for example. The relatively low sectoral-classification detail may overestimate the own-price elasticity of energy intensity related to energy-efficiency improvements through the overestimates of energy consumption savings due to production-technology adjustment and the technology-inducement effect of energy prices.

However, the own-price elasticity of energy intensity still provides a meaningful finding. There was the inducement effect of energy prices on energy intensity: energy efficiency, as part of energy intensity, is also negatively related to energy prices, while cautions should be taken when using the -0.19 short-run own-price elasticity of energy intensity due to energy-efficiency improvements.

4.4 Summary

In this chapter, I primarily examine the behavioral relationship between energy prices and energy intensity in China, in light of the observed fact of continuously declining energy intensity and the increasing energy prices over the last two decades. However, very few analysts has examined the relationship between these two general trends of energy prices and energy intensity. For my empirical econometric study, I cover more than twenty years with a nearly even cut before and after the deregulation of energy pricing. I examine the overall economy as well as the industry sector. Besides the revised empirical models of energy intensity, I also apply the decomposition approach of own-price elasticity of energy intensity proposed in Section 2.3. The results from the input-output technique-based SDA modeling and calculations provide important data support for the decomposition analyses of energy intensity changes and price elasticity of energy intensity. Important intermediate work includes the estimates of the two-portion decomposition of energy intensity changes based on the two-portion decomposition of energy consumption change and the conversion from the shift effect of final demand to its structural-shift effect.

Generally speaking, over the examined twenty-year time period of 1980-2002, China's energy intensity presents a negative elasticity that is statistically significant and persistent. The short-run inelasticity of energy intensity with respect to energy prices exists not only in the overall economy but also in the industry sector, while the industry sector is more sensitive to the changes of energy prices than the overall economy in the process of energy intensity adjustment to changes in energy prices. In the short run, the own-price elasticity of energy intensity for the overall economy is around -0.13 for the average year, while the one for the industry sector is around -0.29. I also find, for the overall economy, the dynamic optimization model is preferable, but we cannot estimate its long-run elasticity due to limited data in China. In terms of the decomposition of own-price elasticity, the portion related to energy efficiency is predominant. The short-run own-price elasticity of energy intensity due to energy-efficiency movement effects for the overall economy is around -0.19 (average year) over the years of 1981-1995, whose corresponding total own-price elasticity is -0.25.

However(different from my expectations), first, the overall economy does not demonstrate a statistically significant reaction, in terms of energy intensity, to changes in the energy pricing system; second, the own-price elasticity of energy intensity does not depend on whether the central government controls energy prices. In addition, the structural shift of production sectors in China does not have a statistically significant impact on energy-intensity changes even at a two-digit level of sector classification, which is contrary to the results of some analysts (Smil, 1990 and Kambara, 1992, Fisher-Vanden et. al, 2004).

Chapter 5

Summary and Conclusion

5.1 Summary of Research Findings

The energy-intensity decline in China is an interesting topic and has drawn a lot of attention. While most analysts indicated that energy-efficiency improvements were the primary reason for the decline of energy intensity and energy savings in China, each relies on different methods to make his/her explanation. However, very few of them have taken energy prices into account in their analytical framework nor have they undertaken a systematic study of the relationship between energy prices and energy intensity. In fact, China's energy prices generally increased when its energy intensity declined. Energy price increases may have played a role in the energy-intensity decline process in China.

I examine this topic in a systematic way and propose the hypothesis that energy intensity in China is negatively correlated with energy prices. I investigate the possible different relationships between energy prices and energy intensity for the overall economy and the industry sector. I also examine the possible different reactions towards the changes in energy prices between total energy intensity and energy efficiency, that is, energy intensity subject to energy–efficiency/production-technology-improvement impacts. I use the own-price elasticity of energy intensity as the indicator for this relationship. Besides the revised empirical models of energy intensity, I also propose a decomposition approach of own-price elasticity of energy intensity, and I conduct an analysis using this decomposition approach and the results from the input-output-based SDA modeling.

The results of studies on China's energy over the last two decades confirmed the hypothesis that China's energy intensity was negatively correlated with energy prices, which is consistent with Kaufmann's findings (2004, Wing and Eckaus, 2004) about the United States. The short-run inelasticity of energy intensity with respect to energy prices existed not only in the overall economy but also in the industry sector, while the one in the overall economy was less in absolute value than the one in the industry sector. The industry sector was more sensitive to the changes of energy prices than the overall economy in terms of the intensity of using energy to make products. In the short-run, the own-price elasticity of energy intensity for the overall economy on average was -0.13, while that for the industry sector was -0.29. In the long run, the own-price elasticity of energy intensity for the industry sector was -0.78.

In addition, I find that energy prices had an inducement effect on energy-efficiency improvement in China, consistent with Wing and Eckaus's study (2004) on the energy intensity of the U.S. economy. Energy intensity varied (statistically) significantly with energy prices, mainly through the price-inducement effects on energy efficiency. From 1981 to 1995, the decomposed short-run own-price elasticity of energy intensity due to energy-efficiency movement effects for the overall economy was around -0.19 on average, whose corresponding total own-price elasticity was -0.25. Energy-intensity declines are not independent of energy prices in China.

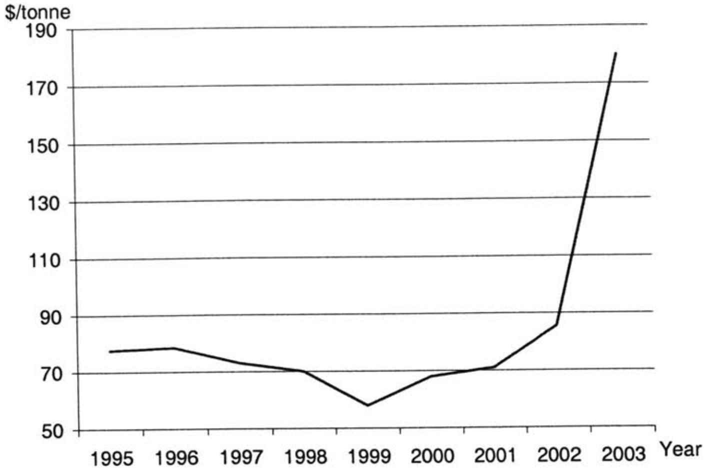
Other findings include the following three points. First, in China, the energy-price effect on energy intensity was persistent over time from 1980 to 2002 and the own-price elasticity of energy intensity did not depend on whether energy pricing was controlled by the Chinese central government. Second, the decomposition of energy-consumption changes over the three time periods, from 1981 to 1987, from 1987 to 1992, and from 1992 to 1995, show that the effect of production-technology adjustments on energy consumption was negative, bringing down energy consumption in China. It also shows that the effects of final-demand shifts were positive, but the effect of final-demand shifts net of GDP growth, that is, the structural-shift effect of final-demand, was negative. Thus, energy consumption in China grew but at a lower rate than did GDP in the last two decades. These findings confirm that energy consumption continued the 1980s trends in the 1990s.

5.2 Implication and Contributions

Many developing countries have been facing a dilemma. On the one hand, they work on accelerating economic development. On the other hand, they worry about their energy conservation and environmental protection due to the rapid economic growth. China's economy has been growing at a high rate of 9% and was the second largest energy consumer globally after the United States in 2002. China's energy consumption was 43 quadrillion Btu (EIA, 2005), accounting for 15% of total world energy consumption. How China consumes its energy, or how China's energy consumption grows compared to its GDP, is very critical for the whole world. In the past two decades, China's energy intensity has continuously decreased, which is good. I have shown that energy-price increases played an important role in that process.

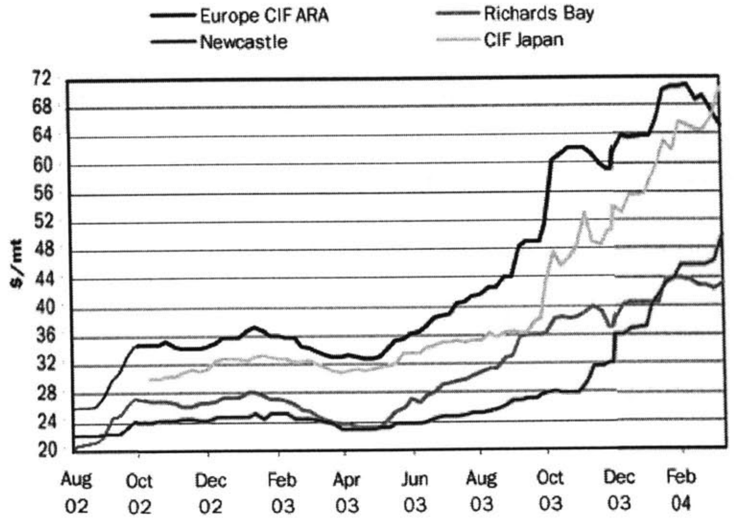
I want to understand the historic energy-intensity decline in China, especially when China's economy is becoming more and more involved in the global market. For example, growth of China's coke output is making China a major supplier in the world coke market. China's domestic coke prices are equivalent to its international prices (Polenske, forthcoming). China's energy prices are not only determined domestically, but they also extensively influence and are influenced by the international market. What is more, the global energy prices have been dramatically increasing within the last two years (Figures 5.1 and 5.2). Incorporating energy prices in the forecasting models of energy consumption, energy conservation, and carbon emission is critical. The type of understanding of the relationship between energy intensity and energy prices I found through this study helps to improve the credibility of future projections.

Figure 5.1: China's Coke Prices in World Market in Recent Years



Source: Patrick Cleary, CRU International, Met Coke World Summit 2003
Note: f.o.b. China, 10.5% ash, average annual values

Figure 5.2: World Coal Prices in Recent Years



Source: Maiello 2003

In addition, this study has some policy implications. First, results show that the overall economy and the industry sector have a different own-price elasticity of energy intensity in China. The industry sector is more sensitive to changes in energy prices than the overall economy with respect to energy intensity. This implies that the non-industry sector is less sensitive than the industry sector regarding the relationship between energy intensity and energy prices. According to this, energy-policy makers need to differentiate their policy packages among different sectors. Energy-related policies and programs could be adjusted according to the changes of energy prices according to budget needs over years.

Second, compared to the final-demand-shift effect and also the final-demand-*structural*-shift effect, production-technology improvement had a significant negative effect on energy consumption based on our study of China's energy use from 1981 to 1995. The energy-intensity decline was not so much a result of economic development with final-demand-structural shifts and production-structural shifts, as it is the product of production-technology improvements. In addition, final-demand's pure growth, which increases the welfare of residents, had a larger impact on energy-consumption changes than the other component of final-demand shifts, that is, the final-demand's structural shift. Energy policymakers need to concentrate on the promotion of production-technology improvements, which results in energy consumption decline indirectly. However, it is foreseeable that the direct consumers of energy, residential households, and public agencies, will use more energy among all the direct and intermediate energy consumers in the near future when Chinese living standard further improves. The consumptions of energy-intensive cars and housings, etc., are increasing dramatically by more than 16%[21], higher than GDP of 9.5%, in 2004. For example, more and more

---

[21] China Economic Informatino Network (CEIN), http://www.ceiceo.cn/Exweb/2005Report/www/Column.asp?ColumnId=21 downloaded 08/08/05. National Bureau of Statistics of China (NBSC),

households own and use their family cars. Then, final-demand structural shifts may have a larger impact on energy-consumption changes. Energy-policy that guides final users to shift their expenditure patterns towards energy savings and to adapt energy-efficient household appliances and facilities are also necessary.

Third, energy prices had an inducement-effect on energy-saving technology and innovations. This inducement effect of energy prices on energy-saving technology was the major factor, which contributed to the decline of energy consumption and energy intensity in China. Energy policy makers need to define packages that target means of facilitating innovations, dispersion, and adoption of energy-saving technology with the consideration of the inducement effect of energy prices.

Hence, I used a perspective, methodology, and data set for my energy-intensity study that differentiates it from previous research on China's declining energy intensity in the following respects. First, I use a different framework from the ones previously used to understand the energy-intensity decline in China. The question concerning why China's energy-output ratio has declined could be answered on a number of levels (Garbaccio, et al., 1999). I mainly analyze the effect of energy prices on the declining energy intensity in China, a factor neglected in most previous studies on this topic. During the 1980s and early 1990s, energy prices were controlled by central government and did not change dramatically in China, so that such an analysis was unnecessary. This may partially explain the lack of energy prices in previous analytical work on energy intensity

---

http://www.stats.gov.cn/tjgb/ndtjgb/qgndtjgb/t20050228_402231854.htm, downloaded at 08/08/05 in China. In my study, the results show that China's energy intensity is statically significantly related to energy prices over the last two decades from 1980 to 2002.

Second, methodologically, this study on energy intensity and energy prices in China utilizes two complementary tools of empirical econometric model of energy demands and the input-output-based structural decomposition model. In addition, I bridge the above two models and introduce a model that decomposes own-price elasticity of energy intensity into the two portions related to energy-efficiency improvement and structural shift of final demand. I also conduct an empirical study. I use four recent input-output tables in constant prices and energy-flow data with the same sector classification as the input-output tables. As more data become available, analysts could use this combined methodology to update current studies on the decomposed energy consumption changes and own-price elasticity of energy intensity.

Third, I conducted my study at a regional level and show the aggregate effect of energy prices on energy intensity. Energy prices may impact energy intensity through two channels at the firm level. First, energy-price increases may bring about energy-efficiency improvements, i.e., technological changes, by new investment in energy-saving production processes or by management improvements in energy utilization at the firm level. Second, energy-price changes may lead energy users to shift from one type of energy to another. For example, price increases in town gas may lead some city users to reuse wood for cooking and heating, which is not accounted for in energy consumption, and consequently may increase energy consumption. Rising coal prices cause shifts away from coal-intensive industries (Fisher-Vanden et al., 2004). I also examine the different reactions of energy intensity to energy-price changes both for the overall economy and the industry sector, which are different.

5.3 Limitations and Future Studies

However, this study also has its limitations. Some of the results should be interpreted with caution, especially about the statistically insignificant effect of the policy change of energy pricing and the persistence of the parameter estimates when we take into account the dramatic and fast changes in the private sectors especially since 1992, contrasted with the relatively slow reform pace of the statistical system. Some analysts cast doubt on China's statistical GDP data and energy consumption data (Sinton, 2001). The sectoral classification and coverage changes for some variables, that is, the energy consumption by the industrial sectors, the fixed assets investment, the value-added by industry sectors, do exist.

The input-output tables and energy-flow data in physical amounts I used in this study are only for 1981, 1987, 1992, and 1995. These infrequent and less-recent input-output tables and energy-flow data could create another type of measurement error. The decomposition of annual energy-consumption changes is based on the assumption that the relative significance of energy-efficiency movement and final-demand structural shift effects on energy consumption is constant over the time period when two corresponding hybrid input-output tables are available. This may bring about measurement errors for the estimation of the efficiency related portion of own-price elasticity of energy intensity.

Another limitation is in the highly aggregated structure of input-output tables in constant prices used in this study. As stated earlier, this limitation may result in my misattributing some of the structural-shift effects on energy consumption changes to production-technology improvement effects. This may lead to an overestimation of production-technology-improvement effects on energy consumption changes, and also on energy-intensity changes. If this is true, this creates another measurement error for the decomposition of the own-price elasticity of energy intensity.

Correspondingly, some related studies should be conducted in the future. First, a decomposition of energy-consumption changes and energy intensity changes for some more recent years and at a more disaggregated level of sectoral classification is useful for the examination of the decomposed own-price elasticity of energy intensity. For my study, only four comparable input-output tables before 1995 are available. Only nineteen producing secotors are identified. Second, regional studies and comparison are necessary. China's energy resources are dispersed very unevenly, and energy intensities have significant regional variations. For example, Shanxi's energy intensity has been twice that of China's. For different regions, energy prices may have different impact on energy intensities. Third, analysts could explore the residential consumer sector because as incomes further increase, China's personal consumption patterns may move towards more energy-intensive products, such as automobiles, air conditioners, etc.

Despite these limitations, I have identified important energy issues and raised questions. Although I do not provide definitive answers, the study is exploratory. Ideally, the insights gained will constitute the basis for a later, more comprehensive, research effort. The results could serve as a benchmark for forecasting and comparison studies. I believe that this study, at least, provides a guideline or a warning sign to include energy prices in the analytical framework for future studies on and forecasts of energy intensity, energy consumption, carbon emission, energy conservation, and energy securities, etc. I also believe that it sheds light on the consideration of energy-price factors in the policymaking process concerning energy.

5.4 Summary

China's energy-intensity decline is of considerable importance for China and the global environment (Garbaccio, et al., 1999). By examining China's case and taking energy prices into account in studies on energy intensity, I confirm Kaufmann's (2004) findings for the United States that energy-intensity declines are not independent of energy prices. I use two complementary tools of SDA and regression analyses. I propose a decomposition model of own-price elasticity to measure the energy price effects on energy efficiency.

Besides the general negative relationship between energy intensity and energy prices, I have four other major findings. First, there is a difference between the sensitivities of the overall economy and the industry sector to energy-price changes in respect to energy intensity. The overall economy presented smaller own-price elasticity than the industry sector. Second, there was a price-inducement effect on energy-efficiency changes, which accounted for the largest share of the own-price elasticity effect and then of the energy-intensity changes. Third, the own-price elasticity of energy intensity was independent of the deregulation of energy prices. Fourth, from 1981 to 1995, the indirect effects of final-demand shifts were much larger than the direct effects of final-demand shifts. Final demand's structural shifts, which correspond to structural shifts in producing sectors, also reduced energy consumption, but not as much as production-technology improvements did. China's international trade actually indirectly contributed to the decrease of energy consumption.

These findings are useful in many ways. By understanding the impact of energy-price changes on energy intensity, analysts can make more accurate forecasts than before of energy consumption and carbon emissions in China. Policy makers can make more informed decisions than at present, which will, in turn, more effectively tackle the dual problems of environmental degradation and economic development. Finally, this study will provide a case for additional international and regional comparative studies.

Appendices

Appendix A: Direct Energy Technical Coefficients in China, 1981

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	0.014	0.004	0.002	0.681	0.000	0.028	1.028	0.171	1.053	0.461	1.170	0.546	0.198	0.112	0.020	0.243	0.037	0.153	0.058
2 Petroleum	0.002	0.066	0.012	0.196	0.000	0.028	0.128	0.043	0.199	0.405	0.053	0.086	0.037	0.029	0.018	0.203	0.005	0.124	0.046
3 Natural Gas	0.000	0.016	0.276	0.001	0.000	0.000	0.017	0.002	0.161	0.041	0.001	0.002	0.006	0.002	0.005	0.002	0.000	0.001	0.001
4 Electricity	0.016	0.024	0.007	0.149	0.000	0.028	0.175	0.311	0.466	0.269	0.125	0.067	0.089	0.033	0.014	0.019	0.008	0.012	0.022
* Hydro Power	0.000	0.000	0.000	0.212	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 Agriculture	0.001	0.002	0.001	0.000	0.000	0.159	0.002	0.002	0.002	0.100	0.004	0.035	0.014	0.304	0.051	0.000	0.025	0.000	0.012
6 Ferrous Metals	0.003	0.007	0.007	0.001	0.000	0.001	0.281	0.016	0.007	0.005	0.076	0.003	0.168	0.018	0.092	0.006	0.001	0.005	0.005
7 Non-ferrous Metals	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.386	0.004	0.015	0.000	0.001	0.067	0.012	0.002	0.001	0.000	0.000	0.000
8 Chemical Fertilizers	0.000	0.000	0.000	0.000	0.000	0.071	0.000	0.000	0.089	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9 Chemical Industries	0.001	0.010	0.001	0.000	0.000	0.009	0.004	0.013	0.026	0.222	0.005	0.026	0.030	0.043	0.012	0.006	0.001	0.005	0.005
10 Cement	0.001	0.001	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.087	0.003	0.000	0.000	0.123	0.001	0.002	0.000	0.000
11 Building Materials	0.001	0.003	0.002	0.000	0.000	0.000	0.017	0.013	0.002	0.001	0.002	0.013	0.007	0.002	0.163	0.001	0.004	0.003	0.021
12 Heavy Mach. & Electronics	0.005	0.009	0.007	0.007	0.000	0.001	0.058	0.030	0.006	0.004	0.048	0.038	0.227	0.010	0.057	0.031	0.023	0.081	0.068
13 Light Industry	0.005	0.006	0.004	0.000	0.000	0.012	0.005	0.018	0.068	0.080	0.064	0.063	0.070	0.304	0.117	0.010	0.173	0.004	0.145
14 Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15 Freight & Communications	0.001	0.009	0.001	0.010	0.000	0.003	0.054	0.021	0.023	0.026	0.044	0.036	0.020	0.017	0.042	0.018	0.012	0.005	0.022
16 Commerce	0.001	0.021	0.005	0.008	0.000	0.004	0.015	0.032	0.026	0.036	0.005	0.005	0.030	0.023	0.018	0.031	0.025	0.009	0.023
17 Passenger Transport	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.001	0.003	0.003	0.003	0.006	0.002	0.001	0.002	0.005	0.004	0.026
18 Other Services	0.001	0.001	0.002	0.002	0.000	0.002	0.011	0.012	0.011	0.016	0.015	0.017	0.029	0.022	0.004	0.036	0.108	0.052	0.060

Source: SDA modeling and calculations.

Appendix B: Direct Energy Technical Coefficients in China, 1987

	1	2	3	4 *		5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	0.014	0.005	0.004	0.723	0.000	0.025	0.838	0.120	1.075	0.226	0.962	0.574	0.082	0.089	0.011	0.120	0.034	0.096	0.034
2 Petroleum	0.003	0.103	0.018	0.096	0.000	0.020	0.057	0.027	0.192	0.192	0.044	0.081	0.015	0.016	0.018	0.159	0.005	0.140	0.022
3 Natural Gas	0.000	0.006	0.300	0.003	0.000	0.000	0.008	0.001	0.118	0.021	0.001	0.004	0.002	0.001	0.004	0.000	0.000	0.001	0.000
4 Electricity	0.015	0.032	0.015	0.143	0.000	0.022	0.162	0.188	0.362	0.129	0.176	0.098	0.046	0.041	0.007	0.024	0.011	0.014	0.016
* Hydro Power	0.000	0.000	0.000	0.209	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 Agriculture	0.001	0.000	0.000	0.000	0.000	0.147	0.001	0.003	0.002	0.061	0.002	0.015	0.004	0.217	0.005	0.000	0.073	0.000	0.009
6 Ferrous Metals	0.002	0.005	0.004	0.001	0.000	0.000	0.276	0.014	0.013	0.007	0.066	0.020	0.138	0.011	0.127	0.005	0.003	0.005	0.004
7 Non-ferrous Metals	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.395	0.005	0.013	0.002	0.010	0.058	0.009	0.005	0.001	0.002	0.001	0.001
8 Chemical Fertilizers	0.000	0.000	0.000	0.000	0.000	0.056	0.000	0.000	0.047	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9 Chemical Industries	0.001	0.005	0.003	0.002	0.000	0.006	0.011	0.023	0.061	0.263	0.016	0.060	0.053	0.040	0.021	0.021	0.003	0.010	0.007
10 Cement	0.001	0.001	0.001	0.001	0.000	0.000	0.002	0.002	0.002	0.001	0.068	0.009	0.002	0.000	0.113	0.001	0.005	0.001	0.005
11 Building Materials	0.000	0.002	0.001	0.001	0.000	0.000	0.024	0.012	0.019	0.008	0.043	0.068	0.018	0.005	0.108	0.002	0.008	0.002	0.009
12 Heavy Mach. & Electronics	0.006	0.017	0.011	0.009	0.000	0.006	0.067	0.034	0.049	0.031	0.071	0.058	0.271	0.034	0.125	0.047	0.019	0.069	0.037
13 Light Industry	0.004	0.004	0.003	0.007	0.000	0.043	0.025	0.029	0.136	0.164	0.128	0.130	0.070	0.287	0.089	0.025	0.170	0.026	0.121
14 Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15 Freight & Communications	0.001	0.012	0.001	0.006	0.000	0.012	0.022	0.016	0.024	0.022	0.024	0.021	0.018	0.028	0.031	0.009	0.011	0.009	0.026
16 Commerce	0.002	0.009	0.002	0.006	0.000	0.009	0.031	0.039	0.040	0.045	0.037	0.038	0.048	0.055	0.038	0.016	0.032	0.013	0.020
17 Passenger Transport	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.002	0.001	0.002	0.005	0.004	0.017
18 Other Services	0.001	0.003	0.003	0.002	0.000	0.016	0.016	0.017	0.018	0.022	0.029	0.034	0.038	0.026	0.006	0.052	0.177	0.067	0.064

Source: SDA modeling and calculations

Appendix C: Direct Energy Technical Coefficients in China, 1992

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	0.055	0.026	0.000	0.810	0.000	0.015	0.652	0.106	0.472	0.116	0.325	0.190	0.039	0.053	0.008	0.046	0.014	0.067	0.021
2 Petroleum	0.003	0.121	0.019	0.063	0.000	0.019	0.044	0.016	0.091	0.095	0.032	0.024	0.005	0.013	0.015	0.130	0.004	0.156	0.026
3 Natural Gas	0.000	0.000	0.016	0.009	0.000	0.000	0.003	0.000	0.164	0.018	0.000	0.001	0.000	0.001	0.003	0.002	0.000	0.000	0.000
4 Electricity	0.018	0.051	0.016	0.151	0.000	0.023	0.140	0.144	0.256	0.080	0.079	0.071	0.023	0.029	0.008	0.025	0.008	0.007	0.015
* Hydro Power	0.000	0.000	0.000	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 Agriculture	0.000	0.000	0.000	0.000	0.000	0.139	0.000	0.002	0.001	0.031	0.001	0.012	0.002	0.161	0.004	0.000	0.040	0.000	0.006
6 Ferrous Metals	0.003	0.007	0.002	0.002	0.000	0.000	0.284	0.012	0.008	0.004	0.058	0.014	0.108	0.018	0.103	0.005	0.013	0.004	0.003
7 Non-ferrous Metals	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.420	0.002	0.010	0.001	0.004	0.044	0.012	0.001	0.000	0.002	0.000	0.000
8 Chemical Fertilizers	0.000	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.043	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9 Chemical Industries	0.002	0.013	0.001	0.004	0.000	0.018	0.010	0.026	0.074	0.277	0.022	0.054	0.044	0.062	0.030	0.036	0.003	0.032	0.008
10 Cement	0.001	0.004	0.000	0.002	0.000	0.002	0.002	0.003	0.002	0.001	0.068	0.011	0.001	0.001	0.108	0.005	0.004	0.002	0.009
11 Building Materials	0.003	0.009	0.001	0.005	0.000	0.004	0.052	0.021	0.037	0.016	0.080	0.101	0.025	0.011	0.152	0.011	0.022	0.006	0.024
12 Heavy Mach. & Electronics	0.013	0.039	0.005	0.028	0.000	0.016	0.076	0.038	0.059	0.034	0.086	0.066	0.231	0.065	0.149	0.102	0.051	0.125	0.068
13 Light Industry	0.008	0.014	0.002	0.014	0.000	0.051	0.031	0.024	0.128	0.102	0.130	0.115	0.081	0.279	0.106	0.055	0.174	0.048	0.151
14 Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.007	0.001	0.009	0.001	0.014
15 Freight & Communications	0.003	0.016	0.001	0.016	0.000	0.011	0.026	0.011	0.031	0.017	0.032	0.022	0.013	0.012	0.034	0.011	0.116	0.011	0.032
16 Commerce	0.006	0.036	0.002	0.018	0.000	0.018	0.073	0.057	0.056	0.049	0.076	0.057	0.065	0.064	0.087	0.040	0.040	0.041	0.043
17 Passenger Transport	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.001	0.002	0.003	0.017	0.004	0.015
18 Other Services	0.004	0.011	0.003	0.009	0.000	0.023	0.068	0.041	0.046	0.036	0.039	0.030	0.036	0.033	0.015	0.029	0.114	0.036	0.098

Source: SDA modeling and calculations.

Appendix D: Direct Energy Technical Coefficients in China, 1995

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	0.002	0.030	0.000	0.799	0.000	0.013	0.590	0.065	0.485	0.062	0.210	0.152	0.035	0.044	0.004	0.025	0.015	0.054	0.016
2 Petroleum	0.002	0.179	0.019	0.049	0.000	0.016	0.026	0.010	0.085	0.040	0.021	0.019	0.004	0.010	0.005	0.121	0.010	0.207	0.023
3 Natural Gas	0.000	0.001	0.018	0.001	0.000	0.000	0.002	0.001	0.184	0.010	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.000
4 Electricity	0.015	0.061	0.017	0.165	0.000	0.021	0.122	0.104	0.254	0.042	0.054	0.059	0.022	0.025	0.009	0.026	0.017	0.010	0.010
* Hydro Power	0.000	0.000	0.000	0.202	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 Agriculture	0.000	0.000	0.000	0.000	0.000	0.172	0.001	0.002	0.039	0.030	0.011	0.016	0.002	0.139	0.004	0.000	0.041	0.000	0.006
6 Ferrous Metals	0.002	0.008	0.002	0.003	0.000	0.000	0.210	0.159	0.010	0.008	0.025	0.021	0.092	0.023	0.073	0.004	0.010	0.003	0.002
7 Non-ferrous Metals	0.001	0.004	0.001	0.002	0.000	0.000	0.165	0.131	0.007	0.005	0.014	0.012	0.044	0.017	0.042	0.002	0.005	0.001	0.001
8 Chemical Fertilizers	0.000	0.000	0.000	0.000	0.000	0.045	0.000	0.000	0.031	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9 Chemical Industries	0.005	0.025	0.002	0.004	0.000	0.021	0.020	0.022	0.345	0.292	0.054	0.052	0.053	0.089	0.026	0.032	0.011	0.023	0.049
10 Cement	0.001	0.009	0.002	0.003	0.000	0.003	0.013	0.011	0.004	0.003	0.045	0.037	0.007	0.003	0.085	0.004	0.007	0.002	0.008
11 Building Materials	0.004	0.018	0.003	0.007	0.000	0.006	0.024	0.021	0.023	0.018	0.104	0.096	0.014	0.011	0.172	0.010	0.016	0.005	0.019
12 Heavy Mach. & Electronics	0.011	0.084	0.017	0.034	0.000	0.030	0.090	0.070	0.075	0.045	0.077	0.073	0.291	0.079	0.145	0.116	0.050	0.132	0.054
13 Light Industry	0.007	0.028	0.006	0.015	0.000	0.088	0.034	0.041	0.149	0.124	0.107	0.116	0.076	0.321	0.093	0.043	0.117	0.035	0.083
14 Construction	0.000	0.001	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.008	0.002	0.010	0.000	0.014
15 Freight & Communications	0.003	0.049	0.002	0.020	0.000	0.015	0.034	0.029	0.016	0.012	0.028	0.029	0.014	0.012	0.034	0.011	0.103	0.009	0.026
16 Commerce	0.004	0.065	0.003	0.015	0.000	0.018	0.069	0.056	0.032	0.024	0.046	0.044	0.047	0.042	0.055	0.025	0.030	0.025	0.028
17 Passenger Transport	0.000	0.002	0.000	0.002	0.000	0.001	0.002	0.002	0.002	0.001	0.003	0.003	0.002	0.002	0.003	0.003	0.018	0.004	0.015
18 Other Services	0.003	0.015	0.002	0.010	0.000	0.023	0.023	0.022	0.023	0.018	0.030	0.031	0.025	0.027	0.011	0.016	0.134	0.031	0.068

Source: SDA modeling and calculations.

Appendix E: Direct and Indirect Energy Technical Coefficients in China, 1981

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	1.045	0.081	0.054	0.873	0.000	0.245	1.899	0.928	1.800	1.134	1.744	0.786	0.999	0.497	0.715	0.370	0.215	0.300	0.298
2 Petroleum	0.012	1.097	0.032	0.268	0.000	0.097	0.338	0.278	0.447	0.732	0.189	0.179	0.248	0.179	0.170	0.260	0.069	0.177	0.131
3 Natural Gas	0.001	0.026	1.382	0.008	0.000	0.025	0.046	0.017	0.262	0.100	0.013	0.014	0.032	0.025	0.023	0.011	0.008	0.009	0.011
4 Electricity	0.025	0.048	0.024	1.211	0.000	0.113	0.403	0.679	0.706	0.526	0.275	0.151	0.344	0.179	0.172	0.065	0.068	0.064	0.100
* Hydro Power	0.005	0.010	0.005	0.257	1.000	0.024	0.085	0.144	0.150	0.111	0.058	0.032	0.073	0.038	0.036	0.014	0.014	0.014	0.021
5 Agriculture	0.005	0.014	0.010	0.011	0.000	1.209	0.041	0.053	0.075	0.241	0.069	0.098	0.111	0.559	0.169	0.025	0.148	0.023	0.120
6 Ferrous Metals	0.006	0.017	0.018	0.014	0.000	0.008	1.441	0.070	0.043	0.041	0.155	0.030	0.334	0.054	0.185	0.029	0.026	0.040	0.046
7 Non-ferrous Metals	0.002	0.004	0.003	0.004	0.000	0.004	0.069	1.645	0.020	0.045	0.022	0.015	0.166	0.038	0.030	0.010	0.014	0.016	0.021
8 Chemical Fertilizers	0.000	0.001	0.001	0.001	0.000	0.094	0.003	0.005	1.104	0.030	0.006	0.008	0.009	0.044	0.014	0.002	0.012	0.002	0.010
9 Chemical Industries	0.003	0.016	0.005	0.008	0.000	0.022	0.027	0.044	0.060	1.316	0.028	0.050	0.077	0.098	0.049	0.019	0.026	0.018	0.032
10 Cement	0.001	0.002	0.002	0.001	0.000	0.001	0.004	0.005	0.003	0.003	1.097	0.004	0.003	0.001	0.137	0.001	0.003	0.001	0.001
11 Building Materials	0.001	0.004	0.003	0.002	0.000	0.001	0.030	0.027	0.009	0.009	0.009	1.016	0.021	0.008	0.172	0.005	0.010	0.007	0.027
12 Heavy Mach. & Electronics	0.008	0.018	0.016	0.024	0.000	0.010	0.142	0.097	0.048	0.047	0.107	0.070	1.354	0.042	0.126	0.057	0.055	0.121	0.115
13 Light Industry	0.010	0.023	0.016	0.019	0.000	0.042	0.070	0.100	0.162	0.211	0.149	0.128	0.199	1.498	0.247	0.050	0.304	0.045	0.262
14 Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
15 Freight & Communications	0.003	0.013	0.004	0.018	0.000	0.010	0.098	0.057	0.050	0.060	0.072	0.050	0.066	0.041	0.080	1.028	0.027	0.016	0.039
16 Commerce	0.002	0.027	0.010	0.019	0.000	0.014	0.048	0.077	0.059	0.084	0.028	0.022	0.073	0.054	0.045	0.045	1.043	0.023	0.044
17 Passenger Transport	0.000	0.001	0.001	0.001	0.000	0.002	0.005	0.006	0.004	0.007	0.006	0.006	0.012	0.005	0.005	0.005	0.010	1.007	0.031
18 Other Services	0.002	0.007	0.006	0.008	0.000	0.009	0.037	0.043	0.033	0.047	0.036	0.032	0.068	0.051	0.033	0.049	0.132	0.065	1.085

Source: SDA modeling and calculations.

Appendix F: Direct and Indirect Energy Technical Coefficients in China, 1987

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	1.040	0.076	0.055	0.907	0.000	0.210	1.573	0.662	1.740	0.709	1.546	0.966	0.673	0.391	0.652	0.242	0.207	0.216	0.178
2 Petroleum	0.008	1.131	0.038	0.139	0.000	0.067	0.172	0.142	0.356	0.377	0.150	0.182	0.132	0.103	0.124	0.209	0.053	0.186	0.065
3 Natural Gas	0.001	0.011	1.430	0.007	0.000	0.014	0.024	0.010	0.190	0.052	0.011	0.016	0.015	0.013	0.016	0.005	0.005	0.005	0.005
4 Electricity	0.023	0.055	0.036	1.199	0.000	0.084	0.357	0.435	0.567	0.309	0.340	0.224	0.235	0.150	0.175	0.070	0.072	0.059	0.065
* Hydro Power	0.005	0.012	0.007	0.250	1.000	0.018	0.075	0.091	0.118	0.065	0.071	0.047	0.049	0.031	0.037	0.015	0.015	0.012	0.014
5 Agriculture	0.004	0.009	0.006	0.012	0.000	1.207	0.052	0.063	0.104	0.218	0.096	0.115	0.097	0.406	0.098	0.029	0.182	0.030	0.077
6 Ferrous Metals	0.005	0.015	0.014	0.013	0.000	0.012	1.427	0.064	0.064	0.051	0.145	0.071	0.291	0.050	0.250	0.029	0.028	0.035	0.028
7 Non-ferrous Metals	0.002	0.005	0.004	0.005	0.000	0.007	0.068	1.671	0.034	0.051	0.033	0.042	0.156	0.039	0.051	0.013	0.017	0.016	0.016
8 Chemical Fertilizers	0.000	0.001	0.000	0.001	0.000	0.070	0.003	0.004	1.056	0.021	0.006	0.008	0.007	0.024	0.006	0.002	0.011	0.002	0.005
9 Chemical Industries	0.004	0.013	0.010	0.011	0.000	0.028	0.056	0.079	0.131	1.403	0.070	0.124	0.140	0.103	0.089	0.044	0.036	0.033	0.035
10 Cement	0.001	0.002	0.002	0.002	0.000	0.001	0.006	0.007	0.006	0.005	1.077	0.013	0.006	0.003	0.125	0.003	0.008	0.003	0.007
11 Building Materials	0.001	0.004	0.003	0.003	0.000	0.005	0.046	0.030	0.033	0.023	0.063	1.084	0.044	0.016	0.139	0.007	0.017	0.008	0.016
12 Heavy Mach. & Electronics	0.011	0.034	0.029	0.033	0.000	0.032	0.180	0.123	0.148	0.122	0.175	0.143	1.455	0.107	0.260	0.089	0.071	0.120	0.083
13 Light Industry	0.011	0.023	0.017	0.033	0.000	0.114	0.142	0.158	0.319	0.415	0.302	0.302	0.264	1.520	0.281	0.084	0.331	0.090	0.229
14 Construction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
15 Freight & Communications	0.002	0.017	0.005	0.013	0.000	0.024	0.052	0.047	0.058	0.061	0.055	0.049	0.057	0.060	0.066	1.021	0.035	0.022	0.042
16 Commerce	0.004	0.016	0.008	0.015	0.000	0.027	0.080	0.098	0.094	0.112	0.089	0.086	0.119	0.111	0.100	0.035	1.068	0.033	0.047
17 Passenger Transport	0.000	0.001	0.001	0.001	0.000	0.003	0.004	0.005	0.006	0.007	0.006	0.007	0.009	0.006	0.006	0.004	0.011	1.006	0.020
18 Other Services	0.004	0.011	0.009	0.011	0.000	0.035	0.063	0.069	0.070	0.085	0.081	0.083	0.109	0.085	0.068	0.073	0.223	0.091	1.095

Source: SDA modeling and calculations.

Appendix G: Direct and Indirect Energy Technical Coefficients in China, 1992

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	1.100	0.163	0.029	1.103	0.000	0.176	1.394	0.632	1.027	0.460	0.743	0.488	0.432	0.331	0.464	0.213	0.212	0.221	0.197
2 Petroleum	0.010	1.162	0.026	0.108	0.000	0.059	0.147	0.100	0.200	0.204	0.109	0.087	0.074	0.083	0.099	0.184	0.069	0.212	0.076
3 Natural Gas	0.001	0.003	1.017	0.012	0.000	0.015	0.011	0.007	0.183	0.031	0.007	0.007	0.006	0.009	0.009	0.005	0.005	0.003	0.004
4 Electricity	0.030	0.096	0.024	1.229	0.000	0.085	0.338	0.367	0.422	0.209	0.205	0.168	0.152	0.133	0.150	0.086	0.081	0.068	0.079
* Hydro Power	0.005	0.017	0.004	0.216	1.000	0.015	0.059	0.065	0.074	0.037	0.036	0.030	0.027	0.023	0.026	0.015	0.014	0.012	0.014
5 Agriculture	0.007	0.021	0.003	0.022	0.000	1.197	0.065	0.059	0.085	0.122	0.086	0.086	0.075	0.307	0.097	0.043	0.130	0.042	0.081
6 Ferrous Metals	0.011	0.033	0.006	0.029	0.000	0.022	1.465	0.077	0.071	0.052	0.148	0.069	0.235	0.082	0.233	0.050	0.068	0.054	0.052
7 Non-ferrous Metals	0.003	0.012	0.002	0.012	0.000	0.011	0.067	1.748	0.034	0.048	0.036	0.035	0.124	0.055	0.049	0.023	0.031	0.025	0.025
8 Chemical Fertilizers	0.000	0.002	0.000	0.002	0.000	0.074	0.005	0.004	1.051	0.015	0.006	0.006	0.005	0.020	0.007	0.003	0.009	0.003	0.005
9 Chemical Industries	0.010	0.041	0.005	0.033	0.000	0.063	0.091	0.114	0.179	1.445	0.109	0.139	0.138	0.171	0.137	0.091	0.074	0.087	0.070
10 Cement	0.002	0.007	0.001	0.006	0.000	0.006	0.013	0.012	0.011	0.008	1.081	0.018	0.008	0.007	0.125	0.009	0.012	0.006	0.017
11 Building Materials	0.007	0.024	0.003	0.022	0.000	0.020	0.121	0.072	0.080	0.053	0.133	1.141	0.075	0.047	0.228	0.035	0.057	0.030	0.056
12 Heavy Mach. & Electronics	0.029	0.095	0.013	0.099	0.000	0.076	0.276	0.191	0.217	0.165	0.250	0.191	1.422	0.208	0.354	0.199	0.183	0.230	0.183
13 Light Industry	0.027	0.080	0.011	0.087	0.000	0.155	0.256	0.212	0.357	0.326	0.367	0.307	0.298	1.552	0.381	0.176	0.387	0.172	0.337
14 Construction	0.000	0.002	0.000	0.002	0.000	0.002	0.006	0.005	0.004	0.004	0.005	0.004	0.004	0.004	1.012	0.004	0.013	0.003	0.018
15 Freight & Communications	0.008	0.036	0.003	0.037	0.000	0.032	0.093	0.066	0.085	0.065	0.085	0.063	0.066	0.060	0.098	1.040	0.156	0.041	0.068
16 Commerce	0.014	0.070	0.007	0.057	0.000	0.058	0.199	0.174	0.156	0.144	0.178	0.136	0.173	0.162	0.213	0.096	1.121	0.100	0.114
17 Passenger Transport	0.001	0.003	0.000	0.004	0.000	0.003	0.010	0.009	0.009	0.008	0.009	0.008	0.009	0.008	0.011	0.007	0.024	1.008	0.021
18 Other Services	0.012	0.039	0.007	0.040	0.000	0.060	0.185	0.143	0.130	0.116	0.126	0.097	0.131	0.119	0.122	0.076	0.188	0.086	1.162

Source: SDA modeling and calculations.

Appendix H: Direct and Indirect Energy Technical Coefficients in China, 1995

	1	2	3	4	*	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Coal	1.100	0.163	0.029	1.103	0.000	0.176	1.394	0.632	1.027	0.460	0.743	0.488	0.432	0.331	0.464	0.213	0.212	0.221	0.197
2 Petroleum	0.010	1.162	0.026	0.108	0.000	0.059	0.147	0.100	0.200	0.204	0.109	0.087	0.074	0.083	0.099	0.184	0.069	0.212	0.076
3 Natural Gas	0.001	0.003	1.017	0.012	0.000	0.015	0.011	0.007	0.183	0.031	0.007	0.007	0.006	0.009	0.009	0.005	0.005	0.003	0.004
4 Electricity	0.030	0.096	0.024	1.229	0.000	0.085	0.338	0.367	0.422	0.209	0.205	0.168	0.152	0.133	0.150	0.086	0.081	0.068	0.079
* Hydro Power	0.005	0.017	0.004	0.216	1.000	0.015	0.059	0.065	0.074	0.037	0.036	0.030	0.027	0.023	0.026	0.015	0.014	0.012	0.014
5 Agriculture	0.007	0.021	0.003	0.022	0.000	1.197	0.065	0.059	0.085	0.122	0.086	0.086	0.075	0.307	0.097	0.043	0.130	0.042	0.081
6 Ferrous Metals	0.011	0.033	0.006	0.029	0.000	0.022	1.465	0.077	0.071	0.052	0.148	0.069	0.235	0.082	0.233	0.050	0.068	0.054	0.052
7 Non-ferrous Metals	0.003	0.012	0.002	0.012	0.000	0.011	0.067	1.748	0.034	0.048	0.036	0.035	0.124	0.055	0.049	0.023	0.031	0.025	0.025
8 Chemical Fertilizers	0.000	0.002	0.000	0.002	0.000	0.074	0.005	0.004	1.051	0.015	0.006	0.006	0.005	0.020	0.007	0.003	0.009	0.003	0.005
9 Chemical Industries	0.010	0.041	0.005	0.033	0.000	0.063	0.091	0.114	0.179	1.445	0.109	0.139	0.138	0.171	0.137	0.091	0.074	0.087	0.070
10 Cement	0.002	0.007	0.001	0.006	0.000	0.006	0.013	0.012	0.011	0.008	1.081	0.018	0.008	0.007	0.125	0.009	0.012	0.006	0.017
11 Building Materials	0.007	0.024	0.003	0.022	0.000	0.020	0.121	0.072	0.080	0.053	0.133	1.141	0.075	0.047	0.228	0.035	0.057	0.030	0.056
12 Heavy Mach. & Electronics	0.029	0.095	0.013	0.099	0.000	0.076	0.276	0.191	0.217	0.165	0.250	0.191	1.422	0.208	0.354	0.199	0.183	0.230	0.183
13 Light Industry	0.027	0.080	0.011	0.087	0.000	0.155	0.256	0.212	0.357	0.326	0.367	0.307	0.298	1.552	0.381	0.176	0.387	0.172	0.337
14 Construction	0.000	0.002	0.000	0.002	0.000	0.002	0.006	0.005	0.004	0.004	0.005	0.004	0.004	0.004	1.012	0.004	0.013	0.003	0.018
15 Freight & Communications	0.008	0.036	0.003	0.037	0.000	0.032	0.093	0.066	0.085	0.065	0.085	0.063	0.066	0.060	0.098	1.040	0.156	0.041	0.068
16 Commerce	0.014	0.070	0.007	0.057	0.000	0.058	0.199	0.174	0.156	0.144	0.178	0.136	0.173	0.162	0.213	0.096	1.121	0.100	0.114
17 Passenger Transport	0.001	0.003	0.000	0.004	0.000	0.003	0.010	0.009	0.009	0.008	0.009	0.008	0.009	0.008	0.011	0.007	0.024	1.008	0.021
18 Other Services	0.012	0.039	0.007	0.040	0.000	0.060	0.185	0.143	0.130	0.116	0.126	0.097	0.131	0.119	0.122	0.076	0.188	0.086	1.162

Source: SDA modeling and calculations.

Appendix I: Time-series data of the overall economy, 1980-2002, China

Year	EI	T	EP	MP	GDP	SS	RD	SL	ST	MKT
1980	13.8	1	101	95	4353	15.9	29			0
1981	13.0	2	101	93	4582	15.2	31	0.4	0.4	0
1982	12.4	3	102	93	4995	14.7	33	0.4	0.3	0
1983	11.9	4	104	92	5539	14.4	37	0.3	0.3	0
1984	11.1	5	104	89	6380	14.0	42	0.3	0.3	0
1985	10.6	6	108	86	7239	13.9	48	0.3	0.3	0
1986	10.3	7	102	79	7881	14.2	52	0.3	0.3	0
1987	9.9	8	100	90	8793	13.7	57	0.3	0.3	0
1988	9.5	9	97	91	9784	13.9	63	0.3	0.3	0
1989	9.5	10	99	99	10182	13.7	67	0.3	0.3	0
1990	9.3	11	100	98	10572	12.9	72	0.3	0.3	0
1991	9.0	12	107	99	11544	13.4	81	0.3	0.3	0
1992	8.3	13	115	101	13188	15.3	104	0.3	0.3	0
1993	7.7	14	147	118	14967	15.5	111	0.3	0.3	1
1994	7.3	15	158	114	16862	15.4	111	0.3	0.3	1
1995	7.0	16	158	115	18634	16.8	112	0.3	0.3	1
1996	6.8	17	167	112	20420	16.1	123	0.3	0.3	1
1997	6.2	18	180	111	22225	16.0	151	0.3	0.3	1
1998	5.5	19	179	109	23963	15.4	165	0.3	0.4	1
1999	5.1	20	184	109	25674	15.6	213	0.2	0.4	1
2000	4.7	21	214	111	27727	15.5	277	0.2	0.5	1
2001	4.5	22	217	108	29806	15.8	319	0.2	0.5	1
2002	4.6	23	224	106	32279	16.0	397	0.2	0.5	1

Sources: National Bureau of Statistics of China, various editions of CSYB; China Labor Statistical Yearbooks; China Population Statistical Yearbooks; Zhongguo 1982 nian ren kou pu cha zi liao (1985.7); China Census, and China Science and Technology Statistical Data Books.

Note: EI is the energy intensity;
T is a time counter variable from 1 to T;
EP is the aggregate energy price;
MP is the price for non-energy intermediate materials;
EP and MP are price indices from industry sectors, basically, deflated by GDP deflator;
GDP is gross domestic product or value added;
SS is structural shifts and based on the value-added of the energy-intensive industrial sectors and GDP in each year;
RD is research and development expenditures;
SL is the amount of skilled labor (K and SL are two quasi-fixed inputs);
ST is the total amount of capital stock; and
MKT is the policy dummy variable.

Appendix J: Time-series data of the industry sector, 1980-2002, China

Year	EI	T	EP	MP	Vain	SS	RD	SL	ST	MKT
1980	21.3	1	101	95	1924	36.1	29			0
1981	20.7	2	101	93	1929	36.1	31	0.2	3.4	0
1982	20.5	3	102	93	2038	36.1	33	0.2	3.3	0
1983	20.1	4	104	92	2216	36.1	37	0.2	3.0	0
1984	19.3	5	104	89	2482	36.1	42	0.2	2.7	0
1985	18.3	6	108	86	2787	36.2	48	0.2	2.4	0
1986	17.8	7	102	79	3066	36.6	52	0.2	2.2	0
1987	17.5	8	100	90	3368	35.6	57	0.2	2.1	0
1988	16.6	9	97	91	3786	35.9	63	0.2	1.9	0
1989	17.0	10	99	99	3900	35.9	67	0.1	1.9	0
1990	17.3	11	100	98	3912	34.9	72	0.1	2.0	0
1991	16.5	12	107	99	4318	35.8	81	0.2	1.9	0
1992	15.0	13	115	101	5091	39.6	104	0.1	1.6	0
1993	13.3	14	147	118	6106	38.0	111	0.1	1.4	1
1994	12.6	15	158	114	6981	37.1	111	0.1	1.3	1
1995	12.2	16	158	115	7882	39.8	112	0.1	1.2	1
1996	10.8	17	167	112	8740	37.7	123	0.1	1.1	1
1997	10.4	18	180	111	9668	36.8	151	0.1	1.1	1
1998	9.2	19	179	109	10208	36.2	165	0.1	1.1	1
1999	8.3	20	184	109	10989	36.5	213	0.1	1.1	1
2000	7.4	21	214	111	12089	35.5	277	0.1	1.1	1
2001	7.1	22	217	108	12966	36.3	319	0.0	1.1	1
2002	7.0	23	224	106	14332	36.0	397	0.0	1.0	1

Sources: National Bureau of Statistics of China, various editions of CSYB; China Labor Statistical Yearbooks; China Population Statistical Yearbooks; Zhongguo 1982 nian ren kou pu cha zi liao (1985.7); China Census, and China Science and Technology Statistical Data Books.

Note: EI is the energy intensity;
T is a time counter variable from 1 to T;
EP is the aggregate energy price;
MP is the price for non-energy intermediate materials;
EP and MP are price indices from industry sectors, basically, deflated by GDP deflator;
Vain is the value added for the industry sector;
SS is structural shifts and based on the value-added of the energy-intensive industrial sectors and the total value-added in the industry sector;
RD is research and development expenditures. It is not limited to the industry sector. Instead, it is the expenditures cross all sectors;
SL is the amount of skilled labor (K and SL are two quasi-fixed inputs);
ST the total amount of capital stock; and
MKT is the policy dummy variable.

Appendix K1: Statistical Description for the Overall Economy in the Partial Adjustment Models

	LNEI	LNEP	LNMP	LNGDP	LNSS	LNRD
Mean	1.763891	5.198779	4.712317	10.02647	2.760494	5.180633
Median	1.766244	5.189877	4.709601	10.04662	2.753770	5.063083
Maximum	2.047691	5.413330	4.766792	10.38218	2.822635	5.984026
Minimum	1.509924	4.988874	4.664102	9.613594	2.731159	4.707318
Std. Dev.	0.206483	0.147505	0.031270	0.251350	0.027942	0.476816
Skewness	0.011632	0.212825	0.247466	-0.201588	1.037580	0.482642
Kurtosis	1.408951	1.745277	2.171855	1.912054	3.363481	1.762330
Jarque-Bera	1.054990	0.731462	0.387826	0.560907	1.849337	1.026499
Probability	0.590081	0.693690	0.823729	0.755441	0.396663	0.598547
Sum	17.63891	51.98779	47.12317	100.2647	27.60494	51.80633
Sum Sq. Dev.	0.383718	0.195818	0.008800	0.568592	0.007027	2.046184
Observations	10	10	10	10	10	10

Source: the author's calculations

Appendix K2: Statistical Description for the Overall Economy in the Dynamic Optimization Models

	EI	EP	MP	ST	SL
Mean	5.947639	182.8464	111.3589	0.385975	0.256075
Median	5.858793	179.4483	111.0079	0.368711	0.256382
Maximum	7.749989	224.3775	117.5415	0.500791	0.301694
Minimum	4.526386	146.7711	106.0702	0.293499	0.206304
Std. Dev.	1.219586	27.30241	3.494942	0.085945	0.029158
Skewness	0.135173	0.352638	0.296734	0.252209	-0.067511
Kurtosis	1.460906	1.746297	2.190964	1.394528	2.215694
Jarque-Bera	1.017457	0.862161	0.419476	1.179991	0.263903
Probability	0.601260	0.649807	0.810796	0.554330	0.876384
Sum	59.47639	1828.464	1113.589	3.859754	2.560748
Sum Sq. Dev.	13.38652	6708.793	109.9316	0.066479	0.007652
Observations	10	10	10	10	10

Source: the author's calculations

Appendix L1: Statistical Description for the Industry Sector in the Partial Adjustment Models

	LNEI	LNEP	LNMP	LNVAIN	LNSS	LNRD
Mean	2.258511	5.198779	4.712317	9.176848	3.610114	5.180633
Median	2.280804	5.189877	4.709601	9.203754	3.601718	5.063083
Maximum	2.587848	5.413330	4.766792	9.570252	3.683018	5.984026
Minimum	1.943871	4.988874	4.664102	8.717106	3.569251	4.707318
Std. Dev.	0.244347	0.147505	0.031270	0.274764	0.032978	0.476816
Skewness	-0.030199	0.212825	0.247466	-0.236718	1.024552	0.482642
Kurtosis	1.497843	1.745277	2.171855	1.990891	3.401374	1.762330
Jarque-Bera	0.941718	0.731462	0.387826	0.517685	1.816638	1.026499
Probability	0.624466	0.693690	0.823729	0.771945	0.403201	0.598547
Sum	22.58511	51.98779	47.12317	91.76848	36.10114	51.80633
Sum Sq. Dev.	0.537349	0.195818	0.008800	0.679458	0.009788	2.046184
Observations	10	10	10	10	10	10

Source: the author's calculations

Appendix L 2: Statistical Description for the Industry Sector in the Dynamic Optimization Models

	EI	EP	MP	ST	SL
Mean	9.827045	182.8464	111.3589	1.168785	0.072595
Median	9.800087	179.4483	111.0079	1.134213	0.068980
Maximum	13.30112	224.3775	117.5415	1.419662	0.113338
Minimum	6.985739	146.7711	106.0702	1.047720	0.040936
Std. Dev.	2.369393	27.30241	3.494942	0.109661	0.024066
Skewness	0.146182	0.352638	0.296734	1.318657	0.328513
Kurtosis	1.547447	1.746297	2.190964	3.789250	1.892426
Jarque-Bera	0.914745	0.862161	0.419476	3.157641	0.691002
Probability	0.632945	0.649807	0.810796	0.206218	0.707866
Sum	98.27045	1828.464	1113.589	11.68785	0.725952
Sum Sq. Dev.	50.52622	6708.793	109.9316	0.108230	0.005213
Observations	10	10	10	10	10

Source: the author's calculations

Appendix M 1: Correlation Matrix of Time-Series Data for the Overall Economy in the Partial Adjustment Models

	LNEI	LNEP	LNMP	LNGDP	LNSS	LNRD
LNEI	1.000000	-0.962808	0.899239	-0.975706	0.172117	-0.959962
LNEP	-0.962808	1.000000	-0.875188	0.970913	-0.083417	0.971811
LNMP	0.899239	-0.875188	1.000000	-0.948215	0.069772	-0.860043
LNGDP	-0.975706	0.970913	-0.948215	1.000000	-0.022047	0.945735
LNSS	0.172117	-0.083417	0.069772	-0.022047	1.000000	-0.139731
LNRD	-0.959962	0.971811	-0.860043	0.945735	-0.139731	1.000000

Note: The correlation matrix shows that both of energy intensity and energy prices, as well as energy intensity and output are highly correlated. The correlation is around 0.9. The reason may lie in the highly trended time-series of these measures. Therefore, I introduce T variable to detrend these data series in the partial adjustment models.
Source: the author's calculations.

Appendix M 2: Correlation Matrix of Time-Series Data for the Overall Economy in the Dynamic Optimization Models

	EI	EP	MP	ST	SL
EI	1.000000	-0.945694	0.913257	-0.976179	0.947360
EP	-0.945694	1.000000	-0.856297	0.962067	-0.965120
MP	0.913257	-0.856297	1.000000	-0.856732	0.935485
ST	-0.976179	0.962067	-0.856732	1.000000	-0.932426
SL	0.947360	-0.965120	0.935485	-0.932426	1.000000

Source: the author's calculations.

Appendix N 1: Correlation Matrix of Time-Series for the Industry Sector in the Dynamic Models

	EI	EP	MP	ST	SL
EI	1.000000	-0.955263	0.921610	0.856303	0.986846
EP	-0.955263	1.000000	-0.856297	-0.811371	-0.945102
MP	0.921610	-0.856297	1.000000	0.894901	0.953491
ST	0.856303	-0.811371	0.894901	1.000000	0.912896
SL	0.986846	-0.945102	0.953491	0.912896	1.000000

Source: the author's calculations.

Appendix N 2: Correlation Matrix of Time-Series for the Industry Sector in the Partial Models

	LNEI	LNEP	LNMP	LNVAIN	LNSS	LNRD
LNEI	1.000000	-0.974389	0.905212	-0.977349	0.777930	-0.970366
LNEP	-0.974389	1.000000	-0.875188	0.970864	-0.759617	0.971811
LNMP	0.905212	-0.875188	1.000000	-0.946791	0.720482	-0.860043
LNVAIN	-0.977349	0.970864	-0.946791	1.000000	-0.713763	0.940270
LNSS	0.777930	-0.759617	0.720482	-0.713763	1.000000	-0.744329
LNRD	-0.970366	0.971811	-0.860043	0.940270	-0.744329	1.000000

Source: the author's calculations.

Appendix O: Measuring Regressors in the Basic Models:

Specifically, I use standard coal equivalent, the physical amount, instead of the economic value, as a measure to document energy consumption and energy intensity in China. Energy intensity is defined as the energy consumption in physical amount per unit of output. Output is measured by GDP. In terms of energy prices, to my knowledge, there is no historical time series in money values to record the changes of energy prices over the whole investigated period and to cross-check the relative factor prices at a particular time. I use an energy-producer price index as an approximation of energy prices. Nominal energy prices are the average of the producer-price indices of coal, electricity, and petroleum industries, weighted by the physical consumption shares of the four primary energy types: coal, hydro-power, and crude oil as well as gas.[22] These price indices are from CSYBs. Similarly, the prices of non-energy inputs are the price indices of production materials. In the regression, I deflate real energy prices and real non-energy prices from their nominal counterparts with a GDP deflator.[23] Given the limited availability of energy-price data, I assume that the overall economy and the industry sector have the same energy prices.

---

[22] I use the consumption of primary energy as weights to calculate general energy prices, instead of the consumption of different types of end-use energy. Primary energy consumption weights are more general and able to capture the production change or conversion-efficiency changes of primary energy processing firms, such as thermal-power generation firms using coal as the input.

[23] I do not use the Consumer Price Index (CPI) deflator, because the CPI takes non-industrial products, for example, agriculture products, into account in the weight basket, but the prices of agriculture products increase faster than industrial products. If we use CPI as the deflator, the price changes of energy will be underestimated, given the fact that industry consumes 70% energy in China. Hence, instead of CPI, I use the GDP index to deflate the nominal energy and non-energy material price index.

As for the measure of total fixed assets, I derived them from fixed-assets investment using the perpetual-inventory method. The depreciation rates are basically of state-owned enterprises from CSYB and Lei Chen's study (2002). The deflator is the price index of investment.[24] The variable of skilled labor is based on the profession classification, instead of educational attainment.[25] It measures the amount of professional and technical personnel.[26]

---

[24] China began to publish the price index of investment in 1991. I estimate those of the earlier years from the Retail Price Index, which is the only traditional price index in China Statistical Yearbooks.

[25] Educational attainment is not the second-best. Different from expectation, the statistical agencies do not release much more population data by educational attainment than population data by profession.

[26] However, this measure is not a regular entry in China Statistical Yearbook even at the overall economy level, and we only have the data in some years, which are 1986, 1990, 1995, and 1999 throughout 2002 for the overall economy and 1999 throughout 2002 for the industry sector. I have to assume that the employee structure by professions does not change in neighboring years. In particular, I use the average share of professional and technical personnel among all employees of 1999 throughout 2000 to present those of other years to measure the skilled labor of the industry sector.

Appendix P: Selection of Energy-Intensive Sectors

Basically, I select the sectors whose energy intensities, which are defined as energy consumption in physical amount per unit of output in value-added term, are above the average in one particular year and which are energy-intensive all the time (specifically, meaning that their energy-intensity ranking does not change dramatically over time). At the industry-sector level, I compare the energy intensities of each industrial subsector with the average of the industry sector respectively in 1987 and in 1997 (Table H.1). I choose the top 12 energy-intensive industry subsectors[27] in two years.

At the overall economy level, my calculation shows that the top two energy-intensive sectors, which have energy intensities above the national levels, are the industry and transportation sectors (Table H. 2). However, the increasing energy intensity of transportation (Guowei, 1998) is lower than any of those 12 energy-intensive industry subsectors in 1997 and even lower than the two industry subsectors of nonferrous metals mining and dressing and rubber products whose energy intensities are below the average of the industry sector. What is more, transportation only consumed 7.6% of the national energy consumption in 2001 while those energy-intensive industry subsectors

---

[27] The industry subsectors' classification and coverage changed. I remove the other manufacturing industry from the energy-intensive sectors although it far ahead of other subsectors in terms of energy intensity in 1987. According to the Standard Industrial Classification, other manufacturing industry includes coal processing/coal products except coking, etc. Hence, in 1980s when there was very little mass provision of gas and heating as well as few other manufacturing industries, such as arts and crafts, the subsector energy intensity of other manufacturing industry may be high. What is more, the coverage of other manufacturing industry subsector is very sensitive to the change of industry classification. Although other manufacturing industry is energy-intensive, its value-added is relatively stable, around 1% in 1987, 1.3 % in 1997, and 1.3% in 2001 compared to that of the whole industry sector. The removal of other manufacturing industry from the energy-intensive sectors will therefore not change the state of structural change very much.

in total consume more than 50% of the national energy consumption. Hence, I omit transportation in the national structural shift calculation and use value-added of energy-intensive industry subsectors to reflect the structural shift of China's economy. In this way, I can analyze energy intensity at a 2-digit sector classification, which is much more efficient than 1-digit industry classification to capture the structural-shift effect on energy-intensity decline in China (Fisher-Vanden, etc. 2004). The regressor of structural shift is shortened to SS in the equation.

Table P.1: Energy Intensity by Industry Subsectors in 1985 and 1997 (tonne sce/10,000 RMB Yuan)

1985	EI	1997	EI
Other Manufacturing Industry	*159*	*Production and Supply of Gas*	*79.5*
Raw Chemical Materials and Chemical Products	46.7	Smelting and Pressing of Ferrous Metals	36.3
Nonmetal Mineral Products	46.6	Raw Chemical Materials and Chemical Products	27.0
Smelting and Rolling of Ferrous Metals	42.7	Petroleum Processing and Coking	25.1
Ferrous Metals Mining and Dressing	30.1	Nonmetal Mineral Products	22.8
Papermaking and Paper Products	27.6	Smelting and Pressing of Nonferrous Metals	21.7
Smelting and Rolling of Nonferrous Metals	26.4	Coal Mining and Dressing	16.7
Coal Mining and Dressing	22.8	Chemical Fiber	14.1
Tap Water Production & Supply	20.5	Production and Supply of Electric Power, Steam and Hot Water	12.7
Chemical Fiber	17.8	Ferrous Metals Mining and Dressing	12.2
Nonferrous Metals Mining and Dressing	17.2	Papermaking and Paper Products	11.7
Timber Processing, Bamboo, Cane, Palm, and Straw Products	12.2	Other Manufacturing Industry	10.9
Nonmetal Mineral Mining and Dressing	12.1	Production and Supply of Tap Water	10.1
Medical and Pharmaceutical Products	11.7	Nonferrous Metals Mining and Dressing	7.2
Petroleum Processing and Coking	10.1	Petroleum and Natural Gas Extraction	6.3
Petroleum and Natural Gas Extraction	9.5	Nonmetal Minerals Mining and Dressing	6.1
Other Minerals Mining and Dressing	9.4		
Textile Industry	9.1		
Food, Beverage, and Tobacco Processing	8.5		
Electric Power, Steam, and Hot Water Production & Supply	8.5		
Mean of all subsectors	15	Mean	10

Source: China Energy Databook V6.0, 2004; CSYB, 1988 and 1999; calculations

Table P.2: Energy Intensities by Sector in 2001

Sector	Consumption (%)	Value-added (%)	Energy Intensity tonne sce/10,000 Yuan
Farming, Forestry, Animal Husbandry, Fishery and Water	4.6	15.8	1.3
Industry	68.4	43.5	7.1
Construction	1.1	6.6	0.7
Transportation, Storage, Post and Telecommunication	7.6	6.1	5.6
Wholesale, Retail Trade and Catering Services	2.3	8.1	1.3
Others	4.5	19.9	1.0
Residential Consumption	11.4		1.4
National			4.5

Source: CSYB 2003 and calculations

Appendix Q: Sector Classification of the Input-Output Tables of China

Sector Code and Title	Contents
1. Agriculture	Crop cultivation, Forestry, Livestock, Fishing, Other agricultural production
2. Coal	Coal mining, Coal cleaning and screening, Coking, Manufacture of gas and coal products
3. Oil & Refineries	Crude petroleum production, Petroleum refineries
4. Natural Gas	Natural gas production
5. Electricity	Electricity, steam and hot water production and supply
6. Ferrous Metals	Ferrous ore mining; Primary iron and steel manufacturing
7. Non-ferrous Metals	Non-ferrous ore mining Primary non-ferrous metals manufacturing
8. Chemical Fertilizers	Manufacture of chemical fertilizers
9. Chemical Industry	Chemical industries, excluding chemical fertilizers Manufacture of rubber product and plastic products for production use
10. Cement	Manufacture of cement, cement products and asbestos products
11. Building Materials	Quarrying of building materials and non-metal minerals Manufacture of building materials and other non-metallic mineral products, excluding cement, cement products and asbestos products
12. Heavy Machinery & Electronics	Manufacture of metal products for production use Manufacture of machinery, excluding that for daily use; Transport equipment; Electric machinery and instrument, excluding that for daily use; Electronic and communication equipment, excluding that for daily use Instruments, meters and other measuring equipments Repair of machinery and equipment, other products for production use
13. Light Industry	Salt mining, Logging and transport of timber and bamboo Production and supply of water; Food manufacturing; Manufacture of textiles Manufacture of wearing apparel, leather and products of leather and fur Sawmills and manufacture of furniture, Papers, cultural and educational articles Chemical products, plastic products and rubber products for daily use Manufacture of medicines; Chemical fibers; Metal products and machinery for daily use; Manufacture of household electrical appliances; Electronic appliances for daily use; Other products for daily use
14. Construction	Construction
15. Transport & Communication	Freight transport and communications
16. Commerce	Commerce; Restaurants
17. Passenger Transport	Railway, highway, water and air passenger transport
18. Other Service	Public utilities and services to household; Cultural, education, health and scientific research institutions; Finance and insurance, Public administration

Source: Guo, Ju-e, 2000

References

Berndt, Ernst R., and Barry C. Field (ed.). 1981, *Modeling and Measuring Natural Resource Substitution*, Cambridge, Massachusetts: MIT Press

Chen, Lei, 2002, “中国▪▪▪期▪▪增▪周期的基本特征及其解▪模型”, Management World (管理世界), V12

China Science and Technology Statistics, China S&T Statistics Data Book, 1998-2003. http://www.sts.org.cn/sjkl/kjtjdt/index.htm

Dunkerley, Joy, and Ramsay, William. et al., 1981. *Energy Strategies for Developing Nations*. Baltimore: Johns Hopkins University Press.

Fisher-Vanden, Karen, et al., 2004. “What is Driving China’s Decline in Energy Intensity?” *Resource and Energy Economics* 26; 77–97.

Garbaccio, Richard F., Ho, Mun S., and Dale W. Jorgenson, 1999. “Why Has the Energy-Output Ratio Fallen in China?” *Energy Journal*, 20: 63 –91.

Guo, Ju-e, 2000. Some Trends on Change in Direct Input Coefficient of China, Paper for the Thirteenth International Conference on Input-Output Techniques. August 21-25, 2000. Macerata, Italy

Hudson, Edward A., and Dale W. Jorgenson, 1978. “The Economic Impact of Policies to Reduce U. S. Energy Growth”. *Resources and Energy*, 1978(1): 205-229.

Kambara, Yatsu. 1992. “The Energy Situation in China”. *China Quarterly*, 13 (September): 608-636

Kaufmann, Robert K., 2004. “The Mechanisms for Autonomous Energy Efficiency Increases: A Cointegration Analysis of the US Energy/GDP Ratio.” *The Energy Journal*, 25(1): 63-86

Leontief, Wassily, 1958? 1985. “The Choice of Technology.” *Scientic American* 252(6): 37-45.

Lin, Xiannuan, and Karen R. Polenske, 1995. “Input–output Anatomy of China’s Energy Use Changes in the 1980s.” *Economic Systems Research*, 7 (1): 67–84.

Lin, Xiannuan . 1996. *China's Energy Strategy Economic Structure, Technological Choices, and Energy Consumption*. Westport, Conn.: Praeger.

Maiello, Domenico, 2003. Presentation of International Coal Trade and Price Developments in 2003 at United Nations Economic and Social Council's Economic Commission for Europe - Committee on Sustainable Energy, Sixth session. Geneva, 17/18 November

Moroney, John R. 1988. "Output and Energy: An International Analysis." *Energy Journal,* 10(3): 1-18.

National Statistical Bureau of China, 1981-2004. *China Statistical YearBook*, Beijing: China Statistics Press

National Statistical Bureau of China, 1987. *China Energy Statistical YearBook 1986*, Beijing: China Statistics Press
National Statistical Bureau of China, 1992. *China Energy Statistical YearBook 1991*, Beijing: China Statistics Press

National Statistical Bureau of China, 1998. *China Energy Statistical YearBook 1991-1996*, Beijing: China Statistics Press

National Statistical Bureau of China, 2001. *China Energy Statistical YearBook 1997-1999*, Beijing: China Statistics Press

National Statistical Bureau of China, 2004. *China Energy Statistical YearBook 2000-2002*, Beijing: China Statistics Press

National Statistical Bureau of China. *China Labor Statistical Yearbook* 1997, 1998, 1999, 2000, 2003, Beijing: China Statistics Press

National Statistical Bureau of China, 2003. *China Population Statistical Yearbook* 2003, Beijing: China Statistics Press

Office of Technology Assessment (OTA), 1990. Energy Use and the U.S. Economy. OTA-BP-E-57. Washington, DC: U.S. Government Printing Office.

Polenske, Karen R. and Stephen Fournier. 1993. "Conceptual Input-Output Accounting and Modeling Framework." In Spreadsheet Models for Urban and Regional Analysis, edited by Richard E. Klosterman and Richard K. Brail. New Brunswick, NJ: Center for Urban Policy Research, pp. 205-228.

Polenske, Karen R.(ed.), 2005 (forthcoming). The Technology-Energy-Environment-Health (TEEH) Chain in China: a Case Study of Cokemaking. Springer

Popp, David, 2002. "Induced Innovation and Energy Prices". *The American Economic Review.* 92(1):160-80.

Sinton, Jonathan E., 2001. "Accounting and Reliability of China's Energy Statistics". *China Economic Review, 12: 373-383*

Sinton, Jonathon E., and Fridley, David G., 2000. "What Goes up: Recent Trends in China's Energy Consumption". *Energy Policy,* 28: 671–687.

Sinton JE, et al. 1998. "Energy efficiency in China: Accomplishments and challenges." *Energy Policy*, 26 (11): 813-829.

Sinton, Jonathon E., and Levine, Mark D., 1994. "Changing energy intensity in Chinese industry: the relative importance of structural shift and intensity change." *Energy Policy,* 22: 239 –255.

Smil, Vaclav, 1990. *China's Energy*. A Report Prepared for the Office of Technology Assessment, U.S. Congress.

US Energy Information Administration, 2005. World Energy Intensity (Total Primary Energy Consumption Per Dollar of Gross Domestic Product), 1980-2003. http://www.eia.doe.gov/emeu/international/other.html#GDP (downloaded in August, 2005)

U.S. Energy Information Administration (EIA), 2005. http://www.eia.doe.gov/

Verbruggen, Aviel, 2003. "Stalemate in Energy Markets: Supply Extension versus Dmand Reduction." *Energy Policy,* 31: 1431-1440.

Wing, Ian Sue, and Richard S. Eckaus, 2004. Explaining Long-Run Changes in the Energy Intensity of the U.S. Economy. *MIT Joint Program on theScience and Policy of Global Change,* Report No. 116

Yan, Changle, and Zhilin Zhao (ed.), 2003. "China's Energy Development Report" Beijing: China Computation Press

Zhang, ZhongXiang, 2003. "Why Did the Energy Intensity Fall in China's Industrial Sector in the 1990s? The Relative Importance of Structural Change and Intensity Change." *Energy Economics,* 25: 625–638.