China’s energy use: the changing relationship between economic growth and energy

Dominic Meagher

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I declare that the thesis is my own original work except where specific attribution is made.

Dominic Meagher

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Abstract

The transformation of China's economy since 1978 is one of the most profound economic transformations in history. Among the most important dimensions of China's transformation is the way rapid economic growth drove energy consumption. All economic activity depends in one way or another upon energy but there is now overwhelming evidence that much of the way we use energy has undesirable externalities, including potentially destabilising effects on the earth's climate system. China is already the world's largest energy user and prospects for future economic growth and therefore energy consumption remain strong. China's energy use is therefore a critical area of analysis. The thesis addresses three core questions. Why has China's energy consumption grown so rapidly since 2002? Is China's economy peculiar in its huge and rapidly growing energy consumption or does it conform to the experience of other countries when they were at similar stages of development? What are the implications for China's energy future? Input-Output Analysis (IOA) and Structural Decomposition Analysis (SDA) are employed to isolate energy relationships with rural and urban household consumption, government expenditure, investment, trade and production. Data from the 2002 IO table (122 sectors) and the 2007 IO table (135 sectors), China's energy statistical yearbooks and a variety of supplementary sources are used. One key contribution of the thesis is to place analysis of energy use in the context of China's broad economic development, drawing on economic growth literature to do so. The second central contribution in contrast to existing literature is extensive interpretation of results. The results indicate China's very rapid energy use growth between 2002 and 2005 may have been a temporary effect linked to China's WTO membership. China's manufacturing export boom beginning in 2002 drove a large portion of the energy use growth, while energy-saving technological improvements declined between 2002-2005. Longer-term drivers are urbanisation, increasing household consumption, and resumption of policy- as well as market-driven energy saving technological progress. Technological progress has been most evident in traded goods sectors, especially importing sectors. A shift to petroleum rather than coal-based energy was observed. The 12th Five Year Plan calls for significantly slower energy use growth. The analysis suggests implementing changes required to meet energy-use targets will be challenging. In particular, the plan calls for a substantial reduction in investment growth and a shift in production toward services that has so far been elusive. China's energy future carries very important strategic implications. Hundreds of millions of Chinese are now aspiring to higher standards of living, inevitably requiring ever more supplies of energy. Understanding the drivers of China's energy-use growth is crucial if it is to be managed so as to ameliorate the problems associated with energy use while still ensuring the Chinese people can realize their aspirations toward a healthier, more comfortable and more fulfilling life.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BTU	British Thermal Unit
CGE	Computable General Equilibrium
EKC	Environmental Kuznets Curve
GDP	Gross Domestic Product
GFC	Global Financial Crisis
GHG	Greenhouse Gas
GJ	Gigajoules
GNP	Gross National Product
GRP	Gross Regional Product
GTAP	Global Trade Analysis Project
GVIO	Gross Value of Industrial Output
IEA	International Energy Agency
KLEM	Capital, Labour, Energy, Materials
LMDI	Logarithmic Mean Divisia Index
LPG	Liquid Petroleum Gas
IDA	Index Decomposition Analysis
INA	Index Number Analysis
IO	Input Output
IOA	Input Output Analysis
IOT	Input Output Table
Mtoe	Million Tons of Oil Equivalent
NAFTA	North American Free Trade Agreement
NBSC	National Bureau of Statistics of China
NDRC	National Development and Reform Commission
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoules
PPP	Purchasing Power Parity
PRC	People's Republic of China
RMB	Renminbi
SAR	Special Autonomous Region
SCE	Standard Coal Equivalent
SDA	Structural Decomposition Analysis
TCE	Tons of Coal Equivalent
TOE	Tons of Oil Equivalent
VAI	Value Added of Industry
WFOE	Wholly Foreign-Owned Enterprise
WTO	World Trade Organisation

Chapter 1. Introduction

The transformation of China's economy since 1978 is one of the most profound economic transformations in history. Among the most important dimensions of China's transformation is the way rapid economic growth drove energy consumption.

The relationship between energy use and economic activity is never constant, especially in a country such as China, undergoing rapid economic transformation including major technological and structural changes. On the technological side, the amount and type of energy used for production is changing rapidly. On the structural side, what is produced and consumed in China is also changing dramatically. Analysing energy in the Chinese economy needs to account explicitly for these transformations.

In this context, the thesis attempts to answer the questions:

- Why has China's consumption of energy grown so rapidly since 2002?
- Is China's economy peculiar in its huge and rapidly-growing consumption of energy or does it conform with the experiences of other countries when they were at similar stages of economic development?
- What are the implications for China's energy future?

A central objective of the thesis is to analyse the impact of the economic transformation in China on the relationship between China's energy use and economic growth, especially since 2002. The thesis draws on the economic growth and stages of development literature to explain China's economic transformation and contextualises that transformation with reference to the experiences of already developed countries. It aims to fill a gap in the literature on China's energy use created by insufficient attention to the impact of structural transformation on the relationship between economic growth and energy use, exacerbated by a shift in scholarly attention from energy use to greenhouse gas (GHG) emissions since around 2005. Input-Output Analysis (IOA) and Structural Decomposition Analysis (SDA) are employed to isolate energy relationships with rural and urban household consumption, government expenditure, investment, trade and production. Data from the 2002 IO table (122 sectors) and the 2007 IO table (135 sectors), China's energy statistical yearbooks and a variety of supplementary sources are used. One key contribution of the thesis is to place analysis of energy use in the context of China's broad economic development, drawing on economic growth literature to do so. A second central contribution in contrast to existing literature is extensive interpretation of results.

Probably the main reason China is such an exciting subject to study is the pace, scale and impact of the changes it is presently undergoing. In his imagery-rich description of being one of the first passengers on board China's CRH380A (the new high-speed rail connection between Beijing and Shanghai) Simon Winchester wrote, "for those of us who look on China from afar, the changes are dramatic and obvious. But, for the Chinese themselves, proud of their so ancient lineage and their cherished customs and traditions, they are surely experiencing change at such a rate that some can barely know who they are" (Winchester 2011). Pre-industrial China is still a matter of living memory for some Chinese. In such a dynamic context understanding why China consumes as much energy as it does, and drawing sensible lessons about China's energy future and its impacts on the world require a broad historical perspective as well as in-depth analysis.

Economic activity is inescapably linked to the 'consumption' of energy. This inescapability is a consequence of the first law of thermodynamics, a statement of the principle of conservation of energy (Planck 1945): "during an interaction between a system and its surroundings, the [change] in energy [experienced] by the system must be exactly equal to the [change] in energy [experienced] by the surroundings" (Cengel and Boles 1989). Because the change in energy of a system occurs either as heat or as work, *all* work involves a change in energy. But what a physicist would call a change in energy, an economist would call a consumption of energy,[2] with the corollary that all work involves a consumption of energy (in an economic sense). Since economic activity is inevitably linked to energy use, the nature of that link merits understanding.

2 In physics, a change of energy may involve the change of state from potential energy stored in fossil fuels such as coal, to a combination of heat, work and other forms of energy that maintain the total quantity of energy. In an economic sense, the value of the coal has been used to create something else of value, thus the physical change of energy can be described as a consumption of energy despite the total amount of energy existing being maintained.

Adapting Christian (2009), the history of human use of energy has four chapters: the palaeolithic, agrarian, fossil-fuel and renewable-energy eras.[3] During the palaeolithic era, the principle method of getting energy was foraging and the main use of energy was feeding oneself. Around 11,000 years ago humans entered the agrarian era with the establishment of farming methods: an energy bonanza that "could support perhaps 50 times as many people as foraging" (Christian 2009). The main use for energy remained feeding, but during the agrarian era more populous settlements were able to generate a small energy surplus that could support a fraction of the population as 'elites' and allowed employment in crafts and other specialisations. The small energy surpluses generated during the agrarian era facilitated the capital accumulation that was a necessary condition for moving into the third chapter of energy use.

Two hundred years ago humans stumbled on a second energy bonanza in fossil fuels. The transition to an energy-economy based on fossil fuels was a critical part of a broader convergence of economic, technological and social changes collectively known as the industrial revolution. Birnie (1930) describes the industrial revolution as the beginning of a series of technological progressions and adaptations that centred on efforts to use energy (usually stored in wood or coal) to turn wheels and drive machinery. From that point, humans were able to use energy to do work without the direct involvement of their own physical labour. Thus economic growth and energy use are not only inevitably related, but the relationship is inevitably changing – sometimes radically so.

In each of the first three chapters of humanity's energy-story, the relationship between the energy use and the economy was radically transformed. Economists who study fields in which population dynamics are important (such as fisheries) will be familiar with the logistics-curve, or S-curve originally proposed by Verhulst (Cramer 2003) that describes population growth. The population dynamics described by a logistics-curve begins from a low population with accelerating growth, up to an inflection point where growth begins to slow and eventually stops. One example of a mechanism by which populations can be constrained at the upper limit of the S-curve was identified by Thomas Malthus when he wrote, "the

3 Christian identifies only three eras: the palaeolithic, agrarian and modern. It is my belief that we are currently in a transition stage into a fourth energy era, namely a renewable-energy era, thus the separation of the modern era into the fossil-fuel and renewable-energy eras.

power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race" (Malthus 1798). Human ability to extract resources acted as a limit to population growth throughout both the palaeolithic and the agrarian eras. The sheer amount of energy unlocked in fossil fuels has shifted the energy constraint on population so far that it has not been binding for 200 years.

The 'big history'[4] of energy offers several points that provide a helpful context for studying the relationship between China's economy and energy use in recent years. Firstly, that economic activity is inescapably linked to energy consumption. Secondly, that historically, economic transformation and development have entailed fundamental changes to the relationship between economic activity and energy consumption. Thirdly, the fossil-fuel era is the period in which per-capita energy supply has grown at the most tremendous rate. But this is not the end of history as far as energy and the economy are concerned; we are already moving out of the fossil-fuel era with its dependence on finite energy-stocks and embarking on a renewable-energy era that once more embraces energy-flows.

The increasingly apparent limits of the third chapter the big history of energy has inspired a great deal of concern regarding sustainability.[5] The writings of Malthus have been subjected to repeated revivals over recent decades, most forcefully in response to the oil crises of 1973 and 1979 and more recently due to concern about the impact of global GHG emissions (largely due to combustion of fossil fuels for energy) on the earth's climate system. We are entering a fourth chapter in the history of human energy use: the renewable energy era. The changes during this transition may be in many ways as profound as the changes between earlier chapters of that story.

In China, where economic growth over the past thirty years has lifted more people out of poverty in a shorter time than any in any other place at any other time in history, the fear that energy will become a binding constraint on continued economic growth is now a major driver of national policy decisions. That same fear is also a powerful influence in global geopolitics, including the Sino-US relationship and China's relations with its Asian neighbours, with Africa, Eastern Europe, the

[4] 'Big history' is a recent field of history that begins with the Big Bang and moves up to the present day (Christian, Big History Project 2011).
[5] Lackner & Sachs (2005) provide an overview of these concerns.

Middle East, Western Asia and Australia. China's growing demand for energy (and other minerals) is now also responsible for a major structural transition of the Australian economy and there are indications that several energy-rich African states are being similarly impacted (Hurst 2012).

'Energy' may constrain growth in two critical ways. First, because all economic activity depends in one way or another upon energy, supply shortfalls or unexpectedly high prices can dramatically constrain production. Second, there is now overwhelming evidence that much of the way we use energy has undesirable externalities, including with potentially destabilising effects on the earth's climate system, but also other forms of localised pollution and in China's case, considerable health concerns. Destabilisation of the earth's climate certainly falls into the category of a potentially binding constraint on economic growth.

The importance of energy to economic growth coupled with a tendency to view matters such as economic growth in national terms has led to concepts such as 'energy independence' and 'energy security'. Energy independence is generally taken to mean the ability of a country to supply its energy needs through its domestic resource endowments, see for example Obama (2009). Energy security is a less exacting ambition, meaning the ability of a country to have reasonable assurance of access to sufficient energy supplies such that energy would not constrain economic growth, see for example The White House (2012). These ambitions are rooted in a supply-side conception of energy use. This is the same cognitive framework that underpins the Kyoto Protocol on Climate Change, where each signatory is obliged to report (and in the case of Annex B countries, limit) GHG emissions occurring within its borders, but no country is obliged to report or limit the GHG emissions generated elsewhere in supplying that nation's consumption.

China's energy consumption has come under particular scrutiny in recent years. In the politics of climate change, opponents of action in countries such as Australia or the United States often point to China as dwarfing their own nation's contributions to GHG emissions therefore rendering their own efforts futile, for example Bolt (2011). The argument is based on supply-side concepts of energy-use that disregards demand-side concepts of embodied GHG emissions. Meanwhile, the shift to Asia of the global economy including China's economic transformation has profound implications for all economies. For instance, supplying China with the raw materials required to meet its demand for energy is currently forcing a major adjustment in the Australian economy amongst many others. For these reasons, and others, studying the relationship between economic growth and energy remains a matter of priority.

The rest of this chapter provides the context of China's energy use, introduces some of the factors that confound analysis of the energy – economic growth relationship, sets out the approach to the problem taken in the thesis, outlines the structure of the thesis and identifies some of its main contributions. As is often the way, to answer these questions many preliminary questions will be raised, and many more will follow. The first such question is just how much energy *is* China consuming?

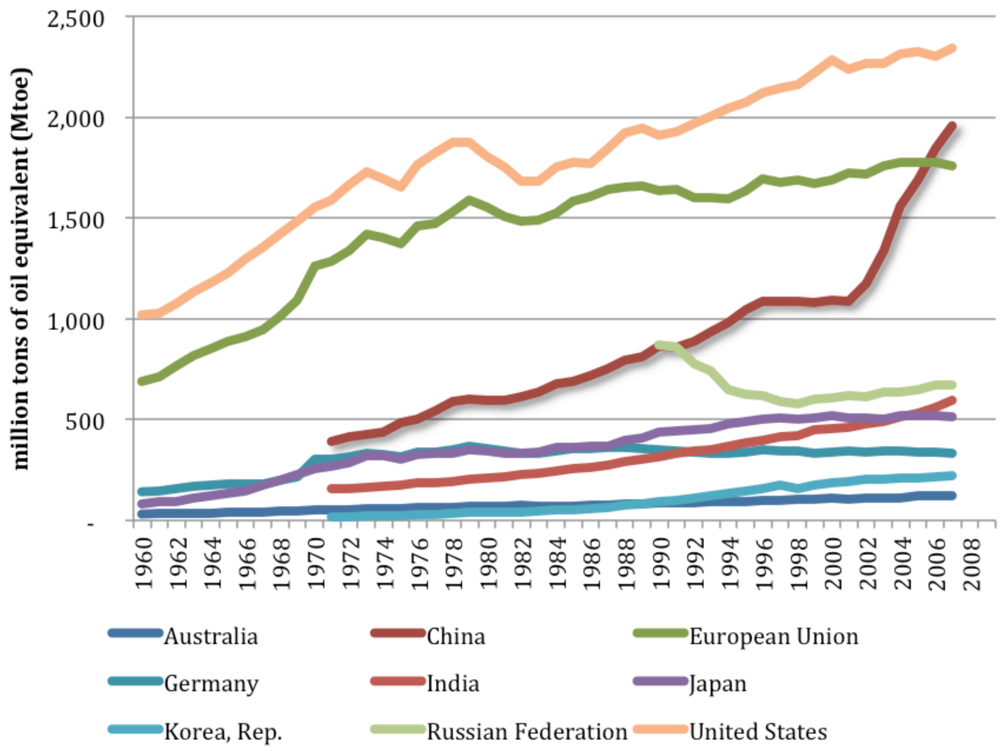
Energy use in China: recent trends

On 20 July 2010 the International Energy Agency (IEA) announced that preliminary data showed that China was the "world's largest energy user" (IEA 2010). The IEA noted that China's energy demand[7] had doubled over the decade to 2010 and that prospects for future growth were strong, given China's low per-capita energy consumption relative to the OECD average.

China's energy use grew rapidly after 2001 to occupy top position by 2009 (IEA 2010). Figure 1.1 shows that China's energy use took almost thirty years to double, from just under 400 mtoe in 1970 to just over 1,000 mtoe in 2001. China's energy-use next doubled three times faster: almost passing 2,000 mtoe in 2007, by which time China was consuming more energy than the entire European Union.[8]

[7] See the "Energy Statistics Manual" (IEA 2005) for a guide to terminology and concepts.
[8] An important caveat is the data excludes 'natural' energy use, thus some of the growth in energy use is more accurately a substitution from unmeasured 'natural' energy use to measured, industrialised energy use.

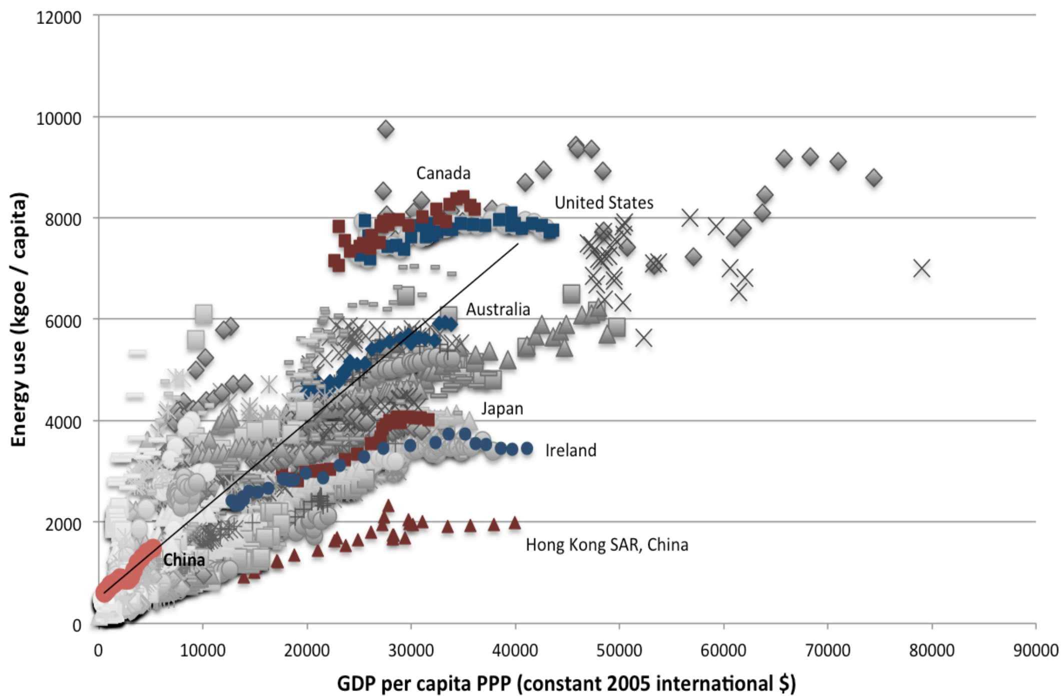
Figure 1.1: Total energy use (China and other countries)



Source: World Bank (2011)

While China's energy use is large in national terms, its per capita energy use is low in comparison to many other countries. Figure 1.2 shows China's energy consumption per capita in comparison with that of other countries plotted against GDP per capita. The data are from the World Bank's World Development Indicators and include 157 reporting countries or regions over the period 1980 to 2007. Some countries with very high energy-use per capita have been omitted, including Kuwait, Qatar, Iceland, The United Arab Emirates, Trinidad and Tobago, and Bahrain. The values for GDP per capita are the World Bank's purchasing power parity (PPP) values, using constant 2005 levels. China appears as the red circles, while most other countries are grey. It is immediately obvious from Figure 1.2 that both China's energy use per capita and China's GDP per capita are relatively low. It is also clear that at higher income levels there is greater diversity of energy use per capita, with Hong Kong, Ireland and Japan achieving high levels of GDP per capita with low levels of energy use, and the United States, Canada and Australia exhibiting similar levels of income but much higher levels of energy use.

Figure 1.2: Energy per capita vs GDP per capita (157 countries and regions, 1980-2007)



Source: World Bank (2011)

It is an open question as to whether China will end up with energy use per capita similar to that of Japan (low) or the United States (high). The simple trend line, shown in Figure 1.2, projecting China's average growth of energy use per capita forward to a point where its GDP per capita reaches PPP$40,000, would result in a level of energy use per capita very similar to the current level of the United States. If that were to occur, China's total energy use would increase by more than five times (assuming no population growth). This would occur within 20 years if China's GDP were to continue to grow at double-digit rates. Even if China's future growth occurs at the lower rates (around 6 to 8 per cent) most economists expect, the energy demand will be very large. Whether such demand for energy is within the earth's tolerable limits is uncertain. These issues underline the interest here in understanding the relationship between China's economic growth and its energy consumption.

The complex relationship between energy and economic growth

There is an abundance of research analysing the link between economic growth and energy consumption, but despite all the attention this relationship has received over the decades the framework for thinking about and understanding it is still inadequate. We lack a theory that satisfactorily relates energy use to economic growth in the context of rapidly changing economic structure. Part of the problem is explained by Bill Adams of PNC: “the underlying assumption of most models is that relationships in the future will be the same as relationships in the past. In China that is often not the case” (Orlik 2011). There are a number of factors that confound the study of the relationship between energy use and economic growth in China, some of which are raised here.

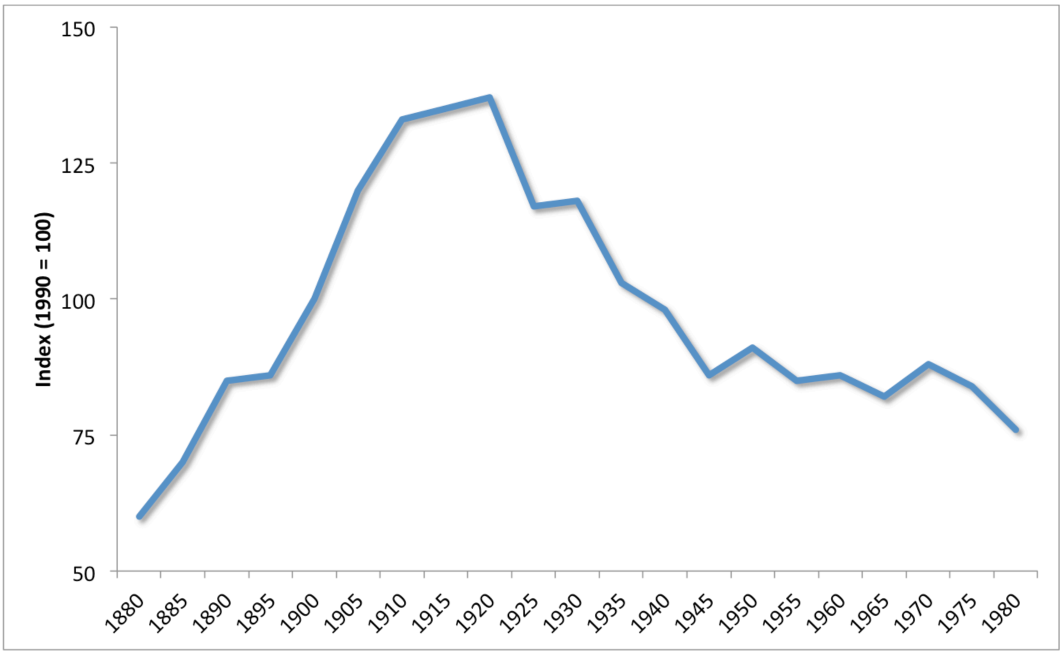
The Kuznets curve for energy intensity

One contender for a theory relating energy use to economic growth, while accommodating a changing economic structure, is the Kuznets curve for energy intensity. In a landmark 1960 study *Energy in the American Economy*, Schurr and colleagues documented a striking historical phenomenon:

> that over the period 1880-1955 the relationship between the consumption of energy… and growth of gross national product (GNP) in the United States had been characterized by two distinctly different long-term trends, separated roughly by World War I. Before World War I the consumption of energy relative to GNP had been generally rising while after the war it had persistently declined (Schurr 1984, 409).

The observation is depicted in Figure 1.3.

Figure 1.3: United States energy intensity (1880-1980)

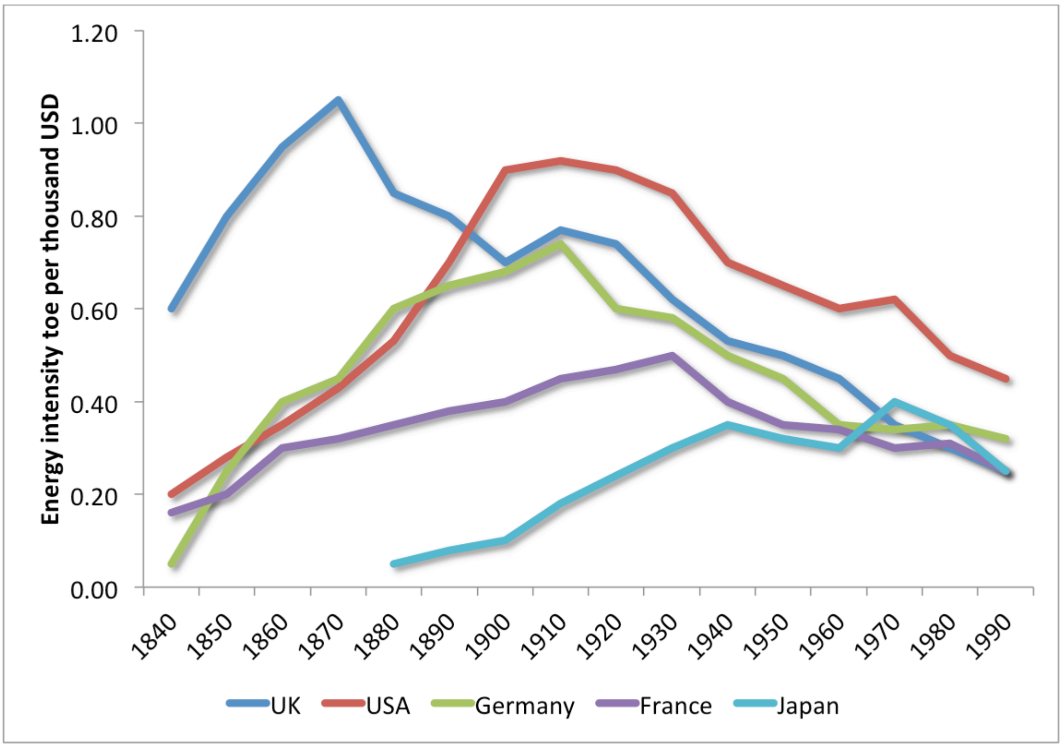


Source: Data estimated from Schurr (1984)

A similar trend has been observed repeatedly in other countries (see Figure 1.4) leading to the hypothesis that a Kuznets curve for energy-intensity exists as a result of the economic development process. An important caveat here is that the Kuznets curve[9] appears to break down if traditional biomass consumption is included. Including traditional fuels, energy intensity appears to decline from an initial peak (Stern 2011). Further, cross-country analyses typically fail to demonstrate strong adherence to such a model. For example, Lenzen et al (2006) conclude that their data do "not support the existence of a single, uniform cross-country relationship between energy requirements and household expenditure." Additionally, the Kuznets curve is only an approximate description of empirical observations and is not, itself, a theoretical explanation for those observations.

[9] So named after Simon Kuznets 1955 observation of rising then falling income inequality in a cross-section of countries plotted against time (McKay et al. 2010)

Figure 1.4: Energy intensity: UK, USA, Germany, France, Japan (1840-1990)

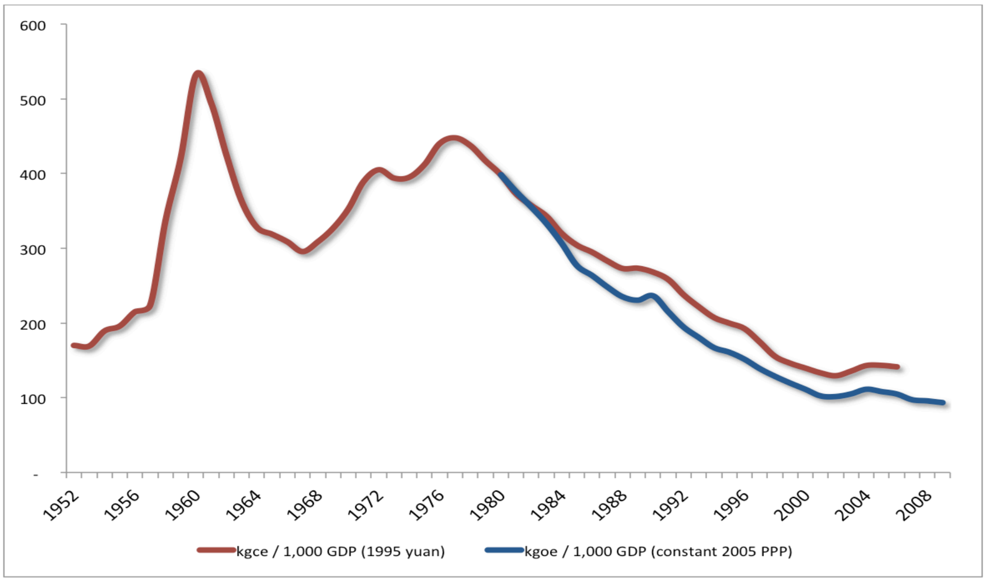


Source: Data estimated from McKay and Song (2009)

For Schurr, explaining the initial rise in energy intensity was relatively simple: the change from a predominantly labour-based economy to a predominantly industrial and machine-based economy necessitated the increasing use of fossil fuels. It was the opposing trend that required a less intuitive explanation. The starting point for Schurr's search to explain these opposing trends was the hypothesis that two factors likely caused the post-war decline in energy intensity: technological change and the "changing composition of national output toward lighter manufacturing industries and services that, on average, used less energy per unit of output than the heavy industries that had been more dominant in the past", or structural change.

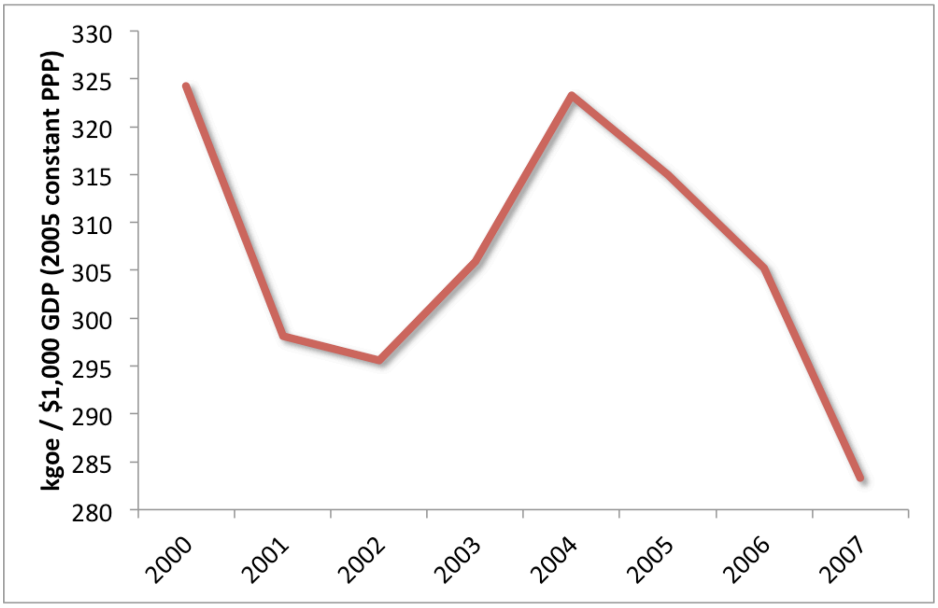
An approximate Kuznets' curve for energy intensity in China also exists, though it is complicated by China's history of central planning. Figure 1.5 shows the energy intensity of the Chinese economy from 1952. The Great Leap Forward, which began in 1958 and continued until 1961 stands out as the fist peak – a major deviation from trend. As soon as the Great Leap Forward ended, China's energy intensity reverted to its long-term trend, resuming its upward trajectory in 1967. The final peak energy intensity occurred in 1977, the year after Mao Zedong's death and the beginning of China's transition toward an open, market-based economy. From then on, the energy intensity of the Chinese economy fell every year until 2002 (Figures 1.5 and 1.6).

Figure 1.5: Energy intensity of the Chinese economy (1952-2009)



Source:
Red: China Energy Databook (Fridley and Aden 2008, 4B.2)
Blue: World Bank World Development Indicators (2011), normalised: 1980=398.55

Figure 1.6: Energy intensity of the Chinese economy (2000-2007)



Source: World Bank, World Development Indicators (2011)

Explaining the increase in China's energy intensity between 2002 and 2004 is essential to understanding China's post-2000 energy boom. A strict Kuznets curve framework is not sufficient to this task, and such a framework should not be used as a strict guide in this analysis.

Lewisian Turning Point

China's economy is currently in a period of structural evolution such that the relationship between energy consumption and economic growth is changing with uncertain outcome. One driver of structural change in China that complicates the relationship between energy and economic growth may be characterised by the Lewis model of transition to labour scarcity. In 2006 Ross Garnaut and Ligang Song wrote:

> China has reached (or is fast approaching) the turning point in its economic development, at which 'surplus' labour from agricultural employment in the countryside ceases to be available to drive the growth of the modern economy; so that labour becomes scarce and valuable; forcing large real wage increases and real exchange rate appreciation; which generate structural change towards more capital-intensive and technologically sophisticated industrial structure at the relative expense of labour-intensive manufacturing and agriculture; and changes fundamentally the character of China's interaction with the international economy. (Garnaut and Song 2006, 2)

In 2010 Garnaut presented new evidence that China was progressing through a 'turning period' and elaborated the implications of associated structural changes. Those implications include a shift in comparative advantage away from labour-intensive products toward "more capital-intensive and technologically sophisticated products" (Garnaut 2010).

Athukorala et al. (2009) point to widespread concerns that China's "easy phase of economic transition fuelled by surplus labour is rapidly coming to an end". They explain that the concern is based on rapid increases in wages in China's coastal urban areas and reports of labour scarcity in the business press (see for example Bloomberg (2010), Barboza (2010) or Bradsher (2011)), a process that has only accelerated since 2009 according to recent reports of competition for workers amongst China's provinces (Lu 2011).

Cai Fang and others identify one apparent consequence of the disparity in rising coastal wages, which they refer to as “flying geese within borders” (Cai, Wang and Yue 2009). The flying geese model was introduced as a method of explaining how Japan might be able to catch up to more technologically advanced countries in the West in the 1960s. It later came to be used to interpret the development experiences of the East Asian ‘tiger’ economies. Applied to China’s provinces, it predicts a process of industrial transfer across regions as a consequence of changing comparative advantages: as unskilled wages in coastal provinces rise, industries that rely on unskilled labour shift to lower-wage provinces, while the higher wage provinces experience booms in other industries based on their new comparative advantage (likely to be service sector industries given China’s rate of producing university graduates).

There is strong debate as to whether China is in fact undergoing such a Lewisian transition as described by Garnaut. Meng and Bai (2007) and Golley and Meng (2011) argue that China’s transition through a Lewisian turning point is difficult to establish based on systematic statistical evidence and that labor market factors such as China’s hukou[10] system may create the illusion of a Lewisian turning point, with symptoms of rising wages even though there are still many unskilled workers that could be made available given certain policy changes.

Regardless of the labour market dynamics, wages for low-skilled work in China, especially coastal, urban China, are increasing. As wages rise, production patterns adjust; as factor prices rebalance, comparative advantage evolves and trade patterns are affected; and as households become richer, consumption patterns change. These changes to consumption, production and trade patterns all point to a dynamic relationship between energy use and economic growth that complicates analysis. The vastness of China and its peculiar internal migration laws further complicate the relationship. How this period of transition affects energy use will depend on a wide variety of factors including labour market frictions such as the hukou system, relative prices of factors such land, resources, capital and labour, and trade issues.

[10] The Hukou system is a residential permit system that controls population movement within China (Liu 2005).

WTO membership

A further complication and source of structural change is China's relatively recent participation in the WTO. As China continues to open up to global market forces and the importance of the private sector within China's overall economy increases, production in China has moved toward its natural comparative advantages. China's economy shifted to take advantage of abundant cheap labour with a resulting boom in manufacturing sectors. The consequent adjustments to China's production patterns have further altered the relationship between energy use and economic growth.

Central planning

Finally, the relationship between energy and economic growth is complicated in China due to the government's attempt to guide the structure of the economy through the implementation of successive national economic plans. Since the sixth five-year plan beginning in 1981, China has placed heavy emphasis on energy conservation, expressed in terms of reducing national energy-intensity.

It has become abundantly clear that China's central government considers the possibility of energy acting as a binding constraint on growth as a matter of highest concern. All twelve of the five-year plans, beginning with the first, in 1953, have incorporated an energy component, but the approach and urgency has changed over the years (Yuan and Zuo 2011). The first ten of these plans, covering the years 1953 to 2005, included explicit coal production targets, while the sixth to the tenth (1981 to 2005) also incorporated a total energy production target. Since the sixth plan a major component of the energy section has been to focus on improving energy efficiency, rather than expanding energy production. Five of the last seven plans included specific targets for reducing national energy intensity, the ratio of total energy consumption to total GDP (see Table 1.1).

The eleventh and twelfth plans represent a shift in the thinking of the Chinese government as the new generation of leaders under Hu Jintao have sought to establish their mark on China's development. The urgency and detail of the energy section of the eleventh and twelfth five-year plans are far beyond those of earlier plans. To appreciate the government's determination to influence the use of energy in the economy we need to consider in some detail the eleventh and twelfth plans.

Table 1.1: Energy targets in China's Five Year Plans

Sixth Plan	1981-85	Energy intensity cut by 2.6 to 3. 5 per cent by 1985
Seventh Plan	1986-90	Energy intensity cut from 1.29 tce to 1.14 tce by 1990
Eighth Plan	1991-95	Energy intensity cut from 0.93 to 0.85 by 1995
Ninth Plan	1996-00	No explicit target
Tenth Plan	2001-05	No explicit target
Eleventh Plan	2006-10	Energy intensity to decrease 20 per cent by 2010
Twelfth Plan	2011-15	Energy intensity to decrease 16 per cent by 2015

Source: Yuan and Zuo (2011)

On 19 March, 2006 Ma Kai, Minister of the National Development and Reform Commission announced that the Fourth Session of the Tenth National People's Congress of the People's Republic of China (PRC) had approved its eleventh five year plan. The plan had two key concepts: "the scientific concept of development" and "building a socialist harmonious society" (K. Ma 2006). Ma announced that China's annual GDP growth was expected to average 7.5 percent during the eleventh plan period (2006-2010), so that GDP would reach 26.1 trillion RMB (19,270 RMB per capita) (US$3.2 trillion and US$2,400 respectively, using expected market exchange rate values).

The "quality" of economic growth was to be improved, the service industry was to increase as a proportion of total GDP and the use of resources was to become more efficient. Specifically, energy consumption per unit of GDP was to be lowered by 20 per cent. This was to happen while 45 million people moved from rural to urban environments during the five year period, raising the urbanization rate to 47 per cent.

Ma proclaimed,

> To realize the above-mentioned great prospects, we should stick to the guidance of the Deng Xiaoping Theory and the important thoughts of "Three Represents", adhere to the Scientific Concept of Development for the guidance of economic and social

> development, maintain stable and fast economic growth, improve independent innovation capacity, accelerate the transformation of economic growth mode, promote economic restructuring and balanced development of urban and rural areas, enhance the building of a harmonious society, and continue deepening reform and opening-up. (K. Ma 2006)

According to the State Council of China (2007), development was to be promoted through six strategies. The first was to expand domestic demand (primarily household consumption) and shift away from investment and export-driven growth. The second was to “optimize industrial structure”. Ma observed that the secondary industry accounted for 47.3 per cent of China’s GDP, while the services industry had fallen from 41.7 per cent in 2002 to 40.3 per cent in 2006. The conclusion China’s leaders drew was that the economic structure increased the pressure on resources and the environment. The third was to improve the environmental and resource efficiency of its economy. China’s leaders perceived an “increasingly prominent contradiction between economic growth and resources and environment constraints” (State Council of China 2007). The remaining strategies were enhancing innovation, deepening reform, and “relying on the people-centered approach” (State Council of China 2007). A number of specific numerical targets were also announced for the period 2006-2010. Those that are pertinent include:

- GDP to grow by 7.5 per cent annually, from 18.2 trillion RMB in 2005 to 26.1 trillion RMB in 2010
- GDP per capita to increase 6.6 per cent
- Service sector to increase from 40.4 per cent of GDP in 2005 to 43.3 per cent in 2010
- Population to increase from 1.30756 billion in 2005 to 1.36 billion in 2010
- Energy consumption per unit of GDP down 20 per cent in five years
- 45 million rural labourers transferred to non-agricultural sectors (Xinhua 2006)

The plan identifies a number of strategies to meet its energy target:

> While advancing the work of saving energy and reducing emissions, the Chinese government depends on structural adjustment as the fundamental approach, on scientific and technological advances as the key, on improved administrations as a crucial measure, on the strengthening of law enforcement as an important guarantee, on the deepening of the reform as an

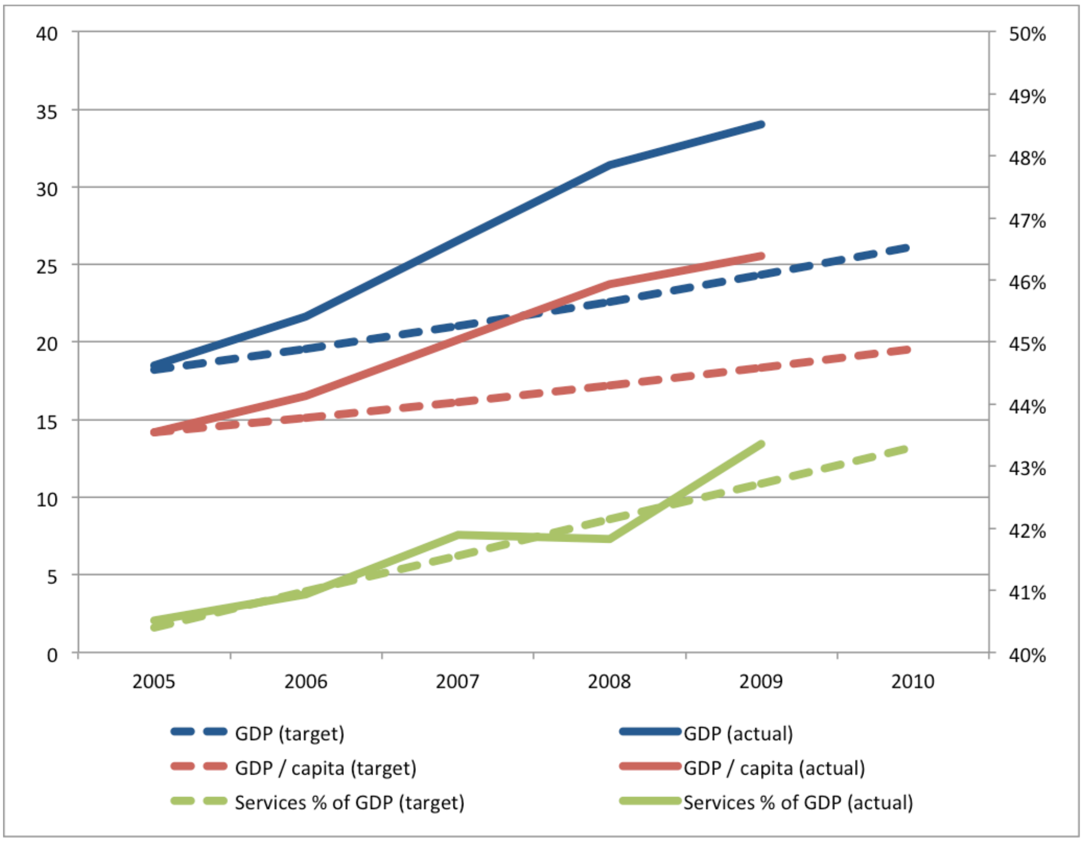
> internal motive force, and on public participation as the social foundation. (State Council of China 2007)

Structural adjustment is identified as a central strategy to meeting the energy targets. Of the five strategies identified by the State Council it explains structural adjustment thus:

> The major reasons for low efficiency of energy utilization for a long time have been the extensive mode of economic growth and a high proportion of high energy-consuming industries in China. The country will put the transformation of the development pattern and the adjustment of the industrial structure and of the internal structures of industries in the key place for the energy-conservation strategy, and work hard to bring into being a pattern of economic development with 'low input, low consumption, less emission and high efficiency.' China will accelerate the optimization and upgrading of its industrial structure, make energetic efforts to develop high- and new-tech industries and the service trades, set strict limits on the development of high energy- material- and water-consuming industries, and eliminate industries with backward productivity, so as to fundamentally change the pattern of economic development and put in place an energy-saving industrial system on an early date. (State Council of China 2007)

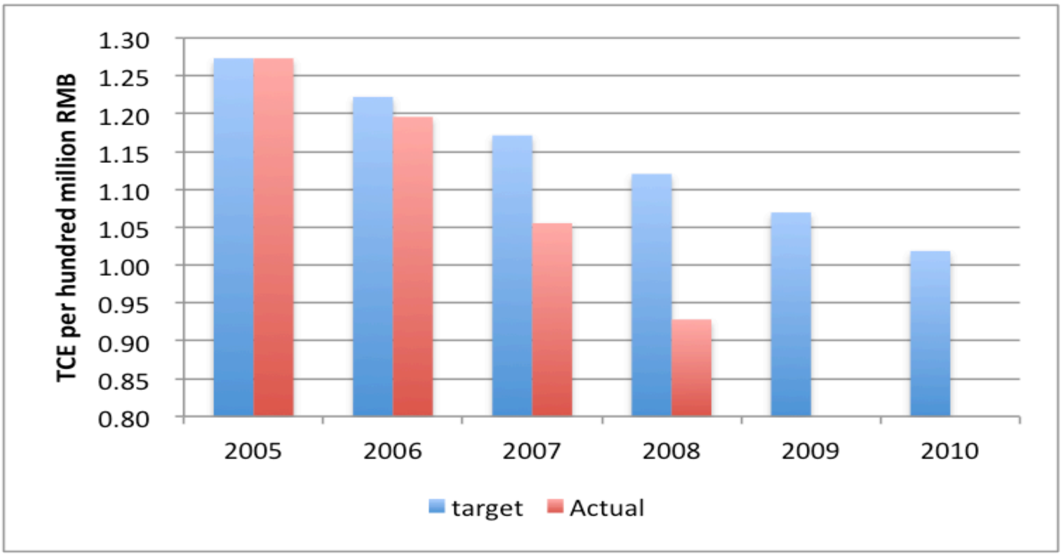
Irrespective of the contribution of each of these various strategies, we can see from Figure 1.7 and Figure 1.8 how successful China has been in surpassing its key targets.

Figure 1.7: Eleventh Five-Year Plan GDP targets versus actual



GDP is measured in trillions of current valued RMB
GDP per capita is measured in thousands of current valued RMB
Source: NBSC (2011)

Figure 1.8: Eleventh Five-Year Plan energy intensity targets versus actual



Source: NBSC (2011)

China surpassed its per capita income target within months of it being announced. Similarly, the five-year goal for total GDP was easily met within three years. The services share of GDP is also on track to surpass the target level. Figure 1.8 shows that, according to China's official data at least, the targeted reduction in energy intensity has also been surpassed two years ahead of schedule.

The eleventh plan included a strong focus on energy intensity, setting out apparently ambitious goals that have, according to China's official data, been surpassed (see Figure 1.8). The emphasis on efficiency was already a major break from the focus in previous plans. The above policy-related discussion demonstrates the extent to which China's central government influence over the economy can complicate the analysis of the relationship between economic growth and energy use.

In 2011, China announced the twelfth five-year plan, which has been described as "likely to go down in history as one of China's boldest strategic initiatives" (Roach 2011). The twelfth plan covers the years 2011-2015. In considering implications of the analysis of the thesis for China's energy future, the twelfth Five-Year Plan offers an important benchmark scenario.

Under the twelfth Five-Year Plan China has set a target of reaching GDP per capita levels of US$10,000 by 2020 (Dickinson 2011). The twelfth plan describes an ambition of substantially restructuring the economy. There are four main foci of the transformation planned:

1. Domestic-led consumption to replace export-led consumption
2. A balance between exports, imports and domestic consumption to replace export reliance
3. Domestic innovation to avert a reliance on imported technology
4. Low-carbon based energy, materials and industrial system (Dickinson 2011).

Except for the use of domestic innovation as a substitute for imported technology, these strategies have considerable implications for analyzing the relationship between energy and economic growth in China. They also provide a useful base scenario for considering China's energy future.

Conceptual framework: Production, consumption, investment and trade

The complicating factors discussed above interact in ways that are not easy to predict so that the net effect on the energy-economic growth relationship is difficult to untangle. Consequently, existing frameworks that attempt to explain the overall relationship between energy use and economic growth are inadequate. The thesis adopts a different approach: it treats the relationship between energy use and economic growth as the aggregate of several relationships, namely energy use with production, consumption, investment and trade.

In an open economy trade allows the relationship between energy-use and production to be determined independently of the relationship between energy-use and consumption. This can be demonstrated with a simple two-country, two-good, two-period example (Table 1.2).

Country A has a lower income than country B, with a GDP of 10 in period 1 compared with 20 for country B, but has a faster growth rate reaching a GDP of 20 by period 2, while country B reaches a GDP of 30. The stage of economic development of country A is also reflected in the consumption profiles. In the first period, 70 per cent of country A's consumption is of the energy-intensive product (this can be thought of as manufactured goods, for example), but in the second period this proportion falls to 60 per cent. On the production side, however, country A is a completely specialised economy, producing only the energy-intensive product. Country B produces only the amount of energy-intensive produce required to satisfy its demand for that product above what can be imported from country A. The rest of country B's output is focused on the non-energy intensive product (this can be thought of as services, for example).

There is no debt allowed in this example, so as each country grows, both their production and consumption remain balanced. Yet the energy requirement for goods *produced* in each country is not equal to the energy requirement for goods *consumed* in each country. In country A, energy used for production is initially 50 units and grows to 100 units, but energy used for consumption is only 38 units, growing to 68 units. While GDP doubles, and energy use for production doubles, energy use for consumption increases by only 80 per cent. This is because country

A is a net exporter of embodied energy (and increasingly so). The energy used for goods *consumed* in a country is referred to as embodied energy. Calculating embodied energy in real-world examples relies upon input-output analysis (IOA) and is the basis for much of the thesis.

Clearly studying the relationship between energy and economic growth requires separate analysis for the relationship between energy and production and the relationship between energy and consumption. However, consumption itself is not a homogenous category. The basic macroeconomic identity, $Y \equiv C + G + I + X - M$, states that total output is equivalent to household consumption, plus government expenditure, plus investments, plus exports, minus imports. Input-Output (IO) tables are structured in a manner that accords with that identity, so that through IOA we can find intensity coefficients for output of any sector to total or sector-specific consumption of any or all of the expenditure categories on the right hand side of the identity. To perfectly match China's IO tables, the consumption identity can be slightly modified: $Y \equiv C_{UH} + C_{RH} + G + I + ci + X - M$, where C_{UH} is urban household consumption, C_{RH} is rural household consumption and ci is changes in inventories.

This thesis separates the components of this basic macroeconomic identity into four components, with separate chapters dedicated to studying the relationship between energy and each of those four components. The four are (1) production, (2) rural, urban and government consumption, (3) investment, and (4) exports and imports. Although changes in inventories appear in the data, there will be no discussion of its determinants or relationship to energy use since it generally amounts to a small contribution with no trend. Rural and urban household consumption and government consumption are treated together since they are all categories of final consumption. While government consumption is not described by the same theoretical determinants, it is of relatively small importance to energy demand in China and does not need to be dealt with in its own chapter. Given the logic of IOA, we might wish to describe government as simply another firm offering services to households. However, the structure of IO tables does not facilitate this type of analysis. The IO tables provide data regarding government purchases from all sectors but do not include data regarding government sales to any sectors: both are necessary for IOA. Government is therefore best treated with household consumption as an additional, separately determined form of consumption. Since rural and urban households are not completely equivalent and yet are sensibly grouped together, there is a precedent for grouping expenditure categories in the analysis. Investment and trade are sufficiently distinct from other forms of final expenditure that they do deserve separate chapters.

Table 1.2: 2x2x2 model: energy for consumption and production with trade

Period 1

Consumption	Energy Intensive	Non-Energy Intensive	Total
Country A	7	3	10
Country B	12	8	20
World	19	11	30

Production	Energy Intensive	Non-Energy Intensive	Total
Country A	10	0	10
Country B	9	11	20
World	19	11	30

Period 2

Consumption	Energy Intensive	Non-Energy Intensive	Total
Country A	12	8	20
Country B	15	15	30
World	27	23	50

Production	Energy Intensive	Non-Energy Intensive	Total
Country A	20	0	20
Country B	7	23	30
World	27	23	50

Energy-use

Country A	Period 1	Period 2	Growth
Energy for production	50	100	2.0
Energy for consumption	38	68	1.8

Country B	Energy Intensive	Non-Energy Intensive	Total
Energy for production	56	58	1.0
Energy for consumption	68	90	1.3

World	Energy Intensive	Non-Energy Intensive	Total
Energy-use	106	158	1.5

Net energy embodied in exports (country A)	Energy Intensive	Non-Energy Intensive	Total
Period 1	15	-3	12
Period 2	40	-8	32

Note: Energy-intensive good requires 5 units of energy to produce
Non-energy intensive good requires 1 unit of energy to produce.

Structure of this thesis

The relationship of energy use to production, consumption and trade informs the structure of the thesis: one chapter is devoted to analyzing each of these relationships separately. Because the methodologies employed in each chapter overlap, a separate chapter, Chapter 2, is devoted specifically to methodological issues. Chapter 2 provides justification for the methodologies used, places the approach within the context of the existing literature and provides a treatment of essential technical issues. It introduces some of the major technical challenges faced when performing the analysis and justifies how these challenges have been dealt with. The key contributions of Chapter 2 are to present a method of disaggregating IO tables in order to minimize aggregation bias, and generating compatible IO tables for China in the years 2002 and 2007 that facilitate the analysis in the thesis.

Chapter 3 deals with the relationship between energy use and economic output. The key contribution of Chapter 3 is to quantify on an annual basis from 1995 to 2007 the relative importance of technological, structural and quantity effects on the production side, in relation to their impact on energy use in China. Chapter 3 also places China's economic output in the context of the stages-of-growth literature and draws implications for China's energy future.

Chapter 4 deals with energy use and domestic consumption and is the first of the three chapters that rely on the concept of embodied energy. The main contribution of the chapter is to quantify the impact on China's energy use of changes to the consumption patterns of rural households, urban households and government consumption between 2002 and 2007. By analyzing China's household and government consumption trends in relation to the experience of developed countries at similar stages of development, Chapter 4 draws implications of the relationship between energy use and consumption given possible future consumption patterns in China, assuming that certain features of the 12th Five-Year Plan come to fruition.

Chapter 5 deals with energy use and investment. The main contribution of Chapter 5 is to calculate the energy embodied in investment in China and to identify which sectors were the most important drivers of energy embodied in investment between 2002 and 2007. The analysis provides a foundation for considering the implications for China's energy future of possible investment patterns under China's 12th Five-Year Plan.

Chapter 6 deals with energy use and international trade. The main contribution of Chapter 6 is to quantify the impact on energy embodied in trade due to technological progress in China and changes to China's trade patterns between 2002 and 2007. The chapter also identifies a difference in the energy efficiency gains in traded sectors relative to non-traded sectors that may have important policy implications.

Each of the four analytical chapters (Chapters 3 to 6) follow a similar structure. They all begin with a conceptualization of how energy is used in each dimension of economic activity. Each chapter then provides a description of the recent history of the relationship before laying out a set of propositions that logically justify analysis of the relationship premised upon structural change. Those propositions are tested and the relative impact on energy use due to structural change, economic growth, population growth and technological progress is decomposed.

Each chapter concludes by considering the implications of the results for issues that have been identified as important, such as implications for China's strategic directions outlined in the 12th Five-Year Plan.

The final chapter draws the arguments of previous chapters into a single analysis of the nature and causes of recent changes in the relationship between energy consumption and economic growth in China's economy. It draws on the results of previous chapters and identifies the key themes resulting from the analysis to answer the key questions posed at the beginning of this chapter.

Chapter 2. Method

Understanding the way rapid and transformative economic growth has driven energy consumption yields a surprising early challenge: measuring 'energy use' is not at all as simple as it may seem. Energy itself can only be observed indirectly by its effect on the material, but it can be quantified in a plethora of units: jules, watts, British thermal units (BTUs), calories, tons of oil equivalent (TOE), tons of coal equivalent (TCE, often 'standard coal equivalent', SCE, in China). Worse, as energy is not actually a tangible substance and according to the law of conservation of energy, the total amount of energy in a system remains constant over time, we do not 'use up' or deplete the total amount of energy available at all. Rather, we transform the 'state' of energy, from one state to another. In physics, energy can exist in several states, often characterised as either potential or kinetic: elastic, thermal, electrical, electromagnetic, radiant, nuclear, chemical, sound, mechanical and luminous. In an economic context, 'using' energy usually relates to the transformation of potential energy, stored in some fuel (such as the chemical energy stored in coal) into some other form of energy that people find useful or derive utility from directly (such as the kinetic energy of a turbine, the electrical energy delivered to the electric grid, or the heat energy that warms a home). While the *energy* is not depleted the coal (in this case) is, so the concept of 'using' the coal is often equated with the concept of 'using' the energy stored in the coal. While this is not entirely precise, it is sufficient for present purposes.

Some Chinese energy data is reported as an index of total energy, while other data is reported for 18 different fuels: raw coal, cleaned coal, other washed coal, coke, coke oven gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, fuel oil, LPG, refinery gas, other petroleum products, natural gas, heat and electricity (NBSC, 2011). The substitutability between these fuels depends upon the use to which they are put. With current technology, washed coal is not a good substitute for gasoline in the transport sector, but makes a good substitute for oil in the production of electricity (notwithstanding greenhouse gas and other environmental or mining safety concerns). However, in general, this thesis is less interested in questions of which fuel is used and more interested in questions of how much energy is employed to meet economy-wide demands. Depending upon the nature of the specific analysis, fuel consumption will be aggregated to either a single energy index or an index of four fuels: coal, oil and natural gas, coke, and non-thermal electric and heat power. The specific conversions relevant to China's data are discussed elsewhere.

One more distinction is helpful from the perspective of economic analysis: the distinction between primary and secondary energy. Primary energy is either "extracted or captured directly from natural resources" (IEA, 2005) while secondary energy commodities include "all energy commodities which are not primary but are produced from primary commodities" (IEA, 2005). Electricity can be either primary or secondary energy: electricity generated from solar, hydro, wind or geothermal is considered primary since it is captured directly from nature, while electricity generated from coal, oil, gas or nuclear is considered secondary since it is produced from primary energy sources.

Settling on a concept of what energy is, what it means to use energy, and how this will be measured is clearly the first step toward the aim of the thesis: to characterise and understand the relationship between China's economic growth and energy use in recent years. Here the objective is to settle on the most appropriate characterisations of 'energy use' as well as the most appropriate methodologies to study each of these relationships in an economy undergoing major economic transformation. The selection of techniques draws on existing literature. Although the main relationships analysed are somewhat different, this chapter addresses the major methodological questions concerning all of them together. This approach is chosen, rather than the alternative approach of addressing the methodological issues of each relationship in turn, since there exist significant commonality and similarities in the methodologies that are appropriate to their study.

The chapter offers an essential treatment of the techniques used throughout this thesis: decomposition analysis and input-output analysis. A substantial body of theoretical literature has developed around the techniques adopted here, focusing on resolving various data and empirical challenges. Some of the more pertinent data and empirical issues that have presented challenges to this thesis and those issues are addressed in this chapter.

Characterising energy use: direct versus embedded energy

There are two main ways in which energy use is characterised throughout the thesis. Chapter 1 suggested a number of reasons for studying the determinants of energy use in China, each of which might require different characterisations of energy use. It showed that energy has a different relationship with production than it does with consumption, investment or trade. These different relationships are require different conceptions of energy use. The difference centres on the concepts of direct verse embodied energy use.

Direct energy-use is usually referred to as 'final energy consumption' in statistical reports and literature that disregards the concept of embodied energy. Final energy consumption is defined by the IEA as energy that is used for any purpose other than fuel conversion or transformation into other forms of energy (IEA, 2005). In the context of economics, the language used to describe energy is often much less precise than in the context of physics. Energy 'used for any purpose other than fuel conversion or transformation into other forms of energy' includes, for example, households' use of electricity to turn on a light, even though from a physicist's perspective that involves the transformation of electrical energy into a combination of heat and luminous energy. Direct energy use, or final energy consumption also includes the burning of coke in blast furnaces to produce steel. From the physicist's perspective this involves the transformation of the potential chemical energy in the coke into heat energy that performs the work of changing the state of the components of steel. From the economist's perspective the fuel (coke) is used and the steel is produced. But direct energy use excludes the burning of coal to produce electricity. From the physicist's perspective this involves the transformation of the potential chemical energy in coal into heat energy that (in a steam turbine system) is then converted into the kinetic energy of moving steam, and a moving turbine before being converted into the electrical energy that is sent to the grid. From the economist's perspective it involves the transformation of a primary energy source (coal) into a secondary energy source (electricity).

Embodied, or indirect energy consumption is explained as "the amount of energy required to deliver a product to final demand" (Miller & Blair, 2009). In the case of a cotton shirt, the embodied energy includes the energy used by: the factory that produced the shirt; the firm that designed the shirt; the farmers who grew the cotton; the firms that produced the fertilizer and equipment used by the farmers; the firms that produced the equipment used by the factory and designers; transport to get the shirts to market; advertising and retailing firms; the builders who built the retail outlet where the shirt was sold; and so on. The concept of embodied energy use is substantially different from that of direct energy use. This method of characterising energy use is far removed from the physicist's characterisation, but is the best method for the purpose of conceptualising the economic relationship between energy use and final consumption.

Determining which concept should be used depends upon the questions being asked. Direct energy consumption is the appropriate concept if we wish to know how much energy will be consumed in a particular country during a given time period. This is important for many matters including those relating to climate change commitments, national energy security concerns, local energy supply decisions, and geopolitical questions. Embedded energy consumption is appropriate if we wish to know how much energy is required to satisfy the demand by a particular group (such as urban households) or for a particular process (such as construction of buildings). This is important for analysis of long-term demand issues, identifying energy-intensive behaviour and generating awareness of responsibility for issues related to energy consumption such as GHG emissions.

In studying the relationship between energy and production, energy use is characterised as direct energy use. This forms the foundation of Chapter 3. In studying the relationship between energy and consumption, investment and trade, energy use is characterised by indirect, or embodied energy use. This forms the foundations of Chapters 4, 5 and 6. The choice of how to characterise energy use also informs the choice of method for studying the relationships between energy use and production, consumption and trade. This choice is the subject of the next section.

Method selection

Chapter 1 established this thesis as an inquiry into the nature of the recent relationship between China's economic growth and energy use. There have, over recent decades, been many studies of the nature and causes of energy use in various countries employing a variety of methodologies. The methodologies for studying energy use in an economy can be broadly characterised as falling into one of three traditions: regression analysis, economic model building, or decomposition analysis. The rest of this section provides a brief review of these traditions with reference to some of the studies employing each. The techniques used in this thesis are all part of the decomposition analysis tradition for reasons that will be discussed below.

Regression analysis

Regression analysis of energy use in economics typically attempts to find correlations between time series data of energy use and GDP. One common approach since the seminal work of Kraft and Kraft (1978) is to look for Granger causality in an attempt to determine whether energy consumption leads to increased wealth and output or increased wealth and output lead to higher levels of energy consumption, or each causes the other. Granger causality tests have become a staple of the energy economics literature (see, for instance: Zhang and Cheng (2009); Yuan et al. (2008); and Al-Iriani (2006)). However, Stern (2011) argues that this body of literature is largely inconclusive. One of the problems with the Granger causality approach is a lack of theoretical foundations.

A second strand of the regression analysis tradition is the environmental Kuznets curve (EKC) approach. Evidence that energy-intensity in a country went through an early stage of rising as the economy expanded, then eventually peaked and subsequently declined dates to the transformative work of Schurr (1960) already discussed in Chapter 1. The EKC became much more widely used after Grossman and Krueger's work on the relationship between economic growth and the environment (Grossman & Krueger, 1994). Although much of that work focuses on environmental pollutants rather than energy-intensity, the link between GHG emissions and energy consumption ensures overlap between the bodies of literature.

While there is no doubt that much useful information has been, and can still be, gleaned from this type of study, they all share one particular characteristic that makes the method unsuitable for the present study. Regression analyses of these types assume a constant relationship between the regressor and the explanatory variables. But the second premise of this thesis (after the premise that a relationship between economic activity and energy use must exist) is that the relationship between energy and the economy is not constant, and it is the nature of the change in that relationship that is under investigation.

Analyses in the regression analysis tradition also have a tendency to focus on final energy consumption (Wang et al. (2010); Wang and Chandler (2009); Ma and Stern (2008); Steenhof (2006); and Phylipsen et al. (2002)). The previous section, discussing the appropriate characterisations of energy, emphasised the importance of analysing embodied energy when considering the relationships of energy use with consumption, investment and trade. Calculating embodied energy has particular data requirements (discussed below) that pose insurmountable challenges to techniques based on the use of high-frequency data. Regression analysis is therefore not an appropriate method to use for this investigation.

Model building

A second widely-used approach to energy analysis is model building. This approach essentially involves sets of simultaneous equations that are defined with reference to economic theory and usually calibrated with reference to statistical analysis. The pioneering effort to establish economic models that incorporated intermediate energy demand was made by Hudson and Jorgenson in 1974 (Rose & Chen, 1991). Since that paper, there have been numerous studies employing flexible function form models based on the KLEM approach of Hudson and Jorgenson (1974). Rose and Chen provide the following appraisal of the approach:

> The resulting parameters yield elasticity measures that are invaluable in policy simulation modeling, but are of less importance in structural analysis, or the study of the broad set of considerations that reflect more permanent changes in the production system. These include, for example, changes in the mix of outputs, changes in the geographic origins and destinations of goods, and changes in technology. (Rose & Chen, 1991, pp. 2-3)

Interpreting changes in energy use in China during the current period of fundamental economic reform requires a method that can accommodate structural changes, including significant changes to the production system and to consumption patterns. The KLEM modelling approach developed by Hudson and Jorgenson (1974), while being a powerful method for forecasting and simulation models is not the best approach for analysing the changing relationship between energy and production in China. Similarly, it does not perform well when analysing the relationship between energy and consumption under conditions of changing consumer preferences (Rose & Chen, 1991).

A second form of economic modelling is computable general equilibrium (CGE) modelling. Much CGE work was pioneered by the Monash Group. Mai, Adams and Dixon (2009) applied their model to China's demand for energy. The Monash group have produced numerous studies using CGE analysis of China's economy (for example Mai, Dixon and Rimmer 2010). Grossman and Krueger applied CGE models to environmental issues in their studies of the environmental impacts of NAFTA (Grossman & Krueger, 1991). The G-Cubed model built by McKibbin has been used to study the relationship between economic growth and energy use (and GHG emissions) (McKibbin, 2006). While analysis using CGE models has a number of strengths, their applicability, as with any tool, depends on the objectives of the practitioner. CGE models emphasise the role of prices in determining outcomes, which is not the focus of this thesis. In addition, the results tend to be presented in the form of, "the change in price of x has caused demand for coal to change by $10 billion dollars a year…" (Layman, 2004). To the extent that the approach lends itself to the present study, the benefits that can be gleaned from a CGE approach are not sufficiently greater than those that can be achieved at far less cost using the much simpler approach discussed below: decomposition analysis. Applying the principle of Occam's Razor, the simpler approach is preferred.

Decomposition analysis

In a case of convergent evolution of knowledge, two different and separate bodies of literature were faced with essentially the same challenge and developed essentially the same mechanism for resolving it. The result is a fragmented body of literature with an illogical etymology. The largest terminological frustration is likely the distinction between structural decomposition analysis (SDA) and index number analysis (INA) or index decomposition analysis (IDA). Methodologically, there is no distinction; but SDA involves the decomposition of changes between two input-output tables, whereas INA and IDA do not.

Skolka (1989) defined structural decomposition analysis (SDA) as "a method of distinguishing major shifts within an economy by means of comparative static changes in key sets of parameters". Rose and Casler (1996) provide another useful description: "the basic rationale for SDA is splitting an identity into its components”. The specification that the object to be split into its components be an identity in the mathematical sense of the word is important and one of the major points of diversion from statistical estimation techniques.

SDA was first applied to the study of energy-related questions as a means of measuring change in embodied energy (Rose & Casler, 1996). Due to limitations in the ability to collect data it was necessarily a comparative static exercise (the compilation of input-output tables is a challenging task for statistical agencies: in China, detailed IO tables are published only for every fifth year).

Chenery and Clark (1959) observe that, “an estimate of the future demand for electric power cannot be made very adequately from a partial-equilibrium study of the existing power market alone but must also take into account the probable changes in output of the power-using industries.” The importance of ‘taking into account the probable changes in output of the power-using industries’ led to the creation of input-output analysis (IOA), developed by Wassily Leontief (Baumol & ten Raa, 2002). Leontief led the construction of the first input-output tables, which were for the United States in the years 1919 and 1929, published in 1936 (United Nations, 1999). Not withstanding certain limitations, the most frequently raised of which relates to price assumptions, explained by Christ (1955), IOA is the best available tool for calculating embodied energy, which for reasons already discussed, is central to two of the relationships that are the focus of this thesis: those between energy and consumption and energy and trade. SDA, which is essentially the comparison of two or more input output tables, allows us to distinguish the change in energy use associated with changes in the quantity, pattern and energy intensity of components of final demand, including consumption, investment and trade. As China, has experienced, and continues to experience, major structural changes, these distinctions are central to an understanding of the relationship between economic growth and energy use.

Chenery and Syrquin were amongst the early pioneers of the method (Rose & Casler, 1996). They employed SDA to study the relationship between factors of production (labour, capital and natural resources) and their use in different sectors of the economy. An early version of SDA was used to study Japan’s remarkable industrialization and modernization (Chenery, Shishido, & Watanabe, 1962) and use of the technique to study the relationship between energy use and structural change dates to Myers and Nakamura (1978). Ang and Zhang (2000) survey an additional 123 papers published prior to 2000 using the technique for energy analysis.

Within the tradition of decomposition analysis there are two main approaches: index number analysis (INA) and structural decomposition analysis (SDA) (Hoekstra & van den Bergh, 2003). SDA is a very useful tool for studying the relationships of energy with consumption and trade because it is able to work smoothly with the embodied-energy characterisation of energy use, however, energy use in production is best characterised as direct energy consumption. There is no need to rely on IO tables that are only published every five years since the less data-intensive form of decomposition analysis (INA), using direct energy consumption data published on an annual basis, is preferred.

These two techniques are complementary. Employing them both provides a more complete exploration of the nature and determinants of all three principal relationships of interest: those of energy with production, consumption, investment and trade.

Decomposition analysis in energy and environment studies

Two excellent summaries of the literature applying decomposition analysis to energy and environmental issues exist: Hoekstra and van den Bergh (2002) and Ang and Zhang (2000). SDA has been applied to environmental issues since Leontief and Ford (1972) (Hoekstra & van den Bergh, 2002). Skolka (1989) formalised the technique by presenting the first complete set of structural decomposition equations. The method has been improved and refined over the two decades since then. Decomposition of aggregate energy intensity came to be treated as an index number problem when Boyd, Hanson and Sterner first observed the similarity with earlier work in economics using index numbers to decompose the value of output of some composite commodity into price and quantity effects (Boyd, Hanson, & Sterner, 1988). Index number theory was developed in response to the challenge of finding a way to study empirical changes within the framework of economic theory: “the index-number problem arises whenever we want a quantitative expression for a complex that is made up of individual measurements for which no common physical unit exists” (Frisch, 1936). Decomposing energy consumption into structural, intensity, and total output effects is an analogous problem since there is no physical unit of economic structure, aggregate energy intensity or changes in aggregate output.

The literature reviewed by Ang and Zhang (2000) includes papers that use IDA. They find that of the 51 papers published before 1995, almost all focus on industrial energy demand analysis, while the 73 papers published between 1995 and 2000 had a wider focus, many of which included analysis of energy-related GHG emissions. In his excellent paper on method selection for IDA, Ang (2004) reports that (by 2004) there were over 200 papers published using the technique. He identifies five application areas: “(a) energy demand and supply, (b) energy-related gas emissions, (c) material flows and dematerialization, (d) national energy efficiency trend monitoring, and (e) cross-country comparisons.”

The literature reviewed by Hoekstra and van den Bergh (2002) includes papers that use SDA. They find 27 papers published since Leontief and Ford’s 1972 paper that introduced the technique to energy analysis. About a third of the papers using SDA analyze GHG emissions, while the remainder focus on energy consumption.

The number of decomposition studies focusing on energy use or pollution emissions has grown considerably over the past decade. Peters (2008) argues that the body of literature that advocates consumption-based national GHG emission inventories that has recently developed is a response to perceived shortcomings in the international response to climate change. These studies all employ SDA techniques. The consumption-based approach favoured for some GHG emissions analyses is based on the same logic of ‘embedded factors’ that underpins the decision to use IO SDA in the analysis of the relationships of consumption, investment and trade with energy use in the present thesis.

Guan et al (2008) use a similar approach to study Chinese GHG emissions from 1980 to 2030. They use nine IO tables with 18 sectors, covering the period from 1981 to 2002. They find that changes in per capita consumption volume have an overwhelming impact on GHG emissions, while changes in production structure, consumption patterns and population effects also cause upward pressure on emissions. Efficiency changes were the only source of restraint in GHG emission growth over the period.

Peters et al. (2007) provide one of the highest resolution studies of China by sector of any existing SDA to date. They use IO tables from 1992, 1997 and 2002 with 97 sectors. Their more detailed study finds that changes in the production structure reduces China's GHG emissions by 11 per cent over the 10-year period.

Guan et al (2009) use IO tables for 2002 and 2005 at the 42 sector classification level. The results of their study are broadly similar to results of their previous studies in emphasising the roles of per capita consumption growth in driving up embodied emissions and technological change in constraining embodied emissions.

The most comprehensive study using SDA to study China's energy use is Lin (1996). Lin uses hybrid IO tables of China from 1981 and 1987 and a Laspeyres index decomposition. The initial decomposition reveals the energy effects of changes in final demand and production technology. An entire chapter is then dedicated to closer inspection of each of these areas of change. Lin identifies the iron and steel industry as one of the most important contributing industries to consumption of energy in China, with a separate chapter dedicated to a case study of this industry. To the author's knowledge, no study since Lin has provided an equally comprehensive structural decomposition analysis of energy consumption in China.

Houghton (1995) provides a similarly comprehensive study of the relationship between energy and economic structure in Japan. It applied SDA to the Japanese economy in the period 1973-1991 and found that the majority of Japan's much heralded 'decoupling' of energy from economic growth was due to two factors: "a round of installation of energy-saving technologies that followed the first energy price shock in 1973" and a change in Japan's comparative advantage due to rapid price changes. By decomposing Japan's energy consumption into component parts, Houghton found that the growth in residential consumption had become the main driver of energy demand, whereas previously energy demand had been driven by the increased energy needs of the manufacturing sector. He further found that much of the change in industry was due to changes in a few industries: iron and steel, aluminum and smelting, cement and the pulp and paper industries.

Many of the other studies decomposing changes in China's energy demand into the effect of structural changes and the intensity effect are much shorter papers.

The focus of most such studies is to test a particular form of SDA or to update the literature when new data becomes available. Consequently, many studies stop short after determining the relative importance of structural versus intensity effects without providing substantial in-depth discussion of the implications of their findings. For instance, Garbaccio, Ho and Jorgenson (1999) provide a very rigorous SDA with an application to China's energy intensity. Although the SDA is carried out with particular attention to a number of methodological issues arising, the implications of the study are given almost no attention. Almost the entire discussion of results occurs in the conclusion:

> between 1987 and 1992, technical change accounted for most of the fall in the energy-GDP ratio. Structural change actually increased the use of energy, while the increased import of some energy-intensive goods had the opposite effect. The results are somewhat different for electric power, where the trend toward increased electrification of the economy resulted in an increase in the electricity-GDP ratio. (Garbaccio, Ho, & Jorgenson, 1999, p. 18).

An exception to this generalization is Andreosso-O'Callaghan and Yue (2000). The study has three objectives:

1. To measure and analyse structural change in China's manufacturing sector (1985-2000),
2. To highlight which industries experienced the greatest change, and
3. To explain the reasons for those changes.

A recent contribution to the literature on China's economy applying IO SDA is Minx et al. (2011). To the author's knowledge, Minx et al. (2011) offer the first use of China's full 2007 IO table in an SDA framework. Their focus is on GHG emissions rather than energy use, and they use different SDA techniques to those employed in the thesis. The broad findings of their analysis are roughly consistent with the results of the analysis here, although they do not discuss energy use in their conclusions at all, making direct comparisons difficult. While Minx et al. (2011) appear to offer the most up to date IOA of the Chinese economy, the discussion of their results is limited.

While it is irrefutable that decomposition analysis is a widely regarded tool for energy analysis, there appears to be a focus on generating basic results while discussion and interpretation of those results is given less emphasis. A thorough discussion of the results of the analysis is, therefore, a contribution of this thesis. Before discussing results, however, a number of theoretical issues associated with decomposition analysis must be considered.

Theoretical issues

As shown above, two distinct bodies of literature focusing on decomposition analysis have developed. According to Hoekstra and van den Bergh (2002) the earlier of the two has origins in index number analysis (INA) predating Fisher (1922), an early seminal text in the field. The second of the two (SDA) has been applied to environmental issues since Leontief and Ford (1972). The first paper to set out the differences in method between index number analysis (INA) and structural decomposition analysis (SDA) was Hoekstra and van den Bergh (2003). They describe the techniques thus:

> The main difference between the two decomposition methods rests on the model being used. SDA uses the input-output framework while IDA uses only aggregate sector information… The economic input-output model in SDA is based on input-output coefficients and final demand per sector. IDA, on the other hand, uses the output per sector for the economic decomposition. Both methods can analyze an intensity measure, ie a measure of the sector's indicator use per unit of output (Hoekstra & van den Bergh, 2003, p. 41).

Other than the use of IO tables, the two methods are quite similar. This section therefore begins with an appraisal of the use of IO tables in preparation for their use with SDA. The next part introduces the basic approach of decomposition and discusses a variety of theoretical issues that must be considered. Empirical application gives rise to a second set of issues that need to be addressed. These are discussed, and justification for how each is dealt with in the thesis is provided in the final part of the chapter.

Input Output Analysis (IOA)

The details of IOA are widely known and readily available so only a very brief outline is presented here. The most comprehensive explanation of IOA can be found in Miller and Blair: *Input Output Analysis: Foundations and Extensions*, first published in 1985 and updated in a second edition in 2009. A brief introduction can be obtained from many mathematics for economists texts, for example, Hoy et al. (2001). This section follows Miller and Blair (2009).

Input-Output tables are arranged as an $n \times n$ matrix of intermediate transactions, $\mathbf{Z}$, an $n \times m$ dimensional matrix of final demands, $\mathbf{f}$, and an n dimensional vector of total outputs, $\mathbf{x}$, where n is the number of sectors in the economy and m is the number of different final consumer groups. In the template table below, there are four sectors, and one consumer group:

	Purchasing sectors				**F** (final demand)	**X** (total output)
Selling sectors						
Value added						
X						

IO tables report output either in physical units or monetary value. Each row of the IO table represents the value (or quantity) of output from that row's sector sold to every other sector and to final consumers. The final value of each row (total output) is the sum of sales to all other sectors and consumers, thus we can express the IO table as a series of equations:

$$z_{11} + \cdots + z_{1j} + \cdots + z_{1n} + f_1 = \sum_{j=1}^{n} z_{1j} + f_1 \tag{2.1}$$

$$\vdots$$

$$z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{2.2}$$

$$\vdots$$

$$z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} + f_i = \sum_{j=1}^{n} z_{nj} + f_n \tag{2.3}$$

where each equation corresponds to row i of the IO table. Grouping the terms of the equation above into sales to producers, sales to consumers, and total output, these equations can be summarised in matrix algebra by the following single equation: $\mathbf{Z} + \mathbf{f} = \mathbf{x}$, where

$$\mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix}, \mathbf{f} = \begin{bmatrix} f_{11} & \cdots & f_{1m} \\ \vdots & \ddots & \vdots \\ f_{m1} & \cdots & f_{mm} \end{bmatrix}, \text{ and } \mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \tag{2.4}$$

Each element of $\mathbf{Z}$, z_{ij} represents the amount of output from sector i used by sector j.

Dividing each element z_{ij} by the total output of sector j, converts the intermediate transactions matrix into a matrix of technical coefficients:

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}, \text{ where } a_{ij} = \frac{z_{ij}}{x_j}, \text{ such that } \mathbf{Z} = \mathbf{Ax} \quad (2.5)$$

The following steps are standard in IOA:

Beginning with: $$\mathbf{Z} + \mathbf{f} = \mathbf{x} \quad (2.6)$$

Substitute $\mathbf{Ax}$ for $\mathbf{Z}$: $$\mathbf{Ax} + \mathbf{f} = \mathbf{x} \quad (2.7)$$

Rearrange: $$\mathbf{f} = \mathbf{x} - \mathbf{Ax}\,. \quad (2.8)$$

Factorise: $$\mathbf{f} = \mathbf{x}(\mathbf{I} - \mathbf{A})\,. \quad (2.9)$$

Pre-multiply both sides by $(\mathbf{I} - \mathbf{A})^{-1}$: $$(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{x}(\mathbf{I} - \mathbf{A}) \quad (2.10)$$

(2.11)

Simplify: $$(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{x} \quad (2.12)$$

Rearrange: $$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}\,. \quad (2.13)$$

Let $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$: $$\mathbf{x} = \mathbf{Lf} \quad (2.14)$$

Equation (2.14) maps the relation between total output of each sector and final demand for each sector. $\mathbf{L}$ is referred to as the 'Leontief Matrix', and is "a matrix of sector-to-sector multipliers, l_{ij}, relating final demand in sector j to output in sector i" (Miller & Blair, 2009). [1]

[1] See Miller and Blair (2009) for further details.

Energy Input-Output Analysis (EIOA)

Relating final demand in sector j to output in sector i, where sector i is the production of energy, is precisely the objective EIOA.

> In general energy input-output typically determines the total amount of energy required to deliver a product to final demand, both directly as the energy consumed by an industry's production process and indirectly as the energy embodied in that industry's inputs. In engineering parlance, calculating this total energy requirement is the result of what is often called a *process analysis*… This process analysis traces inputs back to primary resources; the first round of energy inputs is the *direct energy requirement*; subsequent rounds of energy inputs comprise the *indirect energy requirement*. The sum of direct and all indirect energy requirements comprise the *total energy requirement*. (Miller & Blair, 2009, p. 401)

Owing to the oil crises of the 1970s, and the more recent concerns about climate change, IOA has been frequently applied to questions of energy use. The body of literature that developed around these problems discovered early on that special complications arise in applying IOA to energy analysis. The most fundamental issue involves units of measurement. Each cell of an IO table, z_{ij}, generally and most usefully, represents the value in monetary terms of the transaction between two sectors. One reason a value approach is preferred is that the alternative, representing transactions in physical units, would require an IO table with sufficient sectoral resolution such that every sector produced just one product. Data collection would be a much more significant challenge than it already is. A second reason is that physical units of different products (and services) are not readily comparable. The value approach is generally much preferred. However, in energy analysis, researchers are often concerned precisely with questions of physical quantity.

One approach to convert value transactions into physical transactions would simply be to divide by price. Such an approach would be very convenient, but unfortunately is not feasible for several reasons. One major reason is that different sectors often (and in China, this is always the case) pay different prices for energy resources. Creating separate energy price indices for each sector would be a daunting task and the final result would likely contain considerable errors.

The preferred approach is to construct a hybrid unit IO table (Bullard & Herendeen, 1975). In this approach, energy transactions are measured in physical units (such as Petajoules, PJ), and non-energy transactions are measured in value units. We begin by constructing a new IO table according to the following template:

		Purchasing sectors			
		Z-e (Energy sectors)	Z-ne (Non-energy sectors)	**F** (Final demand)	**X** (Total output)
Selling sectors	Z-e	PJ / PJ	PJ / $	PJ	PJ
Selling sectors	Z-ne	$ / PJ	$ / $	$	$
	Value added	$	$		
	X	PJ	$		

To consider specifically the energy content of each sector, a process analogous to the general IO analysis is required. Instead of beginning with the equation $\mathbf{Z}+\mathbf{f}=\mathbf{x}$ (2.4), the starting point is the equation $\mathbf{E}+\mathbf{q}=\mathbf{g}$, where $\mathbf{E}$ is a matrix of inter-industry energy flows, $\mathbf{q}$ is a vector of energy consumed directly as a final-use product, $\mathbf{g}$ is a vector of total energy consumption. Following the same matrix algebra steps as the general IO process above leads to the equation:

$$\mathbf{g}=\alpha\mathbf{f} \tag{2.15}$$

where $\mathbf{g}$ remains the vector of total energy consumption, α is a matrix of total energy requirements and $\mathbf{f}$ remains the matrix of final demands (Miller & Blair, 2009).

α is a hybrid Leontief inverse matrix, and can be written: $\mathbf{L}^*$. Multiplying $\mathbf{L}^*$ by $\hat{\mathbf{x}}^*$ (the hybrid units version of $\hat{\mathbf{x}}$) delivers the final result: the total energy requirements matrix in physical units.

Decomposition analysis

The objective of decomposition analysis is to isolate the change in a variable according to the changes of its parts. Take the simple identity: $x \equiv y+z$. Given a change in x ,it must be the case that either there was a change in y , a change in z , or both. This can be summarised as: $\Delta x=\Delta y+\Delta z$. Assuming both initial and final data for each of the three variables were available, the decomposition analysis would be trivial. In general, such data is not available.

Consider the following situation, based on Miller and Blair (2009) with some generalisation in terminology. This time, assume the starting equation is $x = yz$. There still exists both initial and final data for each of the three variables, so $x^1 = y^1 z^1$ and $x^0 = y^0 z^0$, where the superscript refers to the time period, are known. Let $\Delta x = x^1 - x^0$. Substituting $y^1 z^1$ for x^1 and $y^0 z^0$ for x^0, results in $\Delta x = y^1 z^1 - y^0 z^0$. "The task is to decompose the total change in outputs into changes in the various components" (Miller & Blair, 2009). Consider:

$$\Delta x = y^1 z^1 - y^0 z^0 \tag{2.16}$$
$$= y^1 \left(z^0 + \Delta z\right) - \left(y^1 - \Delta y\right) z^0 \tag{2.17}$$
$$= y^1 z^0 + y^1 \Delta z - y^1 z^0 + \Delta y z^0 \tag{2.18}$$
$$= \Delta y z^0 + y^1 \Delta z \tag{2.19}$$

Now consider a different, but equally valid expansion and factorisation:

$$\Delta x = y^1 z^1 - y^0 z^0 \tag{2.20}$$
$$= \left(y^0 + \Delta y\right) z^1 - y^0 \left(z^1 - \Delta z\right) \tag{2.21}$$
$$= y^0 z^1 + \Delta y z^1 - y^0 z^1 + y^0 \Delta z \tag{2.22}$$
$$= \Delta y z^1 + y^0 \Delta z \tag{2.23}$$

Both are valid decompositions. In the first decomposition, the change in x is expressed as a function of a change in y weighted by the initial value of z and a change in z weighted by the final value of y. Conversely, in the second decomposition the change in x is expressed as a function of a change in y weighted by the final value of z and a change in z weighted by the initial value of y.

Two decomposition forms that have been widely used are the Laspeyres index and the Paasche index (Ang & Zhang, 2000). The Laspeyres index decomposition uses original year weights:

$$\Delta x = y^1 z^1 - y^0 z^0 \tag{2.24}$$
$$= \left(y^0 + \Delta y\right)\left(z^0 + \Delta z\right) - y^0 z^0 \tag{2.25}$$
$$= y^0 z^0 + (\Delta y) z^0 + (\Delta y)(\Delta z) + y^0 (\Delta z) - y^0 z^0 \tag{2.26}$$
$$= (\Delta y) z^0 + y^0 (\Delta z) + (\Delta y)(\Delta z) \tag{2.27}$$

The Paasche index decomposition uses final year weights:

$$\Delta x = y^1 z^1 - y^0 z^0 \tag{2.28}$$
$$= y^1 z^1 - \left(y^1 - \Delta y\right)\left(z^1 - \Delta z\right) \tag{2.29}$$
$$= y^1 z^1 - y^1 z^1 + y^1 (\Delta z) + (\Delta y) z^1 - (\Delta y)(\Delta z) \tag{2.30}$$
$$= y^1 (\Delta z) + (\Delta y) z^1 - (\Delta y)(\Delta z) \tag{2.31}$$

All four decomposition forms are mathematically equivalent, so it cannot be said there exists a unique decomposition. The problem is that the different forms give different results when applied to actual data. In a celebrated search for the ‘best’ price index, Irving Fisher identified 134 different decomposition forms based on changes in nominal price and quantity (Fisher, 1922). Fisher showed that many of these forms were less desirable than others and nominated one, the geometric mean of the Laspeyres and Paasche indices (now known as the ‘Fisher ideal index’), as the best (Boyd & Roop, 2004).

The theoretical basis for selecting one form over another turns out to be quite weak. Dietzenbacher and Los (1998) reveal the extent of this problem. They prove that the number of equivalent decompositions of the same form is equal to $n!$, where n is the number of factors into which a change is decomposed[2]. They point out that since the problem has been widely known for a long time, it was surprising that there did not exist many attempts to resolve it. According to Dietzenbacher and Los, most authors traditionally avoided the problem either by choosing one of the decomposition forms identified above, reporting both Laspeyres and Paasche, or reporting some average or mid-point weighted index.

[2] The four cases examined so far include two cases of one form and two cases of another form, where the two forms are distinguished by an ‘interaction’ term: $\Delta y \Delta z$.

The Divisia Index

This study will use a form of the Divisia index for the reasons given in the next section. The Divisia Index is defined as a "weighted sum of growth rates, where the weights are the components share in total value" (Hulten, 1973). The Divisia index was first proposed by the French economist, Divisia (1926). The following explanation of the Divisia index is included because the Divisia index is most preferred, although the final form of the indiex is more intuitive than the explanation of how to arrive there. The explanation is based on Diewert (1988). The early work in index numbers in the field of economics in the beginning of the 20th century was mostly on price indices, so the terminology is usually related to quantity and prices. Since the index generalises, this explanation abandons the original terminology and applies a general terminology.

Let $y_i(t)$ and $z_i(t)$, $i \in \{1,...,n\}$ be functions of continuous time and let x at time t be the value $x(t) = \sum_{i=1}^{N} y_i(t) z_i(t)$. Assume $x(t)$ is differentiable.

The rate of change of x at time t is: $\frac{dx(t)}{dt} = \sum_{i=1}^{N} y_i \left(\frac{dz_i}{dt}\right) + \sum_{i=1}^{N} z_i \left(\frac{dy_i}{dt}\right)$.

Dividing both sides of the equation by $\mathbf{Y}(t) \cdot \mathbf{Z}(t) = \sum_{i=1}^{N} y_i(t) z_i(t)$, and letting the time derivative be signified by a dash: $\alpha' = \frac{d\alpha}{dt}$, we arrive after some manipulation at

$$\sum_{i=1}^{N} \left(\frac{y_i z_i'(t)}{x(t)}\right) + \sum_{i=1}^{N} \left(\frac{z_i y_i'(t)}{x(t)}\right) = \frac{\mathbf{Y}'(t)}{\mathbf{Y}(t)} + \frac{\mathbf{Z}'(t)}{\mathbf{Z}(t)} \tag{2.32}$$

Divisia defines $\mathbf{Y}(t)$ and $\mathbf{Z}(t)$ as solutions to:

$$\frac{\mathbf{Y}'(t)}{\mathbf{Y}(t)} = \sum_{i=1}^{N} \frac{\mathbf{Z}_i(t)\mathbf{Y}_i'(t)}{\mathbf{Y}(t) \cdot \mathbf{Z}(t)} \text{ and } \frac{\mathbf{Z}'(t)}{\mathbf{Z}(t)} = \sum_{i=1}^{N} \frac{\mathbf{Y}_i(t)\mathbf{Z}_i'(t)}{\mathbf{Y}(t) \cdot \mathbf{Z}(t)} \tag{2.33}$$

(Diewert, 1988)

By the early 1990s, studies using the Divisia Index became more popular, with approximately equal number using the Divisia and Laspeyres Indexes, the Paasche Index having largely ceased to be used (Ang B. , 2004).

Choosing a decomposition form

> Since there can be an infinite number of [decomposition] methods and it is not possible to try all of them out, it would be helpful if some meaningful criteria can be used to determine the 'preferred' method or set of results. (Ang & Lee, 1994, p. 88)

Much of the most useful recent work on selection criteria for decomposition methods and comparison of different techniques has been done by Ang and his colleagues. Other work on method selection is not at the frontier. For instance Greening et al. (1997) compare six different methods, but all six methods have a residual term, meaning they are not perfect in decomposition and so should not be used. The problem of residual terms was identified by Ang and Choi (1997).

Ang, Liu and Chew (2003) consider a number of perfect[3] decomposition methods that have been proposed by researchers. The merits of these various approaches are comprehensively assessed by Ang (2004). He determines that decomposition based on the Divisia Index, and using a logarithmic mean weighting system is the most preferred method. In particular, it is perfect in decomposition (the results contain no residual), passes the factor reversal test and time reversal test, has the additive property in logs and retains the same form irrespective of the number of factors used in the decomposition. There is also symmetry between the additive and multiplicative forms of indexing change over time and it is consistent in aggregation. Finally, the weighting system based on a logarithmic-mean overcomes a problem that earlier papers had encountered using arithmetic-mean weights, namely computational problems when zero values were encountered.

Ang refers to this decomposition as the Log-Mean Divisia Index 1 (LMDI1). Although Ang introduces an LMDI2, it is subsequently determined that the second version has no significant advantages over the original, but suffers from more complicated equations. From here on, the thesis will drop the numeric demarcation and simply refer to the LMDI1 as the LMDI. The additive version is introduced in Ang and Choi (1997), while the multiplicative version is introduced in Ang and Liu (2001). Since Ang (2004), a wide agreement has developed that the Logarithmic-

[3] 'Perfect' in this context refers to zero residual in the decomposition

mean Divisia Index (LMDI) is the most preferred method of decomposition, though Dietzenbacher argues in favour of the average of the Laspeyres and Paasche indexes (Dietzenbacher & Los, 2000). Selection between the additive and multiplicative forms has no bearing beyond interpretation and so is generally considered a matter of author preference.

Logarithmic Mean Divisia Index (LMDI): additive and multiplicative versions

Sato (1976) proposed the logarithmic mean for use in decomposition analysis as "the ideal log-change index number". The log-mean of two values, x and y is defined by $L(x,y)=(x-y)/\ln(x/y)$, where x and y are non-equal positive numbers. If x and y are E_i^T and E_i^0, the total energy component of sector i in time period T and 0 respectively, we have

$$L\left(E_i^T, E_i^0\right)=\frac{\left(E_i^T-E_i^0\right)}{\ln\left(E_i^T\right)-\ln\left(E_i^0\right)} \tag{2.34}$$

The following summary is from Ang (2005). We begin with V, the object of the decomposition. Further, we nominate an identity, such that the terms on the right hand side, $x_1, x_2 \ldots$, are the decomposition factors of the object variable:

$$V=\sum_i V_i=\sum_i x_{1,i}, x_{2,i}, x_{3,,i} \tag{2.35}$$

In energy decomposition analysis, the decomposition factors are commonly such things as structural change, change in total output, and change in energy intensity.

Additive LMDI

The additive LMDI approach begins with the following identity, assuming k decomposition factors:

$$\Delta V_{tot}=V^T-V^0=\Delta V_{x_1}+\Delta V_{x_2}+\ldots+\Delta V_{x_k} \tag{2.36}$$

ΔV_{tot} and $\Delta V_{x_{1,2,..k}}$ represent the total change in the object variable over the two periods, and the change due to each of the three decomposition factors respectively. The value of the k^{th} decomposition factor is determined by:

$$\Delta V_{x_k} = \sum_i \frac{V_i^T - V_i^0}{\ln V_i^T - \ln V_i^0} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \tag{2.37}$$

Multiplicative LMDI:

The multiplicative LMDI approach begins with the following identity, assuming k decomposition factors:

$$D_{tot} = \frac{V^T}{V^0} = D_{x_1} D_{x_2} \ldots D_{x_k} \tag{2.38}$$

D_{tot} and $D_{x_{1,2,\ldots,k}}$ represent the total change in the object variable over the two periods, and the change due to each of the k decomposition factors respectively. The value off the k^{th} decomposition factor is determined by:

$$D_{x_k} = \exp\left(\sum_i \frac{\left(V_i^T - V_i^0\right) \Big/ \left(\ln V_i^T - \ln V_i^0\right)}{\left(V^T - V^0\right) \Big/ \left(\ln V^T - \ln V^0\right)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right)\right) \tag{2.39}$$

Both the additive and multiplicative versions are theoretically sound, and the results are readily interchangeable. Selecting between them becomes a question of application. Hoekstra and van den Bergh (2002) find that most practitioners favour the additive approach, which decomposes the relative difference of an indicator. Reasons are rarely given for such decisions, but ease of interpretation seems a likely factor.

While some people may find results of the sort, “technological effects caused a reduction of x million tce drop in energy consumption”, such a result implies undue faith in the precision of statistics. Further, the very large numbers used in energy data (hundreds of millions of tons of coal or oil equivalent, quadrillion BTUs) are non-intuitive. Comparing the relative importance of various effects also becomes a challenge for the reader who cannot be expected to know whether 15 quadrillion BTUs is contextually a large number. For those reasons, results describing percentage changes and relative growth rates are easier to interpret, communicate and compare. Further, in analysing Chinese energy consumption, there is greater interest in relative growth rates because China’s energy targets are themselves expressed in terms of relative growth rates. For these reasons, relative growth rates are favoured in the thesis.

Decomposing relative growth rates is the purview of the multiplicative decomposition, therefore, the thesis predominately applies the multiplicative LMDI method. However the concluding chapter (Chapter 7) compares the relative importance of the different relationships of energy use with consumption, investment and trade: not just their relative growth rates, but also their relative size. That chapter requires that results be presented according to the additive decomposition. Because the results are readily interchangeable this poses no challenge. The next section looks at some of the empirical challenges associated with this method, and how they are dealt with here.

Data and empirical issues

According to Miller and Blair, "among the most formidable challenges in using input-output analysis in practice is assembling the detailed basic data needed to construct input-output tables characterizing the economic area of interest" (Miller & Blair, 2009). They devote an entire chapter (Chapter 4) to data collection challenges.

IOA: the fundamental equation

The first step in performing EIO-SDA is to construct the data sets required for the EIOA formulas outlined above. The principal equation to solve is:

$$\alpha = \mathbf{G}\hat{\mathbf{x}}^{-1}\left(\mathbf{I}-\mathbf{A}\right)^{-1} \tag{2.40}$$

or, equivalently:

$$\alpha\hat{\mathbf{x}} = \mathbf{G}\left(\mathbf{I}-\mathbf{A}\right)^{-1} \tag{2.41}$$

where α is the total energy coefficients matrix which solves the equation: $\mathbf{g} = \alpha\mathbf{f}$ (total energy consumption equals alpha times final consumption), $\mathbf{G}\hat{\mathbf{x}}^{-1}$ is the total energy consumption per unit of output for each sector[4]. It is constructed from the direct energy requirements matrix and the vector of total outputs. $\left(\mathbf{I}-\mathbf{A}\right)^{-1}$ is the

[4] See Appendix B: Notes on matrix algebra (points 3 & 5) for an explanation of this equation

Leontief inverted matrix, $\mathbf{L}$. The first term of the rearranged equation, $\alpha\hat{\mathbf{x}}$, is the total energy requirements matrix. It tells us how much energy is used, in total, due to final consumption of each sector. Estimating the value of $\alpha\hat{\mathbf{x}}$ for both 2002 and 2007 is the principal objective of the first part of this chapter. The second part is devoted to a discussion of the results, in particular, the determinants of differences between the 2002 and 2007 results.

Three principal data sets are required to satisfy the above method: the direct energy requirements matrix, $\mathbf{G}$, the vector of total output, $\mathbf{x}$, and the Leontief matrix, $\mathbf{L}$. Construction of these three datasets such that separate years are comparable is a somewhat involved process. This section outlines step by step the process that has delivered the data used in this study. The first part focuses on the direct energy requirements matrix ($\mathbf{G}$). The second part focuses on ensuring all data tables, including $\mathbf{G}$ and the two IO tables (2002 and 2007) represent consistent sectoral aggregations.

Direct energy requirements matrix (G)

The direct energy requirements matrix, $\mathbf{G}$, is an $m \times n$ dimensional matrix, where m is the number of primary energy sectors and n is the total number of sectors (either producing or consuming) in the economy. It is defined as $\mathbf{G}_{mn}$, with each element, g_{jk} representing the total amount of energy of type j consumed directly by economic sector k.

The data sources used in the construction of the direct energy requirements matrix for 2002 and 2007 are:

- The China Energy Statistical Yearbook (hereafter CESY) 2005 Table 4-2: Energy balance of China – 2002 (physical quantity) (NBSC, 2005)
- CESY2005 Table 5-3: Final energy consumption by industrial sector – 2002 (physical quantity) (NBSC, 2005)
- CESY2008 Table 4-2: Energy balance of China – 2007 (Physical quantity) (NBSC, 2011)
- CESY2008 Table 5-2: Final energy consumption by industrial sector – 2007 (Physical quantity) (NBSC, 2011)
- Peters, Weber and Liu (Construction of Chinese energy and emissions inventory, 2006)

While the original data forms a pair of matrices: $\mathbf{G}^{t}_{44,20}$ (where $t = 2002, 2007$) it is not usable in this form. It must be converted to produce a corresponding pair of matrices: $\mathbf{G}^{t}_{4,144}$. The rationale and procedure for this conversion are explained below.

Fuel aggregation

Combining the energy balance and final energy consumption tables produces a table quantifying the consumption of 20 fuels by 44 economic sectors plus five final 'consumers': rural households, urban households, imports, exports, and changes in inventories (a total of 49 fuel consuming categories). The fuel consumption is measured in physical quantities for both 2002 and 2007. For the direct energy requirements matrix to be usable in IOA, the fuel categories need to correspond to the primary energy sectors identified in China's IO tables: coal; petroleum and natural gas; coke; and electric and heat power. The 20 fuels are aggregated according to the mapping in Table 2.1 to produce a table of 49 consumers of 4 fuels.

Table 2.1: Mapping of fuel sources to China's primary energy sectors

Primary energy sectors	Fuel sources
Mining and washing of coal	Raw coal
	Cleaned coal
	Other washed coal
	Briquettes
Extraction of petroleum and natural gas	Other gas
	Crude oil
	Gasoline
	Kerosene
	Diesel oil
	Fuel oil
	LPG
	Refinery gas
	Other petroleum products
	Natural gas
Coking	Coke
	Coke oven gas
	Other coking products
Production and supply of electric power and heat power	Non-fossil heat
	Non-fossil electricity

Since the energy content of one ton of raw coal is not equivalent to the energy content of one ton of diesel oil (for example), to aggregate the consumption of different fuels it is necessary to express the consumption of each fuel in consistent and comparable energy units. To convert the physical quantity of each fuel type into consistent units of energy (petajouls), the net calorific values (NCV) identified by Peters, Weber and Liu (2006) are adopted. It is assumed that NCVs of each fuel type did not change between 2002 and 2007 so the same values are used throughout the time period of the study.

Loss, non-energy use and transformations are accounted for following the approach outlined in Peters, Weber and Liu (2006).

The result is a table (sheet-E in the files: *Direct energy requirements matrix 200x – G 44+5x4, 200x={2002,2007}*) quantifying in consistent units the direct energy consumption of 20 fuel types by 44 sectors and 5 consumers in 2002 and a comparable table for 2007. Aggregating fuel types according to the schedule in Table 2.1 is now a simple matter of performing the appropriate additions. The final results are presented in sheet-G of the files.[5]

To use the constructed direct energy requirements matrices in conjunction with China's IO tables, the 44 sectors and 5 consumers must correspond to sectors and consumers in the IO tables. Unfortunately the 2002 and 2007 IO tables themselves have non-corresponding sectors, with the 2002 IO table being constructed for 122 sectors while the 2007 table has 135. Before a correspondence between $\mathbf{G}$ and the IO tables is established, there should be a sectoral correspondence between the 2002 and 2007 IO tables themselves.

Correspondence between 2002-2007

Ensuring a one-to-one sectoral correspondence for each data table is essential. The direct energy requirements matrix ($\mathbf{G}$) and corresponding IO table must be expressed in comparable terms in order to estimate the total energy requirements matrix ($\alpha\hat{\mathbf{x}}$), and $\alpha\hat{\mathbf{x}}_{2002}$ must be comparable to $\alpha\hat{\mathbf{x}}_{2007}$ in order to perform the SDA and make meaningful comparisons over time. Mapping the tables into a compatible

[5] The files containing original data and all manipulations outlined in this section are available under the following file names:
Direct energy requirements matrix 2002 – G 44+5x4
Direct energy requirements matrix 2007 – G 44+5x4

sectoral aggregation has been done according to the schedule identified in Appendix A.

Aggregation versus disaggregation

There is an extensive body of literature employing SDA to study changes in the relationship between energy and the economy. According to Lenzen (2011, p. 73), "analysts carrying out input-output analyses of environmental issues are often plagued by environmental and input-output data existing in different classifications, with environmentally sensitive sectors sometimes being aggregated in the economic input-output database." He explains that there are essentially two alternative responses this misalignment: aggregation, "which entails an undesirable loss of information" or disaggregation "based on fragmentary information" (Lenzen, 2011). Lenzen shows that it is almost always preferable to choose disaggregation.

The effect of aggregation bias can be seen in the results many energy-IO studies. Most studies find that technological change is the main factor exerting downwards influence on the energy intensity of the economy while there is disagreement between studies as to how much change in energy intensity can be attributed to structural change. This disagreement generally rests on the level of sectoral aggregation upon which the different studies were based. Where a sector from one year corresponds to multiple sectors from the other year, creating a one-to-one correspondence involves a choice between aggregating the data of the second table or disaggregating the data of the first table. Garbaccio et al. explain that

> in general, for a given level of aggregation, any subsector reallocation of production cannot be discerned from technical change. The level of aggregation is thus of crucial importance in separating technical and structural factors in changes in the energy-output ratio. (Garbaccio, Ho, & Jorgenson, 1999, p. 3)

Huang (1993) for instance used a Divisia index SDA to study changes in China's energy consumption from 1980 to 1988. The study finds 73 to 87 per cent of the decline in energy intensity was due to technical change, although only six industrial sectors were studied so the opportunity to observe structural change is limited.

Sinton and Levine (1994) use a Laspeyres index to study changes from 1980 to 1990. They find that 58 to 85 per cent of energy savings were due to technical change. They use a variety of measures ranging from 11 to 267 sectors, though their use of IOA is limited to 49 sectors.

The most comprehensive study of China’s energy consumption to date is Lin (1996). Lin uses IO tables aggregated to 18 sectors and performs SDA with a Laspeyres index approach. He finds that all of the energy savings were due to technical change. China’s demand shift from 1981 to 1987 led to an 80 per cent increase in energy consumption (75 per cent through embodied energy, 5 per cent through increased direct consumption), while the impact of changes in consumption patterns was estimated as having a marginally *positive* impact on energy consumption.

Garbaccio et al. (1999) use SDA on 29 sectors between 1987 and 1992 and find that technical change within sectors accounted for most of the fall in the energy-output ratio, while structural change actually increased the use of energy.

With one exception, when creating a correspondence between IO tables in this thesis, data from the more aggregated table has been disaggregated to match the finer data set. That is, there is a preference for disaggregation over aggregation. In general, this has involved disaggregating the 2002 IO table to match the 2007 sectoral composition, although there are eight sectors from the 2007 table that have been disaggregated to match the 2002 definitions.

This approach is more involved than aggregating the more detailed sectors to match the more general composition but is chosen because the implicit assumptions better reflect reality. The reason can best be explained through an example. The 2002 sector: ‘manufacture of other specialised machinery’ (36065)[6], corresponds to three sectors in the 2007 table: ‘manufacture of special purpose machinery for mining, metallurgy and construction’ (069); ‘manufacture of special purpose machinery for chemical industry, processing of timber and non-metals’ (070) and ‘manufacture of other special purpose machinery’ (072). Special purpose machinery for mining, metallurgy and construction, as well as ‘other’ special purpose machinery are all used as inputs in the extraction of ‘coal’ (006) and ‘oil and natural gas’ (007), but special purpose machinery for the chemical industry is not used by those sectors at all. Aggregating the three sectors would carry the implication that buying sectors, such as the coal, oil and natural gas extraction sectors, used these three sectors in equal proportions. The aggregating approach sacrifices a lot of information present in the IO tables.

[6] The number in parentheses is the sector identification number. China’s 2002 IO table uses 5 digit sector identification numbers, while the 2007 IO tables uses only 3 digits.

Rather than assuming aggregated sectors are always consumed in equal proportions, the disaggregation approach requires the assumption that a purchasing sector retains fixed proportions of the disaggregated inputs from 2002 to 2007. In the example given above, the coal extracting sector (006) purchased 22,900 million RMB worth of special purpose machinery for mining, metallurgy and construction (069) and 2,204 million RMB worth of other special purpose machinery (072) in 2007 (there were no purchases from (070)). Of these three sectors, the coal extracting sector (006) made purchases totalling 251,041 million RMB in the following proportions: 069: 91 per cent; 070: 0 per cent; 072: 9 per cent. In 2002 the coal extracting sector (06007) made purchases totalling 53,872 million RMB of 'other specialised machinery' (36065). Assuming the proportions of purchases of specialised machinery remained constant across specialised machinery for mining, metallurgy and construction; chemical industry, processing of timber and non-metals; and 'other' from 2002 to 2007, we can conclude that the 2002 purchases were in the following amounts: 069: 49,142 million RMB; 070: 0 RMB; 072: 4,730 million RMB.

The process discussed above involves disaggregating sales of a single output to a single sector into sales of multiple outputs to a single sector. The opposite scenario must also be dealt with – disaggregating purchases of one sector's products by a single producing sector into purchases by multiple sectors. The process is equivalent.

In this study, only one sector is aggregated: 'loading, unloading, portage and other transport services' (102) from the 2007 IO table. This sector is embedded in each of the transport sectors in the 2002 table and cannot be isolated. It is assumed that each of the transport sectors in 2007 used these services in equal intensities (that is, equal expenditure on transport services per unit of output). Sales of transport services to other sectors of the economy (row 102) have been proportionately distributed among the other ten transport sector rows, supplementing the amount by which those sectors sell to the economy. Similarly, purchases made by the transport services sector (column 102) have been proportionately distributed among the other ten transport sector columns, increasing the value of purchases of intermediate goods made by those sectors.

The result is an IO table with 142 sectors, for both 2002 and 2007.[7]

Disaggregation of G

Constructing corresponding direct energy requirements matrices involves essentially the same mathematical process but the implicit assumption is different since $\mathbf{G}$ is expressed in physical units, not prices. The implicit assumption made to disaggregate $\mathbf{G}_{4,44}$ to $\mathbf{G}_{4,142}$ is that the more finely classified sectors corresponding to a single, less finely classified sector are each faced with the same prices for a given fuel type.

For example, “Farming, Forestry, Animal Husbandry, Fishery & Water Conservancy” is treated as a single sector in China’s energy data tables, but corresponds to six sectors in China’s IO tables (see Appendix A). In 2002 the sector directly consumed 338.05PJ of coal products. The RMB expenditure (in 2002 prices) of each of those sectors in 2002 on output from the ‘coal mining and washing’ sector can be seen in Table 2.2. From the table, we can also see the share of agricultural expenditure on coal due to each of the six sub-sectors.

Table 2.2: Agricultural expenditure on coal (2002)

Sector	Expenditure on coal (10,000RMB, 2002 values)	Share of total
Farming	861,402	59.6%
Forestry	34,260	2.4%
Timber and bamboo	30.562	2.1%
Animal husbandry	396,258	27.4%
Fisheries	66,276	4.6%
Services in support of agriculture	55735	3.9%
Total	1,444,493	

Source: NBSC (Input-Output Tables of China, 2002)

If the assumption that each of these sub-sectors faces the same price for coal is valid, the share of the sector’s total expenditure on coal is equivalent to the share of the physical quantity of coal consumed. We can take the shares identified in Table 2.2 and multiply them by the physical quantity of coal consumed by the

[7] All calculations involved in establishing a one-to-one correspondence between sectors in the 2002 and 2007 IO tables are contained in the file *Appendix – IO disaggregations*. Where a *#Div/0!* result is obtained, the cell has been replaced with a zero value.

entire agricultural sector to determine the physical quantity consumed by each sub-sector. This process has been repeated for each fuel type and each sector requiring disaggregation to create a one-to-one correspondence between the direct energy requirements matrix and the IO table for each year. The calculations are contained in the file: *Direct energy requirements matrix 2007 & 2002 – G 142x4*.

Zero values

Ang and Liu (2007) separate zero value problems for SDA into two types: Type I problems are those where the energy use for a particular sector goes from zero to zero across the comparison periods (that is, a particular energy source was not used in a sector in both years). This is the most common type of zero value problem. Type II problems are defined as “from/to a zero to/from a positive value” (that is, when an energy source is introduced or ceases to be used).

The equation for calculating the log-mean is the source of the problem in SDA. The log-mean of two numbers is given by

$$L_{(X,Y)} = \frac{(X-Y)}{\ln(X)-\ln(Y)} \tag{2.42}$$

A type II problem, where one of the numbers has a zero value the natural logarithm is undefined, so the log-mean cannot be calculated. This problem can be resolved by adding a very small number to all zero values (in this case, 1×10^{-20} was used). However, this approach does not resolve type I problems where both values are zero, since the denominator becomes zero and the log-mean becomes indeterminate. Type I problems are essentially unresolvable. They are the source of minor errors in several of the results in the thesis where the SDA estimates results that diverge from the actual result by up to 4 per cent. Such errors are always reported.

Inflation

IO tables summarise the value of sales from supplying industries to purchasing industries. Typically, as is the case in China’s IO tables, the values are measured in current value local currency units. To make meaningful comparisons over time, units must be converted to constant currency units. If IO tables of two separate years were compared without converting the currency to constant units, an observed change (for example, technical coefficients) would partially reflect a change in the value of the units due to inflation. It would then be impossible to determine how much of the change in a technical coefficient was due to the quantity effect and how much was due to the price effect (Dietzenbacher & Hoen, 1998). To express two IO tables in constant prices, one table must be adjusted. There are several methods of adjusting IO tables to account for inflation. A brief discussion of two of the most important is presented here with an explanation for the choice of method made.

Double deflation method

The double deflation method is a widely used method of adjusting IO tables for inflation. It is outlined in the United Nations handbook of input-output table compilation and analysis (United Nations, 1999). Using this method, output from each sector is deflated by that sector's price index. The method used in this study is a simplified version of the comprehensive double deflation method outlined by the UN (1999).

Chinese price index data

Although China's entire IO tables are not available in constant prices, China statistical yearbooks publish price index data that correspond to almost all sectors. Several tables must be combined to achieve this. The Chinese data leave some gaps, particularly in the services sectors, but most sectors are covered. Despite the shortcomings, using this data is preferable to relying on alternative estimation techniques such as the RAS method, based upon a much smaller set of data. This section outlines the sources from which price indices have been drawn.

Agricultural price indices for 2003 to 2006 are from Table 9-9: Indices of Producers' Prices for Farm Products (NBSC, 2007) while the 2007 indices are from Table 8-9: Producers Price Indices for Farm Products (NBSC, 2009).

Price indices for manufacturing sectors for 2003 to 2006 are from Table 9-16: Ex-Factory Price Indices of Industrial Products by Sector (NBSC, 2007) while the 2007 indices are from Table 8-12 Producer Price Indices for Manufacture Goods by Sector (NBSC, 2009).

The retail price indices come from Table 8-7: Retail Price Indices by Category of Commodities by Region (NBSC, 2009).

Price indices for transport, communication services, dining out, real estate, leasing, tourism, household services, education, health care, and cultural and recreational articles for 2003-2006 are from Table 9-6: Consumer Price Indices by Category and Region (NBSC, 2007) while the 2007 indices are from Table 8-3: Consumer Price Indices by Category (NBSC, 2008).

Price indices for construction are from Tables 9-14 (NBSC, 2005), 9-15 (NBSC, 2006), 9-15 (NBSC, 2007), 8-16 (NBSC, 2008) and 8-16 (NBSC, 2009), all titled Price Indices for Investment in Fixed Assets by Region.

China does not publish sectoral level price index data for the following sectors: services in support of agriculture, hotel accommodation, financial services, insurance, business services, specialised and other technical services, scientific research, geological surveys, water conservation and management, management of environmental resources and public facilities, public safety and social welfare and public management and social organization. Prices for these service industry sectors are assumed to rise at the same rate as the overall consumer price index.

Order of processes

Inflation adjustments have been made after disaggregation of sectors to ensure consistent one-to-one correspondences across all data tables, but before performing the IOA. In some cases where a single sector has been split into multiple sectors, the resulting sectors are not all affected equally by inflation. This creates a situation where the inflation adjusted total output value of a disaggregated sector does not necessarily equal the sum of all purchases of that sector. A judgment is required as to whether to retain the adjusted total output value as it links to the original data, or substitute a value based on the actual sum of adjusted sales. In the present study the value is linked to the original total output value rather than the sum of the adjusted parts.

Whether to adjust raw data and perform IOA and SDA on the adjusted data, or to perform the IOA on raw data first and adjust the results to facilitate the SDA is worthy of consideration as each alternative will give somewhat different results.

In the thesis IOA and SDA is always made on already adjusted data. The rationale for this approach is that performing analysis on less detailed data will obscure some of the variation. Refining the results after performing the analysis will not recover the full level of detail. If the adjustments are valid, the maximum information is obtained by adjusting the data first. Conversely, if the adjustments are not valid they should not be performed at all.

Leontieff inverse

The Leontief Inverse Matrix, $\mathbf{L}$, can be interpreted as a matrix of total input coefficients, where $\mathbf{L}_{ij}$ is an estimate of the total amount of output from sector i required to produce 1 RMB worth of sector j. It includes sector i product that is used in the production process of the inputs to sector j as well as the amount used in the production of those factors *ad infinitum*. Constructing a standard Leontief inverse matrix is relatively straightforward. The only data required are the relevant input-output tables. In this case, the two tables used were:

Input Output Tables of China 2007 (NBSC, 2007)
Input Output Tables of China 2002 (NBSC, 2002)

The $\mathbf{A}$ matrix is constructed by dividing each element of the IO table by its column sum. A separate sheet in Excel has been used to supply the identity matrix, $\mathbf{I}$ and a third sheet to calculate $(\mathbf{I}-\mathbf{A})$. The resulting matrix is adjusted by adding 1×10^{-15} to each cell. This is a common method in IOA to ensure the matrix is not singular by removing all zero values and replacing them with a very small value. The impact on results is minimal, however, it allows the matrix to be inverted, which is the final step in creating the Leontief inverse matrix.

Conclusion

This chapter has explained the most appropriate characterisations of 'energy use'. It has identified decomposition analysis as the most appropriate method for studying each of the key energy-economy relationships (energy with production, consumption and trade) in the Chinese context. The main data sources that the thesis has relied on were outlined, indicating where and how each data source is used.

Decomposition analysis involves a variety of theoretical and empirical challenges, which have also been discussed, and the approach to dealing with each of these has been explained and justified. Most of the theoretical discussion occurred in the context of IO-SDA since that is the technique used in Chapters 4, 5 and 6, however the next chapter, Chapter 3 does not employ IOA. The only methodological difference that results is that SDA is performed on time series that are not IO tables. It means that only direct energy intensity can be measured, rather than embodied energy intensity, the merits of which will be discussed in Chapter 3. It is hoped that by explaining and justifying the methodological detail of the thesis, this chapter may also serve as a useful aid for practitioners seeking to apply IOA and SDA techniques, especially in the context of analysing China's energy use.

The key contribution of this chapter is the creation of compatible data sets that enable energy SDA between the years 2002 and 2007 for China without sacrificing accuracy by creating substantial aggregation bias. This chapter lays the foundation for analysing the key relationships between energy and economic growth in subsequent chapters.

Chapter 3. Energy and production

Introduction

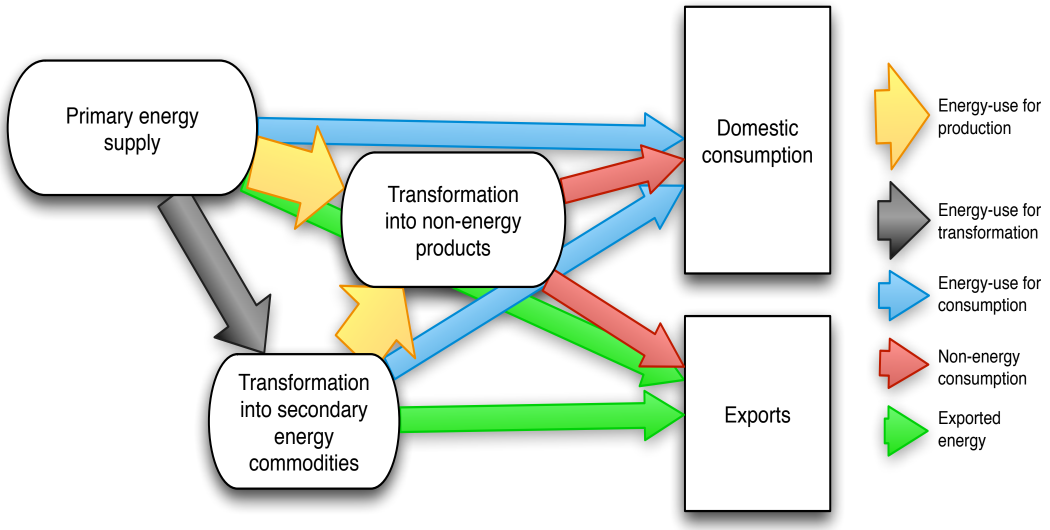
The majority of direct energy use is for the purpose of production. The fact that the IEA was able to report China as the world's largest energy user is largely a consequence of China being the world's largest producer of manufactured goods. This Chapter investigates changes to the relationship between economic output and energy use in China. In some sense this is the first stage of the energy flow in a modern economy: energy begins in its various forms in the environment, is captured by humans and converted into usable forms (such as electricity), then converted by firms into products. The last step of the energy flow is when the products that embody energy are used by consumers; that step will be dealt with in subsequent chapters.

How much energy is needed for production depends largely on the technologies used, the choices about what is produced, and how much is produced in aggregate. The State Council of China (2007) identified structural transformation as one of the key strategies for reducing the energy intensity of China's economy. This chapter therefore pays particular attention to the extent to which structural change has affected energy use in China. It examines how China's recent experience fits with the general story of changing production patterns during the process of economic growth and provides some measure of the extent of structural change in Chinese production. Then, using the index decomposition analysis introduced in Chapter 2, the impact of the changing structure of China's production on energy use is quantified, along with the impact of energy intensity at the sectoral level, the impact of population growth, and the impact of China's rapidly expanding output per capita. The final part of the chapter presents some hypotheses as to what caused the specific changes to the production side of China's economy that have had such dramatic impacts on energy use over the last decade.

Energy-use in production

What is meant by energy use in production? This refers to all energy, both primary and secondary, used as a factor of production by firms producing goods or services. This definition excludes the transformation of primary energy into secondary energy forms but includes that energy when it is converted into a non-energy product.

Figure 3.1: Basic energy flow diagram



In the basic energy flow diagram presented in Figure 3.1, energy use in production is represented by the yellow arrows. It is easily observed that the transformation of primary energy into secondary energy (such as the burning of coal to produce electricity) is an energy transformation, not a supply-side use of energy. Final energy consumption is defined by the International Energy Agency as "deliveries of [energy] commodities to consumers for activities that are not fuel conversion or transformation activities" (IEA, 2005, p. 27). In Figure 3.1, final energy consumption includes the flows represented by both the yellow and blue arrows.

Justification for supply-side focus

There are at least four reasons to study energy use for production. First, producers account for the majority of final energy consumption, so understanding patterns of energy-use for production is a large component of an understanding of the patterns of total final energy use. Second, as demonstrated in Chapter 1, energy use for production and energy embodied in consumption are at least partly independent in an open economy because of both energy trade and trade in goods that embody energy. Energy use for production depends on an additional set of determinants from energy use for consumption. It therefore makes sense to study the two separately. Third, technological progress is a key component of economic growth and can be either energy-saving or energy-using: the nature of technological progress (a supply-side issue) is integral to the relationship between energy and economic growth. Finally, it is also a fact that signatories to the Kyoto Protocol are obliged to report GHG emissions on a direct emission basis that is largely dependent upon energy-use for production, so climate change concerns also motivate a study of energy-use for production.

As discussed in Chapter 1, that the determinants of energy demand as a factor of production should be different from those of energy demand as a consumption good (or an embodied component of consumption goods) is clear from international trade theory. Factor demand depends upon technology, prices and aggregate demand. To determine a home country's factor demand in an open economy, the relevant aggregate demand is global aggregate demand; the relevant prices are home and world prices; and the relevant technology is home country technology. In contrast, domestic consumption (including embodied consumption) is determined by home country aggregate demand, home and world technology, and home and world prices (Krugman & Obstfeld, 2006). Since their determinants are different, there is justification to study energy-use for production separately from energy-use for consumption.

Dominance of the supply side in final energy consumption

The overwhelming majority of final energy consumption in China is energy use for production, as evidenced by China's national energy balance sheets (NBSC, 2009). A template for China's energy balance sheets is provided in Table 3.1. The correspondence with Figure 3.1 can be seen clearly. The first section: 'total primary energy supply', corresponds to the top-left bubble of the energy flow diagram: 'primary energy supply'. The second section of the energy balance sheet: 'transformations', corresponds with the lower-left bubble: 'transformation into secondary energy commodities'. And the third section of the balance sheet: 'total final consumption', corresponds with both the 'transformation into non-energy products' and the 'domestic consumption' bubbles in the energy flow diagram.

China's total final consumption from 1980 to 2008 is depicted in Figure 3.2. Statistical difference is excluded because it is not an actual user of energy but a record of reporting inaccuracies. Energy-use for production accounted for 80 per cent of total final energy consumption in 1980, rising to almost 90 per cent by

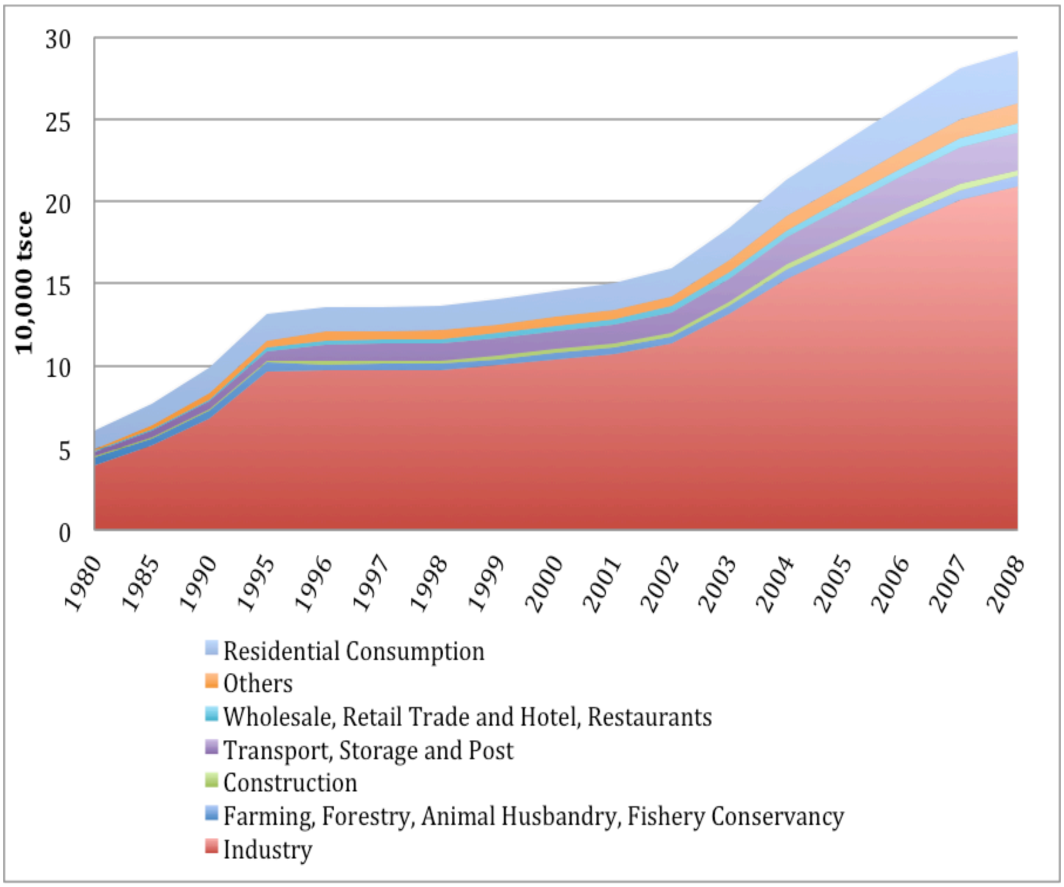
1996. That China's total final energy-use is related primarily to domestic production is clear from the figure.

Table 3.1: China's energy balance sheet template

Flow	Fuel type
Total primary energy supply	
Domestic production	
Hydro power	
Nuclear power	
Recovery of energy	
Imports	
Chinese airplanes & ships refuelling abroad	
Exports	
Foreign airplanes & ships refuelling in China	
Stock changes	
Transfers between commodities	
Transformations	
Thermal power	
Heating supply	
Coal washing	
Coking	
Petroleum refineries	
Gas works	
Coke input (-)	
Briquettes	
Loss	
Total Final Consumption	
Farming, forestry, animal husbandry, fishery & water conservancy	
Industry	
Non-energy use	
Construction	
Transport, storage, postal & telecommunications services	
Wholesale, retail trade and catering services	
Residential consumption	
Urban	
Rural	
Other	
Statistical difference	

Note: Fuel type is left blank. Chinese statistics list up to18 different fuel types, listed in Chapter 2.
Source: NBSC (2009)

Figure 3.2: Total final energy consumption by user-group (1980-2008)



Source: NBSC (2008, pp. 5-27)

Energy and production during economic transformation

Central to this thesis are the following propositions: (1) the relationship between energy and economic output is not constant; (2) as economies develop, the production structure changes; (3) China has experienced a fundamental transformation in production over the past 30 years; and (4) the fundamental transformation in production experienced by China over the past 30 years has substantially altered the energy-economy relationship.

Evidence that the relationship between energy and economic output is not constant has been provided in Chapter 1. That the production structure changes as economies develop has been demonstrated in literature dating back to Adam Smith, who considered structural change as part of the necessary process through which the wealth of nations grew:

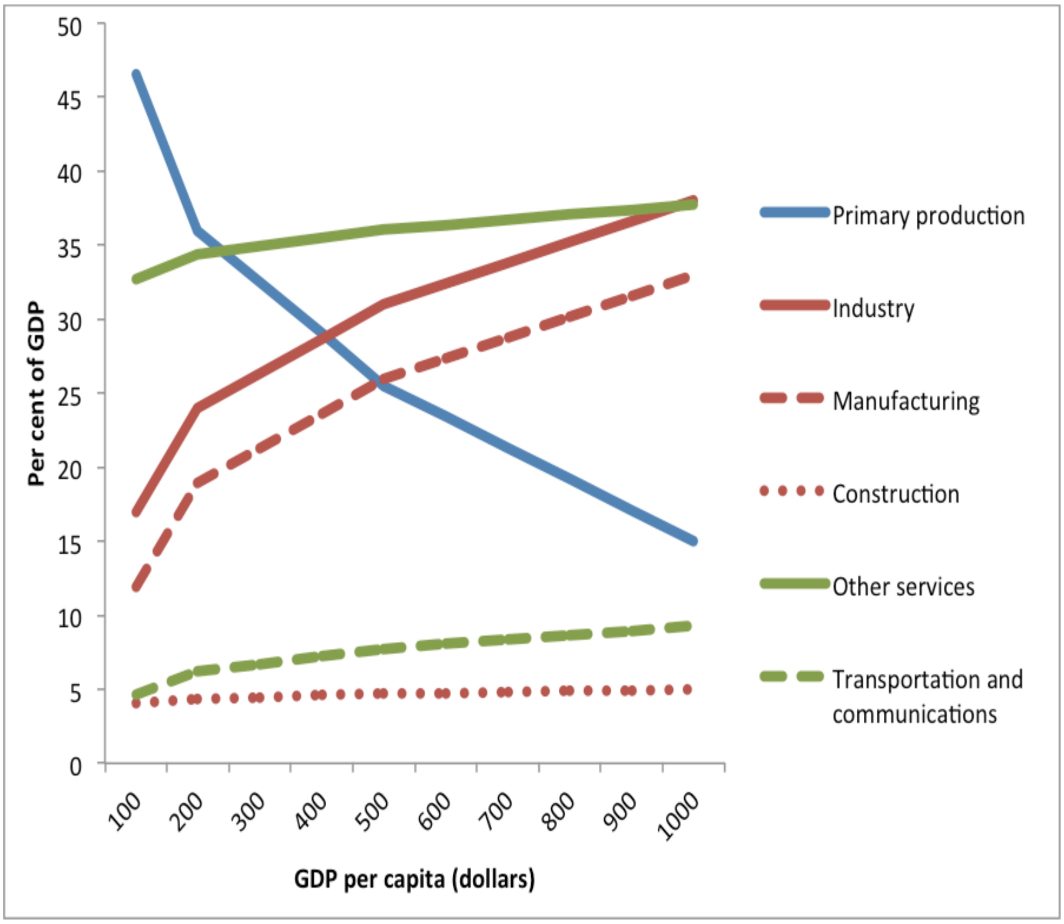
> As subsistence is, in the nature of things, prior to conveniency and luxury, so the industry which procures the former, must necessarily be prior to that which ministers to the latter. The cultivation and improvement of the country, therefore, which affords subsistence, must, necessarily, be prior to the increase of the town, which furnishes only the means of conveniency and luxury. It is the surplus produce of the country only, or what is over and above the maintenance of the cultivators, that constitutes the subsistence of the town, which can therefore increase only with the increase of the surplus produce (Smith, 1776, p. 272).

A central concept of much of the growth and development literature is that economic development progresses through roughly definable stages. Lewis (1954) considered modernisation to be the process of rebalancing between the ‘capitalist’ sector and the ‘subsistence’ sector. Rostow (1960) developed an explicit list of five sequential phases that he hypothesised economies passed through as they develop. Economists have since backed away from such explicitly demarked stages, but the underlying concept is still evident (see for example, Garnaut and Song (2006)).

One of the earliest attempts to quantify structural change in economic growth was by Simon Kuznets (1957), who divided the economy into agricultural sectors, the manufacturing sectors (including mining and construction) and the services sectors. Kuznets studied 59 countries, which he divided into seven groups according to per capita income. He showed that of the richest two groups, in no country did agriculture account for greater than 30 per cent of GNP, while in the poorest group, agriculture accounted for more than half of GNP in 9 of the 13 countries. Similarly, of the richest two groups, the manufacturing sectors accounted for at least 30 per cent of GNP in 11 of 13 countries, while only one of the 12 poorest countries derived greater than 30 per cent of GNP from the manufacturing sectors. Finally, the services sectors accounted for greater than 40 per cent of GNP in ten of the 13 richest countries and in only one of the 12 poorest.

These observations provided some of the first statistical evidence in support of arguments that economic growth was associated with structural change. Kuznets later went on to show that similar observations could be made for stages of economic growth within a country by doing state-by-state comparisons within the United States (Kuznets, 1958). By 1960, Chenery was able to describe these observations as ‘well established’. Chenery described the process of industrialisation as involving three key structural changes to the economy: “a rise in the relative importance of manufacturing industry; a change in the composition of industrial output; and changes in production techniques and sources of supply for individual commodities” (Chenery, 1960). Chenery used cross-sectional data of 38 countries in the period 1950-56 to estimate the relationship between GDP per capita and the sectoral distribution of the economy. Figure 3.3 is a reconstruction of the results of Chenery’s analysis, converted from log to linear scale. It gives clear support for the statement that the structure of production changes as an economy develops.

Figure 3.3: Share of major sectors in national product



Source: Adapted from Chenery (1960)

By 1973, the expansion of the services industry had been observed as a main characteristic of modern economic growth. Rapid structural change was described as a principal characteristic of economic growth, the major aspects of which included “the shift away from agricultural pursuits and, recently, away from industry to services” (Kuznets, 1973). The observation has continued to be supported by subsequent data, such that Angus Maddison could declare that in the past two centuries, “rapid technical change, structural transformation, and rising per capita incomes were the norm” (Maddison, 1998).

The centrality of structural change in economic growth has important implications for our understanding of the relationship between energy and the economy. In his book, *On the Principles of Political Economy and Taxation* (1817) Ricardo’s explanation of the gains to be made from trade by following the strategy of comparative advantage implicitly acknowledged different production functions for different products (in different countries). The different productive sectors each have different needs for energy as a factor of production, so as their relative importance in the economy changes, the relationship between energy use and economic growth must also change.

Divergence in factor intensities relating to energy specifically was elaborated by Schurr, who devoted a large portion of his seminal study of energy in the US economy to consumption patterns according to sectors (Schurr, 1960). This concept is crucial to establishing the proposition that the relationship between energy use and economic output is dependent upon the production structure.

Other authors have advanced this proposition more recently. For example, Song and Sheng write

> … when economic growth makes a country cross certain economic development stages, the adjustment in production technique and consumption pattern can lead to structural changes in energy demand. For example, when a country grows from a farming society into an industrialised society, it is expected that capital and energy-intensive industrial production will substitute for primary products or labour-intensive production and thereby generate a large demand for energy. (Song & Sheng, 2007, p. 238)

An illustrative numerical example can articulate this point. Table 3.2 shows three sectors, each with a different energy intensity: $1 worth of agricultural product requires two units of energy, while the equivalent value of manufacturing sector product requires four units of energy, and the equivalent value of services sector product requires just one unit of energy. The example includes three different industrial structures:

1. 60 per cent agriculture: 40 per cent manufacturing
2. 30 per cent agriculture: 60 per cent manufacturing: 10 per cent services
3. 10 per cent agriculture: 40 per cent manufacturing: 50 per cent services

and three different levels of economic development: GDP = $10, $50, $100.

Table 3.2: Illustrative non-linear energy-GDP relationship

	Energy per $	Share of GDP (%)	Energy use given GDP =		
			$10	$50	$100
Agriculture:	2	60 30 10	12 6 2	60 30 10	120 60 20
Manufacturing:	4	40 60 40	16 24 16	80 120 80	160 240 160
Services:	1	0 10 50	0 1 5	0 5 25	0 10 50
		Total energy use: (energy intensity)	28 (2.8) 31 (3.1) 23 (2.3)	140 (2.8) 155 (3.1) 115 (2.3)	280 (2.8) 310 (3.1) 230 (2.3)

The amount of energy used by each given industrial structure and each level of development is given in the bottom row. Reading across the 'totals' row, if industrial structure remains constant, the energy intensity of the economy remains constant and total energy use increases with GDP. Reading down the 'totals' row, it is clear that the second economic structure is the most energy intensive, while the third structure is the least energy intensive. This illustration exhibits the Kuznets curve for energy intensity and reveals how structural change in an economy (changes in what is produced) can impact the relationship between economic growth and energy use. Thus establishing the proposition that the relationship between energy and economic growth is not constant.

The next section examines evidence that China has undergone a fundamental supply-side economic transformation over the past 30 years and that this transformation will substantially alter the relationship between energy and economic growth.

China's production transformation

China's White Paper on the Socialist System of Laws with Chinese Characteristics (State Council Information Office, 2011) provides an overview of China's reform program from a legislative perspective. The changes spurred by ongoing reforms in China, especially following the 1978 Party Congress and even more so in the lead up to, and immediately after WTO membership, have been transformational. However, it remains to be formally established that China's production transformation is observable in Chinese production data. The characteristics of China's production transformation of interest in this thesis are the scale of output, the structure of output, and the technology used. That is, how much is produced, what is produced, and how much input (particularly of energy) is required per unit of production.

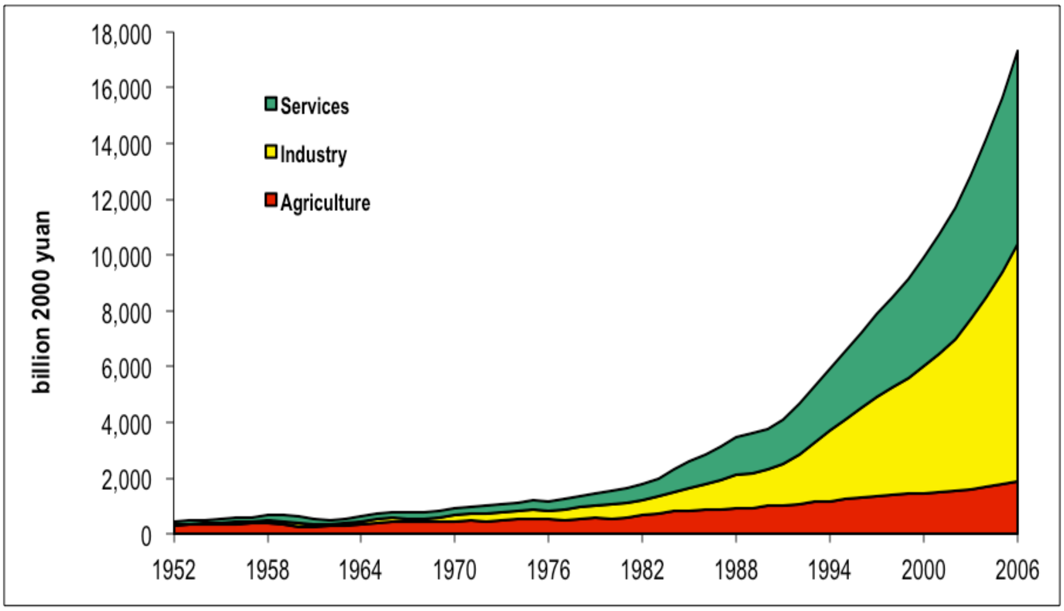
On one level China's gross output values, presented in Figure 3.4 establish that China is undergoing an economic transformation. It is clear that while there was some expansion of industry through the 1970s, the real acceleration began in 1980. Expansion of output at that pace is, by itself, transformative. If there was no structural change and no technological change, the surge in output evidenced in Figure 3.4 would result in a surge in the use of energy as a factor of production. But Chapter 1 showed that beginning in 1977 there was an almost constant decline in China's aggregate energy intensity. What were the reasons for this change in the relationship between energy use and economic growth?

Figure 3.5 shows the composition of China's GDP from 1952. It depicts steady economic transformation. When the People's Republic of China was established the economy was heavily rural, with the agricultural sector generating over 70 per cent of GDP in 1952, while 23 per cent came from services and just eight per cent from industry. Excepting the abnormality of the Great Leap Forward (1958-1962), the share of GDP from agriculture fell almost constantly, reaching just 11 per cent by 2006. The decline in relative importance of agriculture was due mostly to the rapid expansion of China's manufacturing base, which, according to Fridley and Aden (2008) grew from just 6 per cent of GDP in 1952 to 43 per cent by 2006. The exact point at which industry became a larger share of GDP than agriculture depends on which data source is used. According to Fridley and Aden (2008), services and industry both surpassed agriculture in 1985, while industry did not surpass the services sector until 1992. In this data set, the services sector reached 39 per cent in 1988 and scarcely deviated from that point over the next two decades.

Data from the World Development Indicators (World Bank, 2011) tell a slightly different story. The World Bank data only extends back to 1980. According to the World Bank, at that time China's industrial production had already exceeded that of agriculture with industry accounting for 48 per cent of GDP compared with 30 per cent from agriculture and just 22 per cent from services. The discrepancy may have been to some extent influenced by the difficulty in correctly valuing the historical record of China's service sector. While the two datasets are not exactly equivalent, both depict China's economy as experiencing considerable transformation in terms of the relative share of GDP from agriculture, industry and services until the late 1990s, after which the relative importance of each sector seems to have stabilised.

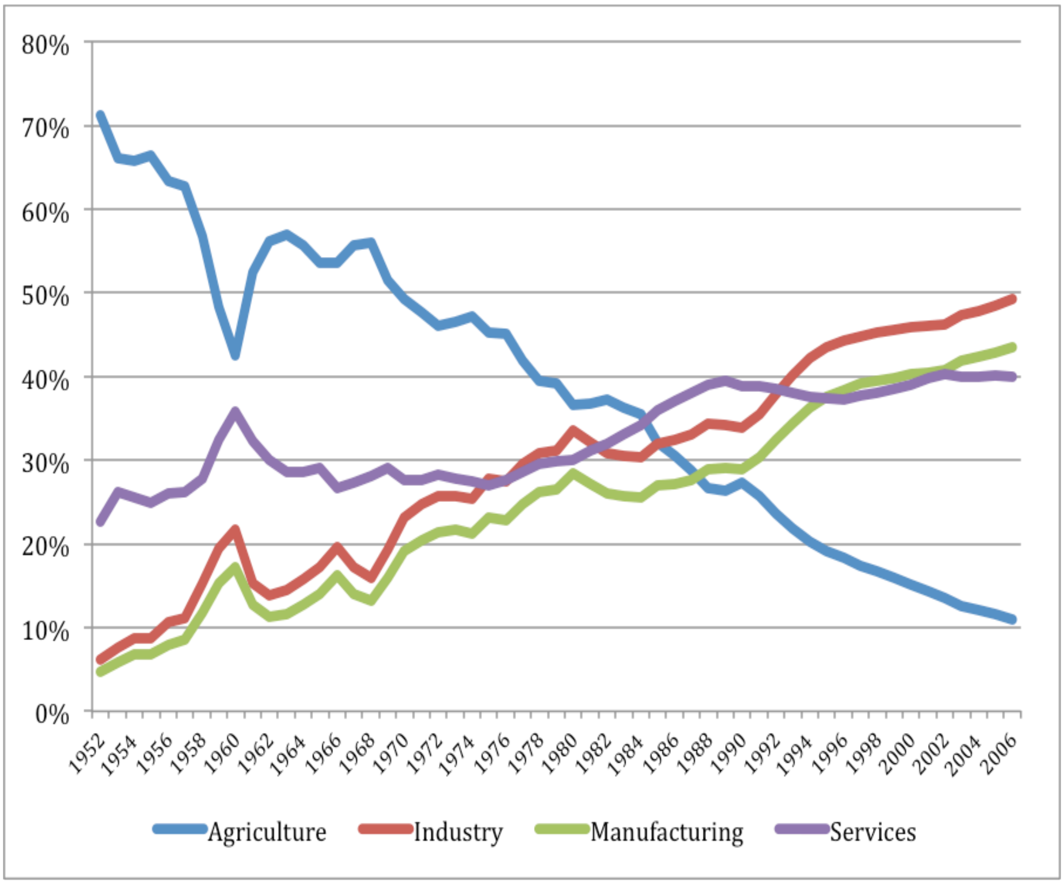
The representation in Figure 3.6 shows stagnation in China's structural change. It shows GDP per capita on the horizontal axes (rather than time) to capture the relationship between structural change and economic growth with GDP per capita measured in PPP current international dollar terms, ranging from around PPP$250 to almost PPP$7,000.

Figure 3.4: GDP by Sector (1952-2006)



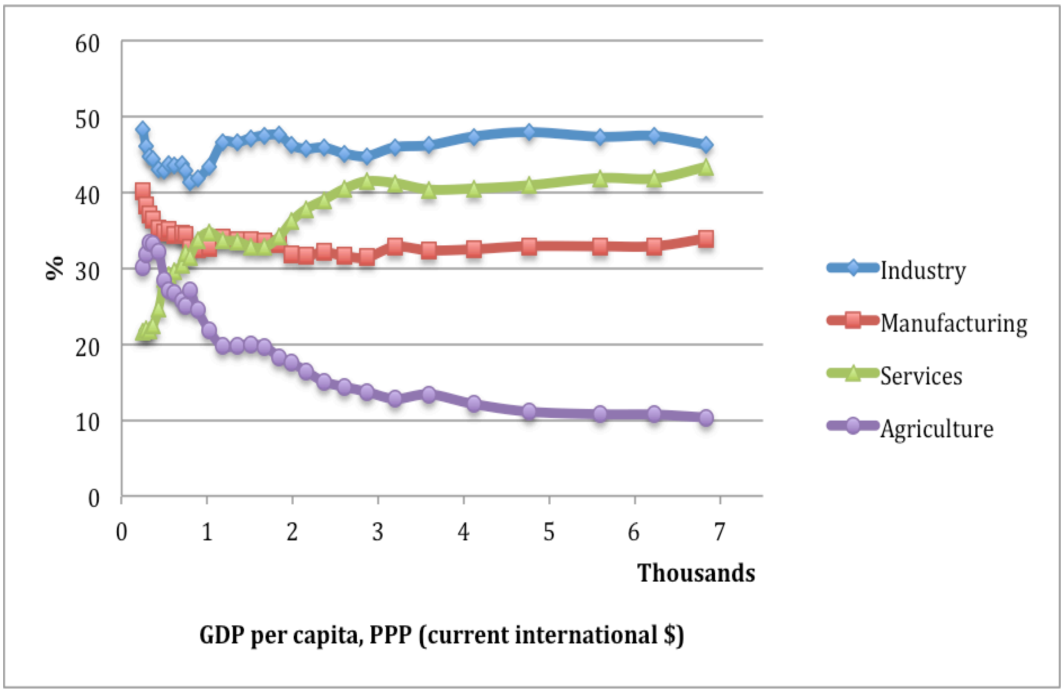
Source: Fridley and Aden, (2008, p. 10B.1)

Figure 3.5: Composition of GDP (1952-2006)



Source: Author's calculations from Fridley and Aden, (2008, p. 10B.1)

Figure 3.6: Composition of GDP versus GDP per capita (1980-2009)



Source: World Bank (2011)

There is an initial increase in the relative importance of agriculture due to the early reforms beginning in 1978. This is followed by a constant decline in the relative importance of agriculture, with two clear periods in which the service sector expanded: from around PPP$250 to around PPP$1,000 (1980 to 1992) and again from PPP$1,600 to PPP$2,800 (1996 to 2002). While the initial shift toward a service-based economy was offset by relative declines in all three other major sectors, the second period of service sector expansion was almost entirely at the expense of the agricultural sector. The importance of industry and manufacturing had remained almost constant since the end of the initial period of structural change prior to reaching GDP per capita levels of around PPP$1,000 in 1996. The World Bank data show a second period of services sector expansion, from GDP per capita of PPP$1,507 (reached in 1995) when services accounted for 32.8 per cent of GDP to GDP per capita of PPP$2,863 (reached in 2002) when services accounted for 41.5 per cent of GDP. Since 2002 there has been little change in the relative output of the major sectors (World Bank, 2011).

Figure 3.6 is surprising since it appears to show that structural change in China's economy has stalled, despite the ongoing rapid economy-wide transformation apparently evident. Two alternative hypotheses are proposed to account for this apparent discrepancy:

1. These macro-sector structural changes obscure some of the structural changes that have occurred in recent years at finer levels of sectoral detail.
2. China's provinces are undergoing counter-balancing structural changes: expansion of the services sector in some provinces is off-set by expansion of the industrial sector in other provinces such that the national level data reports no change.

To demonstrate that China has experienced a fundamental transformation over the past 30 years, one of these two alternative hypotheses must hold. Otherwise the apparent economic stability identified in Figure 3.6 must be taken as contradicting the proposition and structural change must be abandoned as an explanation for the change in the relationship between economic production and energy use in China over recent years. Testing of the alternative hypotheses is set out below.

Alternative hypothesis 1: structural change exists below the three-sector classification

The level of sectoral detail presented in Figure 3.4, Figure 3.5, and Figure 3.6 is very broad. It distinguishes between only three sectors (and one subsector). It is plausible that while these three sectors have remained relatively stable in terms of their relative share of GDP since around 2002, there exists significant variation in the relative output of subsectors.

To investigate the presence of structural change at finer sectoral disaggregation than the three-industry level presented so far, a simple test is carried out. The growth of each sector over the twelve years (1995 to 2007) can be compared with the total GDP growth creating a measure of relative sectoral growth as the difference in compound annual growth rates, according to the following formula:

$$R_i^{0-T} = \left(\left(\frac{Y_i^T}{Y_i^0} \right)^{\frac{1}{n}} - 1 \right) - \left(\left(\frac{GDP^T}{GDP^0} \right)^{\frac{1}{n}} - 1 \right) \tag{3.1}$$

where R_i^{0-T} is the relative growth rate of sector i over the period beginning in year 0 and ending in year T, Y_i^t is the output of sector i in year t, GDP^t is the total GDP in year t and n is the number of years from 0 to T. A value greater than zero for any sector implies the average annual growth rate of that sector was faster than that of the economy as a whole. Similarly, a value less than zero for any given sector implies the growth rate of that sector was less than the growth of the economy as a whole. Economic growth in the absence of structural change would result in all sectors exhibiting a relative growth rate of zero, while economic growth in the presence of structural change would result in diverse relative growth rates.

Constructing a complete 'value added' dataset

To determine the presence of structural change demands data that meet certain requirements. Firstly, the data should measure output at a finer level of sectoral disaggregation than the three sectors presented above. Secondly, it must be comprehensive, in order to cover the complete set of sectors so that the sum of output of all sectors is equal to GDP. Finally, it needs to be consistent over time so that temporal comparisons are meaningful.

There are several measures of output by sector available. The two most relevant are 'Gross Value of Industrial Output' (GVIO) and 'Value Added of Industry' (VAI). Both of these indices are available at similar levels of sectoral detail for a similar number of years and both represent the value of output. The main distinction is that GVIO measures the total value of output of each sector, while VAI excludes the value of inputs and measures only the activity performed by the sector itself.

An example can help show why VAI is more appropriate for present purposes. Consider the case of the sector, 'manufacturing of chemical fibres'. In 2007, the GVIO of this sector was 412 billion RMB while the VAI was just 81 billion RMB (NBSC, 2008, pp. 13-2). Only 20 per cent of the value of the sector's output was created by the sector itself. The remaining 80 per cent of the value of total output was the value of intermediate goods purchased from other sectors. In 2007, the chemical fibres industry consumed 15 million tce of energy. This energy consumption fuelled the processes within the industry, but it did not contribute toward the production of the intermediate goods purchased by the industry. In calculating the energy intensity of the industry, we are therefore interested in the ratio of VAI to energy consumption, not the ratio of GVIO to energy consumption. The distinction is important. In this case the energy intensity using the incorrect, GVIO measure would be 262 million RMB per tce instead of the correct 51 million RMB per tce. VAI is therefore considered the appropriate index of sectoral activity for the purposes of this chapter.

The NBSC reports sufficiently reliable and comprehensive data on output for 42 sectors covering the years 1997 to 2007, but excluding 2004. Total GDP in current 2010 prices is available from the China Statistical Yearbook 2010 along with the value added due to the primary, secondary and tertiary industries, plus the construction sector for the years 1978 to 2009 (NBSC, 2011, pp. 2-1). The explanatory notes from the same volume provide details of which sectors are included in each industry:

> Primary industry refers to agriculture, forestry, animal husbandry and fishery and services in support of these industries.
>
> Secondary industry refers to mining and quarrying, manufacturing, production and supply of electricity, water and gas, and construction.

> Tertiary industry refers to all other economic activities not included in the primary or secondary industries. (NBSC, 2011)

The next section will need to match value-added in each sector to energy consumption, therefore the sectoral detail of the value-added data must match the sectoral detail of the energy data. Therefore the five sectors composing the primary industry are treated as a single sector in this chapter and no further data are required for that part.

Value-added in the tertiary industry sector is provided at a six-sector classification from 1978 to 2009 for the first time in the most recent China Statistical Yearbook (NBSC, 2011, pp. 2-6). These data are easily aggregated to match the three sectors for which energy consumption data are available.

Data for the secondary industry sector (excluding the construction sector) are less conveniently available. Sectoral level value-added data for the secondary industry are available for the years 1995-1998, 2003, and 2005-2007 from the China Statistical Yearbooks, 1996-1999, 2004, and 2006-2008. Data for the years 1999-2002 are from the China Industry Economy Statistical Yearbook 2001, 2002 and 2003. Unfortunately these data are all recorded in current prices relative to their reporting year and so are not comparable in their raw forms. Rather than rely upon the accuracy and correlation of price index data, the value-added for each sector in each year has been converted into a percentage of industrial value-added for that year. Since the total value of industrial value-added is available in current, 2010 RMB, the percentages are then multiplied by the 2010 value of industrial value-added to derive sectoral value-added for industrial sectors in current, 2010 prices. The final, adjusted data are reproduced in Appendix D.

Confirmation of alternative hypothesis 1

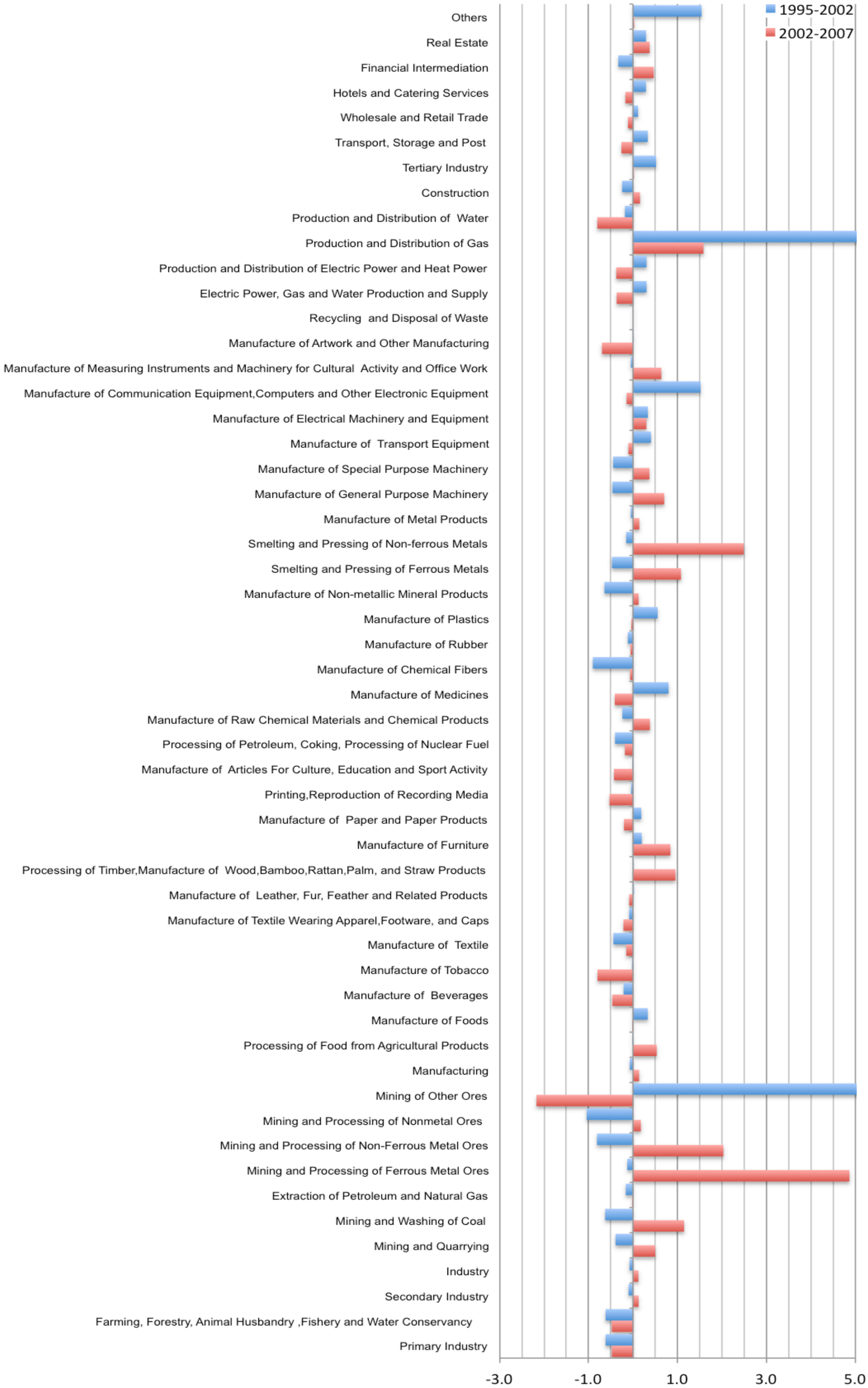
The results of this simple analysis over the periods are presented in Figure 3.7. Results for 1995 to 2001 are presented separately from the results for 2002 to 2007 because the apparent suspension of structural change observed at the three-industry level is most strongly observed in the 2002 to 2007 period. It is clear from Figure 3.7 that over both periods structural change is present, however the pattern of change is not the same. For instance, the average annual growth rate of value-added in nominal terms of the sector that exceeded national growth by the largest margin since 2002, mining and processing of ferrous metal ores, averaged 31 percentage points higher than GDP but averaged 1 point lower than GDP in the seven years prior to 2002.

The period from 1995 to 2002 saw substantial structural change, as observed in Figure 3.5. The results depicted in Figure 3.7 show that the agricultural sectors' average annual growth was 6 percentage points lower than GDP, causing the observed decline in the share of GDP from the primary industry. Conversely, with the exception of financial intermediation, the tertiary industry sectors grew faster than GDP: the transport and real estate sectors grew 2 per cent faster than GDP, while wholesale and retail trade grew 1 per cent faster and 'other' services grew on average 9 per cent faster than GDP per annum.

The largest changes were within industry. The mining sector as a whole grew more slowly than GDP over the period, with the mining of coal almost two thirds of a per cent slower, however, the 'mining of other ores' was the over all fastest growing sector, growing 32.3 per cent faster than GDP. This rapid growth was achievable largely because the sector was so small to begin with, producing just 233 million RMB value added of the 298,248 million RMB value added for the mining sector as a whole (less than 0.8 per cent of value added in the mining sector). By 2002 this sector had expanded to produce 1.7 per cent of the value added in the mining sector. During this period, the greatest expansion of sizeable industries came from the manufacture of communications equipment, computers and other electronic equipment, electrical machinery and equipment, transport equipment, and the manufacture of medicines and plastics.

The period from 2002 to 2007, represented by the red bars in Figure 3.7, appears to indicate more structural change than the previous period. The agricultural sector continued to decline in relative importance, growing on average 6 per cent slower than GDP over the period, but the real interest is in the secondary and tertiary industries. The tertiary industry grew at almost exactly the same rate as the economy as a whole, leaving the relative importance of that industry largely unchanged. Within the tertiary industry, different services sectors exhibited markedly different rates of growth. For instance, the hotels and catering services sector averaged 2 per cent slower growth than GDP and the transport, storage and post sector averaged 3 per cent slower, while the real estate sector averaged 4 per cent faster growth than GDP and the financial intermediation sector averaged 5 per cent faster. The tertiary industry as a whole retained its relative share of GDP because of the counter-balancing effect of the relative growth rates of the different services sectors over the 2002 to 2007 period. Similarly, the secondary industry averaged, just 1 per cent faster net growth than GDP over the period. This result masks substantial variation within the industry, with smelting and pressing of ferrous and non-ferrous metals averaging 10 and 19 per cent faster growth than GDP, respectively, and mining and processing of ferrous and non-ferrous metal ores averaging 31 and 16 per cent faster growth than GDP, respectively. These rapidly growing sectors were counter-balanced by the slower growth of a wide range of manufacturing sectors.

Figure 3.7: Sectoral growth relative to GDP growth



Source: Author's calculations
Note: 1995-2002: Production and distribution of gas = 13.02; Mining of other ores = 32.34

In addition to the visual effect of Figure 3.7 it is useful to have an index that can objectively compare the scale of structural change over the two periods. Adding a single step to the previous equation creates an index of structural change according to the following formula:

$$\Delta^{0-T} = \frac{\sum_i \left| R_i^{0-T} \right|}{I} \tag{3.2}$$

where I is the number of sectors and Δ^{0-T} is the index of average annual structural change during the period 0 to T. This index can be used to compare relative levels of structural change in a single country at different periods of time, assuming the data retains a consistent sectoral decomposition. The process is a slight deviation from that proposed by Roman (1969), which used the arithmetic mean of the ratios of sectoral to total output growth, while this formulation uses the differences of sectoral to total output growth. Although the formulation proposed by Roman has been criticised as not being "independent of changes in the overall growth rate unaccompanied by structural change" (Moore, 1978) the criticism does not seem to hold for the formulation presented here. Further, the solution proposed to resolve this criticism involves an overly complex approach based on vector space and involving trigonometry. For the purposes of the argument, this degree of complexity is not required.

The results of the delta-index are as follows:

	1995-2007	1995-2002	2002-2007	2002-2005
Δ^{0-T} (per cent)	3.1	4.8	6.5	7.8

The index results show that at the level of 47 sectors adopted in China's more detailed industrial value-added data tables, structural change did not cease after 2002, but was in fact greater on average during the years 2002 to 2007 than it was during 1995 to 2002. The years 2002 to 2005 were amongst the periods of highest structural change at this level of sectoral disaggregation.

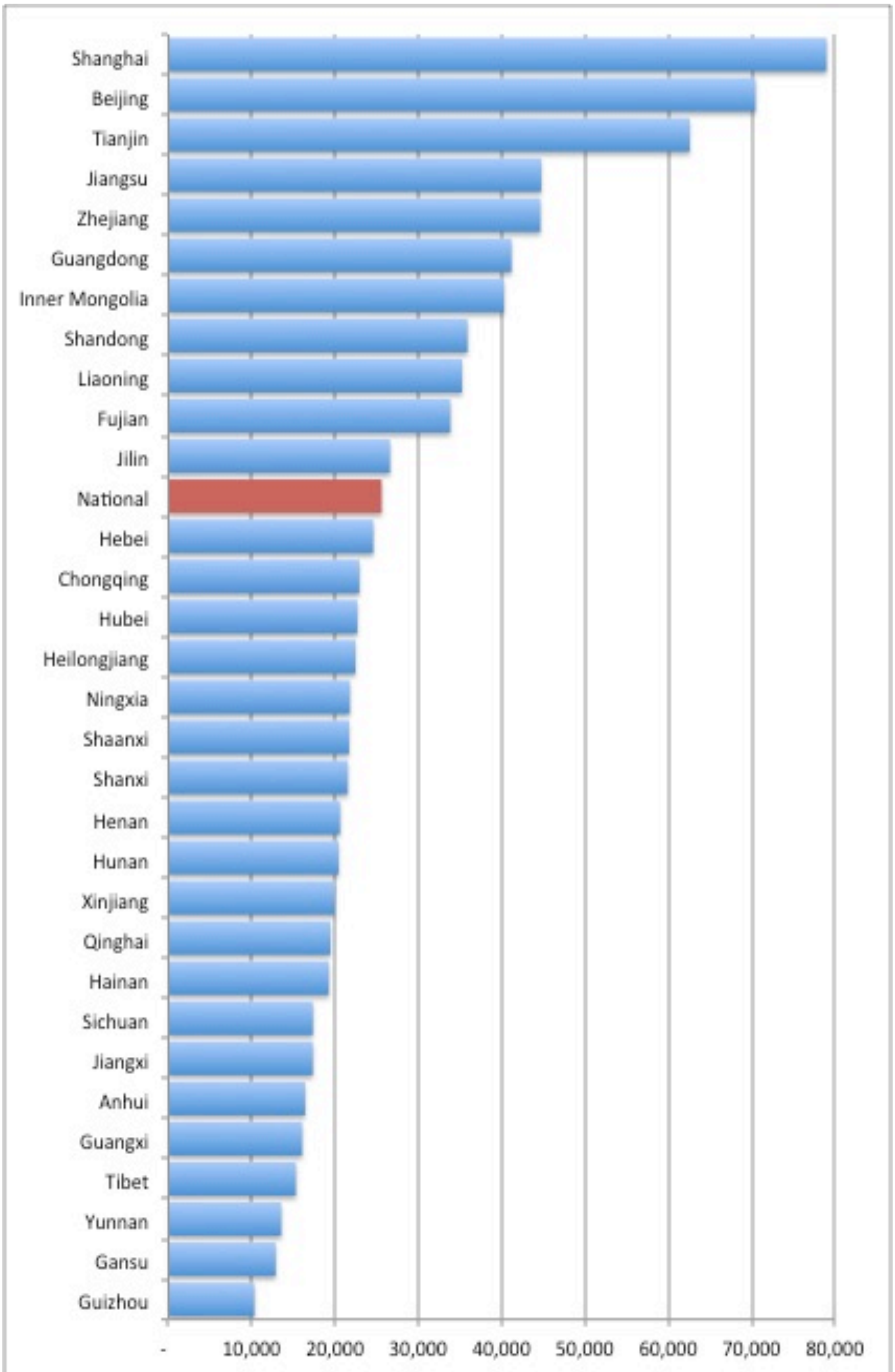
We have thus confirmed the first alternative hypothesis: structural change continued to occur in China post-2002. The change was scarcely exhibited at the three-industry level of economic aggregation because finer levels of sectoral aggregation exhibited counterbalancing changes.

While this is sufficient to establish the proposition that structural transformation has occurred, the possibility of the second alternative hypothesis, that China's provinces are undergoing counter-balancing structural changes, should still be considered.

Alternative hypothesis 2: Structural change is regionally off-setting

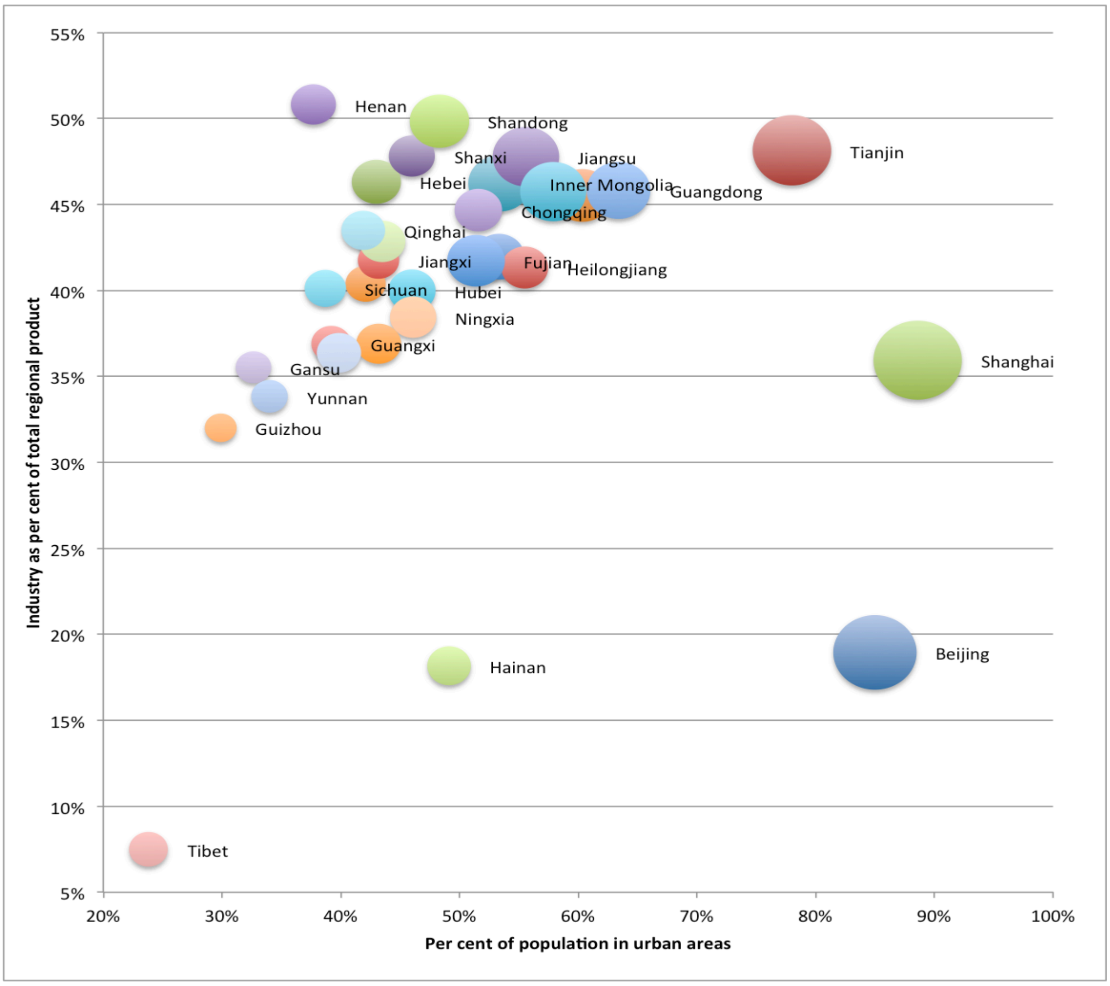
The overwhelming feature of China is its size. Size dominates almost every analysis of China. But China is composed of 23 provinces, five autonomous regions, four municipalities and two special autonomous regions (SARs) that can be studied separately. The two SARs (Hong Kong and Macau) are set aside in this study because they are substantially different cases to the rest of China. However it is plausible that the remaining 32 administrative divisions (hereafter referred to collectively as 'provinces' for convenience) exhibit significant variation in their economic growth patterns. To see the plausibility of this hypothesis, one only need consider the variation in GDP per capita across the provinces. Figure 3.8 shows the considerable divergence in Gross Regional Product (GRP) per person across China's provinces. While national GDP per capita is RMB 25,575 per capita, GRP ranges from three times that much in Shanghai to less than half that much in Guizhou.

Figure 3.8: Gross Regional Product (2009) (RMB per person)



Source: NBSC (2011, pp. 2-15)

Figure 3.9: GRP, urbanisation and industry share of GRP (2009)



Note: The area of each bubble is proportional to GDP per capita in 2008
Source: NBSC (2011, pp. 2-15 and 3-4)

The diversity of China's provinces is further illustrated in Figure 3.9. The horizontal axis shows the percentage of population living in urban areas. The municipalities of Shanghai, Beijing and Tianjin stand apart from the rest of the country, with urbanisation rates of 89, 85 and 78 per cent, respectively, while the majority of China's provinces have urbanisation rates between 40 and 60 per cent with several provinces below 30 per cent. Similarly, the three richer municipalities are also amongst the provinces that have witnessed the largest deindustrialisation, in terms of the fall in share of GRP from industry measured against the peak level for that province (Beijing, with the largest deindustrialisation, witnessed industry fall from 65 per cent of GRP in 1978 to 19 per cent in 2009) (NBSC, 2009).

Comparing sectoral shares of gross regional product (GRP) with sectoral shares of GDP over the period 2000 to 2007 reveals whether or not the apparent stay on structural transformation evident in Figure 3.6 was due to offsetting structural change across the different provinces. It appears that structural change at the three-sectoral level is more apparent when looking at provinces separately, rather than the country as a whole. Table 3.3 shows that while the secondary sector's share of China's GDP rose from 39 per cent in 2002 to 42 per cent in 2007 its share of Beijing's GRP fell 2 per cent over the same period while its share of Jiangxi's GRP rose 13 per cent. Similarly, the service sector's share of China's GDP remained between 41 and 42 per cent throughout the period from 2002 to 2007, but its share of Xinjiang's GRP fell by 8 per cent over the same period while its share of Guizhou's GRP rose 6 per cent. The change in sectoral shares of GRP for each province and for China as a whole over the period 2002 to 2007 are reported in Table 3.3.

Table 3.3: Change in sector share of GRP from 2002 to 2007

	Primary	Secondary	Industry	Construction	Tertiary
National	-3.0	2.5	2.2	0.4	0.4
Shanghai	-0.6	0.9	2.2	-1.3	-0.4
Beijing	-0.9	-2.0	-1.3	-0.7	2.9
Tianjin	-1.7	7.6	7.7	-0.1	-5.8
Jiangsu	-3.4	2.7	4.6	-1.8	0.7
Zhejiang	-3.3	2.9	2.9	-0.0	0.4
Guangdong	-2.1	5.8	6.9	-1.1	-3.7
Inner Mongolia	**-5.7**	**9.7**	**9.6**	**0.1**	**-3.9**
Shandong	-3.9	6.4	7.7	-1.2	-2.6
Liaoning	-0.5	5.3	4.4	0.8	-4.8
Fujian	-4.0	3.6	3.0	0.6	0.5
Jilin	-4.2	6.7	6.9	-0.2	-2.5
Hebei	-2.7	4.4	4.9	-0.5	-1.7
Chongqing	**-3.8**	**3.7**	**3.6**	**0.1**	**0.0**
Hubei	-1.9	2.4	2.4	-0.0	-0.5
Heilongjiang	**-1.1**	**3.7**	**3.9**	-0.2	**-2.6**
Ningxia	-3.0	10.2	10.8	-0.6	-7.2
Shaanxi	-1.7	9.5	10.2	-0.7	-7.8
Shanxi	-1.7	9.5	10.2	-0.7	-7.8
Henan	-6.6	9.3	10.0	-0.7	-2.7
Xinjiang	-1.1	9.4	11.1	-1.8	-8.3
Qinghai	**-2.1**	**7.5**	**14.8**	**-7.3**	**-5.4**
Hainan	-5.2	6.6			-1.5
Sichuan	-2.8	7.5	8.2	-0.7	-4.7
Jiangxi	-5.4	13.2	12.7	0.5	-7.8
Anhui	-6.0	6.7	**4.0**	1.0	-0.7
Hunan	-2.7	5.9	6.2	-0.3	-3.1
Guangxi	-3.0	7.2	7.4	-0.2	-4.2
Tibet	-8.5	8.6	0.9	7.7	-0.1
Yunnan	-2.4	2.8			-0.5
Gansu	-3.2	6.6	7.7	-1.1	-3.4
Guizhou	-7.4	1.8	**6.4**	-3.7	5.6

Note: data points in bold indicate no data available for 2007. In that case data for 2006 was used.
Source: NBSC Provincial Yearbooks, various

The second alternative hypothesis, that China's provinces are undergoing counter-balancing structural changes, also appears to be correct[1], supporting Proposition 4, that China has experienced a fundamental transformation in production over the past 30 years, despite the apparent evidence that the process of transformation stalled in 2002 presented in Figure 3.6.

[1] Note, the hypotheses are not alternative to each other, but are alternative to the appearance of 'no structural change' given by Figure 3.6. There is no contradiction with both 'alternative' hypotheses being true.

The continuance of China's production transformation

It has now been demonstrated that China's production structure has continued undergoing a substantial transformation since 2001 despite the evidence presented in Figure 3.5 and Figure 3.6. At the national level, the structural change of production has continued to occur, albeit at a finer level of sectoral detail than the three principle sectors. However, at the provincial level continual changes to the relative importance of the three principle sectors have continued at least up until 2007. The next section links China's continued transformation of production directly to aspects of change and non-linearity in the energy use – economic growth relationship.

Impact of China's production transformation on energy

Table 3.2 gave an illustrative example of how structural change can impact the energy-economy relationship when sectors have unequal energy intensities. As can be seen from Table 3.2, changes in energy use can be traced back to changes in energy intensity, structural change, and changes in total output. Chapter 2 argued that the preferred methodology for isolating the changes in energy intensity, structure and magnitude of production in China was index decomposition analysis, IDA, and that the best index form to use was the multiplicative version of the logarithmic mean Divisia index.

The first step to implement LMDI is to define a general identity:

$$V^t = \sum_i V_i^t = \sum_i x_{1,i}^t, x_{2,i}^t x_{3,i}^t \tag{3.3}$$

according to the following definitions:

V^t is total non-residential primary energy consumption in year t

V_i^t is total energy consumption of sector i in year t

$x_{1,i}^t$ is energy intensity of sector i in year t

$x_{2,i}^t$ is sector i's value added share of total GDP in year t

$x_{3,i}^t$ is GDP in year t

Diverging from the standardised terminology, the general identity can expressed more intuitively as an *energy identity*:

$$E^t = \sum_i E_i^t = \sum_i \frac{E_i^t}{Y_i^t} \cdot \frac{Y_i^t}{Y^t} \cdot Y^t \qquad (3.4)$$

Where E is non-residential primary energy consumption; t identifies the year, i identifies the sector, and Y represents output (value added). The right hand side represents the energy intensity of each sector; the share of each sector in total output; and the scale of total output. The energy identity formulation makes clear that the issue is one of sustainable development. Accepting that higher values of Y^t are desirable, but higher values of E^t are not, the challenge is to achieve lower values of $\sum_i \frac{E_i^t}{Y_i^t} \cdot \frac{Y_i^t}{Y^t}$.

Following the multiplicative LMDI approach, the change in energy consumption between years is decomposed according to the following general decomposition equation:

$$D_{tot} = \frac{V^T}{V^0} = D_{x_1} D_{x_2} D_{x_3} \qquad (3.5)$$

given the following definitions:

- D_{tot} is the total effect: the ratio of total non-residential primary energy consumption in year T to year 0
- V^T is total non-residential primary energy consumption in year T
- V^0 is total non-residential primary energy consumption in year 0
- D_{x_1} is the intensity effect
- D_{x_2} is the structural effect
- D_{x_3} is the quantity effect

Each of the decomposition factors are estimated according to the following equation:

$$D_{x_k} = \exp\left(\sum_i \frac{\left(V_i^T - V_i^0\right) \Big/ \left(\ln V_i^T - \ln V_i^0\right)}{\left(V^T - V^0\right) \Big/ \left(\ln V^T - \ln V^0\right)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0} \right) \right) \tag{3.6}$$

One of the great advantages of the IDA approach is the relatively simple data requirement. The above decomposition requires two sets of data: primary energy consumption and value-added of industry. The energy statistical yearbook (NBSC, 2009) publishes national primary energy consumption at the sectoral level for 44 sectors for the years 1995 to 2008. Data for sectoral value-added must be collected from a wider variety of sources. Unfortunately China stopped reporting sectoral level value-added data from 2008 onward, so our decomposition analysis is restricted to the years 1995 to 2007. Most of the value-added data come from China Statistical Yearbooks and China Industry Economy Statistical Yearbooks. Appendix C tabulates the data sources used for each component of the sectoral value added table. The full table is presented in Appendix D.

IDA Results

Table 3.4 presents the decomposition results for the changes in primary energy consumption by producers. All the results are presented as ratios. The intensity effect estimates the change in total primary energy consumption by producers due to changes in the amount of energy consumed per unit of value-added by a given sector, summed across all sectors. The structural effect estimates the change in total primary energy consumption by producers due to changes in the share of GDP accounted for by the value-added of different sectors. The quantity effect estimates the change in total primary energy consumption by producers due to change in total GDP. The total effect estimates the change in total primary energy consumption by producers. The error is the difference between the total effect and the actual, observed change, largely due as explained in Chapter 2 by Type I errors.

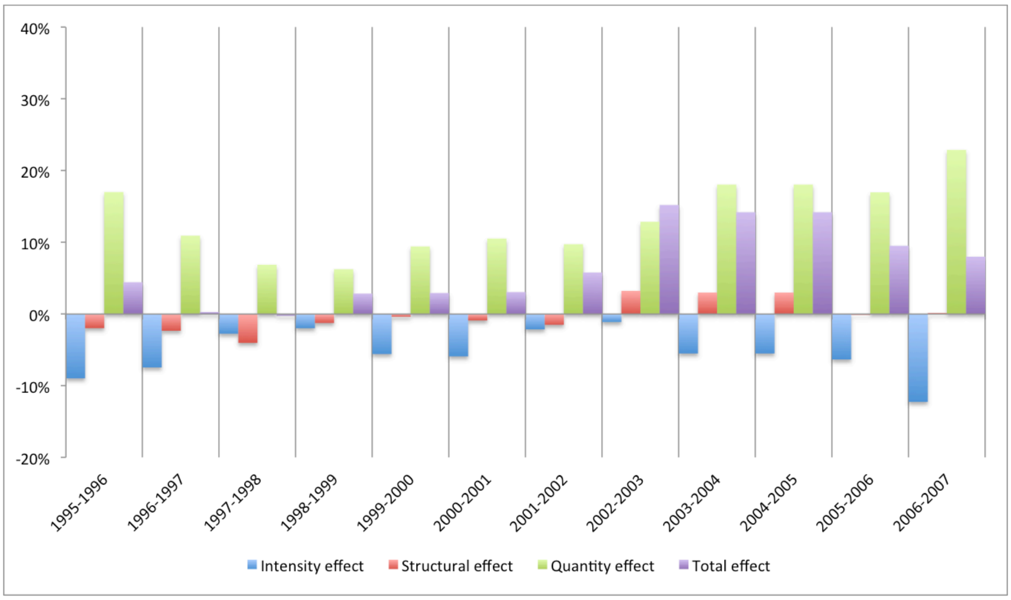
In all cases, a value of 1 indicates no change from one year to the next. A value below one indicates a reduction and a value above one indicates an increase. For instance, the intensity effect in 1995-1996 is 0.91. This tells us that if the total quantity and structure of GDP did not change from 1995 to 1996, but the energy intensity of production was equal to the observed change, then total primary energy consumption in 1996 would be 0.91 times the level of 1995. We can interpret this as estimating that changes in energy intensity for 1995-1996 resulted in a 9 per cent reduction in energy consumption.

Table 3.4 reveals much about the nature and determinants of the relationship between energy use and production in China over the past 12 years. Each value represents the ratio of energy use in the later period to the former period. One advantage of the LMDI approach is that results for several consecutive years can be calculated simply by multiplying the results for each of the years in the string. For instance, the intensity effect for 1995-2007 in Table 3.4 is calculated by multiplying the intensity effect of each year from 1995 to 2007. The top section of the table presents year-on-year results, while the bottom section presents results for longer groups of years.

Figure 3.10 and Figure 3.11 provide alternative graphical representations of the results presented in Table 3.4. Figure 3.10 shows the annual results, adjusted by simply subtracting 1 from each result and expressing the values as percentages. The effect is that a value of 1 in Table 3.4, which represents no change, is expressed in Figure 3.10 as 0 per cent, while a value less than 1 in Table 3.4 is expressed as a negative percentage change, and a value greater 1 in Table 3.4 is expressed as a positive percentage change. Figure 3.11 presents the cumulative impact of each effect.

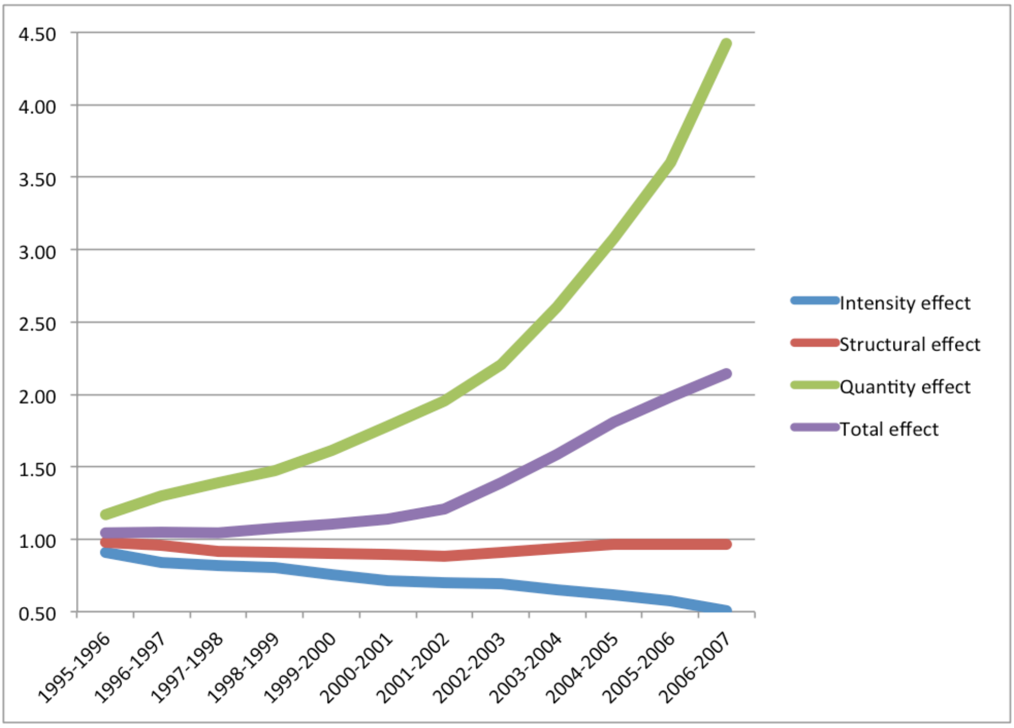
Figure 3.11 provides the most striking results. The overwhelming impact of the quantity effect is instantly observable. In an economy growing as quickly as China's, this is to be expected. It is also clear that both the structural effect and intensity effect have acted to offset the quantity effect, however the intensity effect has had far more impact than the structural effect.

Figure 3.10: IDA results (1995-2007) – annual



Note: results for 2003-2005 have been split evenly
Source: Author's calculations

Figure 3.11: IDA results (1995-2007) – cumulative



Note: results for 2003-2005 have been split evenly
Source: Author's calculations

Table 3.4: IDA results (1995-2007)

	Intensity effect	Structural effect	Quantity effect	**Total**	*Error*
1995-1996	0.91	0.98	1.17	**1.04**	*0.000*
1996-1997	0.93	0.98	1.11	**1.00**	*-0.003*
1997-1998	0.97	0.96	1.07	**1.00**	*-0.004*
1998-1999	0.98	0.99	1.06	**1.03**	*-0.004*
1999-2000	0.94	1.00	1.09	**1.03**	*-0.007*
2000-2001	0.94	0.99	1.11	**1.03**	*-0.003*
2001-2002	0.98	0.99	1.10	**1.06**	*-0.002*
2002-2003	0.99	1.03	1.13	**1.15**	*-0.001*
2003-2005	0.89	1.06	1.36	**1.28**	*-0.001*
2005-2006	0.94	1.00	1.17	**1.10**	*-0.001*
2006-2007	0.88	1.00	1.23	**1.08**	*-0.001*
1995-2007	**0.51**	**0.97**	**4.32**	**2.11**	
1995-2002	0.70	0.88	1.96	**1.21**	
2002-2007	0.72	1.10	2.21	**1.75**	
2002-2005	0.88	1.09	1.54	**1.48**	
2005-2007	0.82	1.00	1.44	**1.18**	

Note: IVA data for 2004 is not available
Source: Author's calculations

Table 3.4 presents the results more precisely. The results for the period 1995 to 2007 show that total primary energy consumption by producers has more than doubled, with energy consumption in 2007 being 2.11 times the level in 1995. If output structure and energy intensity had remained constant over the whole period, the growth in GDP would have resulted in 2007 energy consumption being 4.32 times the 1995 level. Only a very small part of the restraint on energy consumption was due to shifts toward less energy-intensive sectors, with the structural effect leading to a 3 per cent saving over the whole period. The overwhelming constraint on growth of energy use by producers was due to changes in the energy intensity of production, which resulted in a 49 per cent decrease in energy use.

It has been demonstrated that China's economy underwent a major transformation since the beginning of the reform era and that this transformation did not cease after 2001. Why, then, did structural change have such a small impact on the energy use by producers? A partial answer to this question can be gleaned from Figure 3.11. The cumulative impact of the structural effect from 1995 was increasing reductions in energy consumption, but in 2002 this changed, with the cumulative effect of structural changes causing an increase in energy use. Throughout the period 1995 to 2002 structural changes resulted in modest but real declines in energy consumption. While the structural effect each year contributed only modest reductions in energy use, over the full seven years, an estimated 12 per cent reduction in energy use in production can be attributed to structural effects. Then in the year from 2002 to 2003, the direction of structural transformation with respect to energy use changed such that producers' energy consumption grew by 3 per cent over the year. Unfortunately China has not published value-added data for 2004 so changes in the period 2003-2004 cannot be isolated from those in the period 2004-2005: the change from 2003-2005 must be considered together. The structural effect over this two-year period continues in the same direction as 2002-2003, resulting in a 6 per cent increase in energy use over the two years.

Taken together, the period 2002 to 2005 saw structural changes resulting in a 9 per cent increase in energy use by producers. The two subsequent years for which data are available ended this trend, but did not reverse it, with close to zero change in energy use by producers attributable to the structural effect for the years 2005-2007. Table 3.4 shows that the structural effect from 2002-2007 resulted in a 10 per cent increase in energy use by producers, almost completely reversing the 12 per cent decrease attributed to structural change in the earlier period from 1995-2002.

The annual effects reveal a second change in the period 2002-2007 compared with the earlier period 1995-2002. From 2002, the magnitude of the quantity effect was considerably greater. This is clearly observable from the change in the gradient of the quantity effect in Figure 3.11. Table 3.4 reveals the significance of this change: the quantity effect over the seven years from 1995 to 2002 was 1.96, while the quantity effect over the five years from 2002 to 2007 was 2.21. Counterfactually, in the absence of any change in the economic structure or energy intensity, the change in output would have less than doubled energy use in the seven years prior to 2002, but more than doubled energy use in the five years following 2002. These two observations provide the beginning of an explanation for China's energy boom.

Figure 3.10 also reveals that improvements in energy intensity were not constant over the 12-year period. There were two periods of very modest reductions in energy intensity: 1997-1999 and 2001-2003. Energy intensity fell much more rapidly in each of the other seven years. The years 2003 to 2007 were amongst the years in which energy-intensity fell most rapidly, with the single greatest improvement occurring between the years 2006 and 2007.

These results raise their own questions. Why was there a boom in output beginning in 2002? Why was the boom most pronounced in relatively energy-intensive sectors? Why did the shift toward energy-intensive sectors cease by 2005 while the general boom continued? Why did reductions in energy intensity stall in 2001 and then improve so dramatically after 2003?

Discussion

Chapter 1 raised three fundamental forces that may be driving China's economic transformation: central planning, China's entry into the WTO, and China's transition through the Lewisian turning point.

The timing of China's production boom and the change in direction of structural change point to the impact of entry into the WTO as a likely contender for explaining recent trends; however, exactly what real changes resulted from China's entry to the WTO is unclear.

One explanation is a major change in policy orientation following China's entry to the WTO when Chinese policy makers embraced the idea that the market would solve any and all problems (Zhou, Levine, & Price, 2010). In 1979 Deng Xiaoping proposed to quadruple GDP in 20 years, while energy use would only double. In response, China implemented an entire energy efficiency apparatus including:

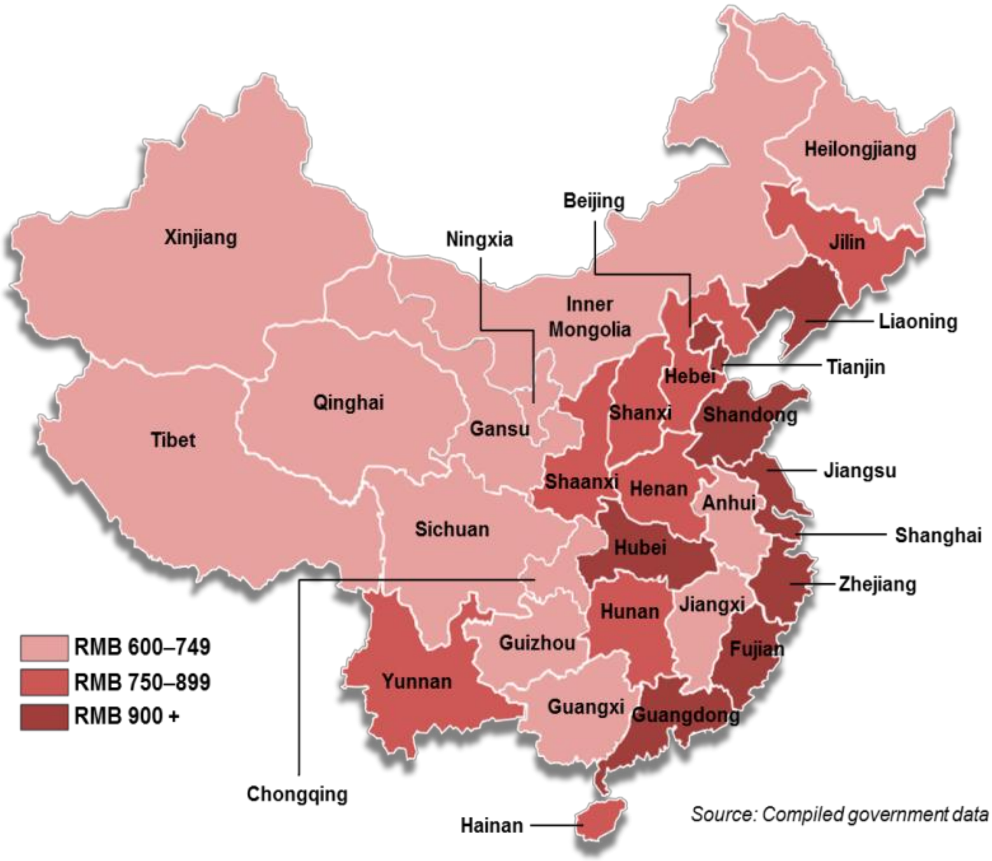
> quotas on factories; monitoring systems; promotion of energy efficient technology at the factory level; closure of outmoded factories; financial incentives including a national program to invest in efficiency; establishing the China Energy Conservation Investment Corporation with branches throughout China to evaluate projects; establishment of 70 energy conservation

service centres throughout the country to train people as energy conservation experts for their city or province (Levine, 2009),

After joining the WTO, that energy efficiency apparatus, including detailed energy data collection, was “almost entirely abandoned” in favour of market mechanisms (Levine, 2009) allowing the unchecked growth of steel and cement production and the expansion of other energy intensive sectors, especially related to the construction sector. The 11th Five-Year Plan marked the end of the short period of policy blindness toward energy efficiency, with its major focus on energy intensity discussed in Chapter 1. The ‘policy explanation’ is supported by the results in Table 3.4, which show a shift toward energy-intensive industries and a decline in energy-efficiency savings. But the results in Table 3.4 also show an increase in the quantity effect that is unlikely to be related to energy efficiency policies.

A second explanation is the result of China transitioning through the Lewisian turning point. If Garnaut, Song, Cai and others are correct that China is currently in the process of navigating the Lewisian turning point, can this explain the results observed in the previous section? According to Garnaut and Song (2006), the impact of the Lewisian turning point is to “generate structural change towards more capital-intensive and technologically sophisticated industrial structure at the relative expense of labour-intensive manufacturing and agriculture; and changes fundamentally the character of China’s interaction with the international economy” (Garnaut & Song, 2006). The changes described by Garnaut and Song effectively amount to a change in the factor endowments of an economy. Their conclusion follows the Heckscher-Ohlin theory, one result of which is that in the case of a relative increase in the endowment of one factor of production, output of products that employ that factor relatively intensively will expand, a result referred to as the Rybczynski effect (Feenstra, 2004). The results presented in Table 3.3 show that China’s provinces are at different stages of structural transformation, while Figure 3.12 shows the variation in minimum wages across China’s provinces that could be driving the Lewisian effects.

Figure 3.12: China's minimum wage by region



Source: APCO Worldwide (2010)

Identifying the impact of any Lewisian turning point effect, and isolating it from factor endowment changes due to other causes requires analysis beyond the scope of the present study. China's labour market is notorious for the *hukou* system, and as Huang and Wang (2010) explain, China is yet to liberalise other factor markets. Golley and Meng (2011) show that the data are far from conclusive in support of the argument that China is currently navigating the Lewisian turning point. They argue that the evidence presented to support such arguments is misleading and that China's institutional and policy barriers to a free labour market (not the exhaustion of surplus labour) are responsible for rising wages in the coastal provinces. A further point of complexity arises out of what Garnaut has come to recognise as the 'turning period' rather than the 'turning point' (Garnaut, 2010): the impacts of the turning period are distributed over a longer period of time, making the results more difficult to observe. Regardless of whether the Lewsian model is an accurate depiction of China's current situation, it is still likely that changes in the factor markets in China (especially rising wages in coastal provinces) have contributed significantly to the results presented in this chapter.

Conclusion

Analysing recent aspects of complexity and dynamism in the energy use – economic growth relationship in China necessarily begins with inspecting the relationship between energy use and economic production. The importance of the production side and the link between output and energy use have been established in this chapter. To demonstrate how the relationship between energy use and economic growth changes over time the chapter first linked energy use to production, then demonstrated how the structure of production in any economy transforms over time. The recent transformation of production in China was considered in some detail before analysing the impact of aspects of China's recent transformation in production on energy use.

The results of the analysis show firstly that the acceleration of production has dominated other aspects of the energy use – economic growth relationship. But it also linked the period from 2002 to 2005, in which China's energy intensity grew for the first time since 1980, to the structural shift toward more energy-intensive sectors and a temporary decline in the rate of efficiency gains. Since 2005 China has increased the rate of efficiency gains and eliminated the structural shift toward energy-intensive sectors. Explaining why these changes occurred is a difficult task made even more difficult by insufficient data and multiple, apparently reinforcing events occurring roughly simultaneously. China's entry to the WTO not only sparked a surge in production as China's exports increased, but also a shift in policy orientation, an adjustment in factor prices and a change in consumption behaviour.

While this chapter has emphasised the link between energy and production, production does not occur in a vacuum: it is a response to demand. The next chapters consider how changes to various aspects of demand since 2002 have impacted China's energy use, beginning with Chapter 4, which focuses on household consumption and government services.

Chapter 4. Energy and consumption

Consumption is the sole end and purpose of all production
Adam Smith (1776)

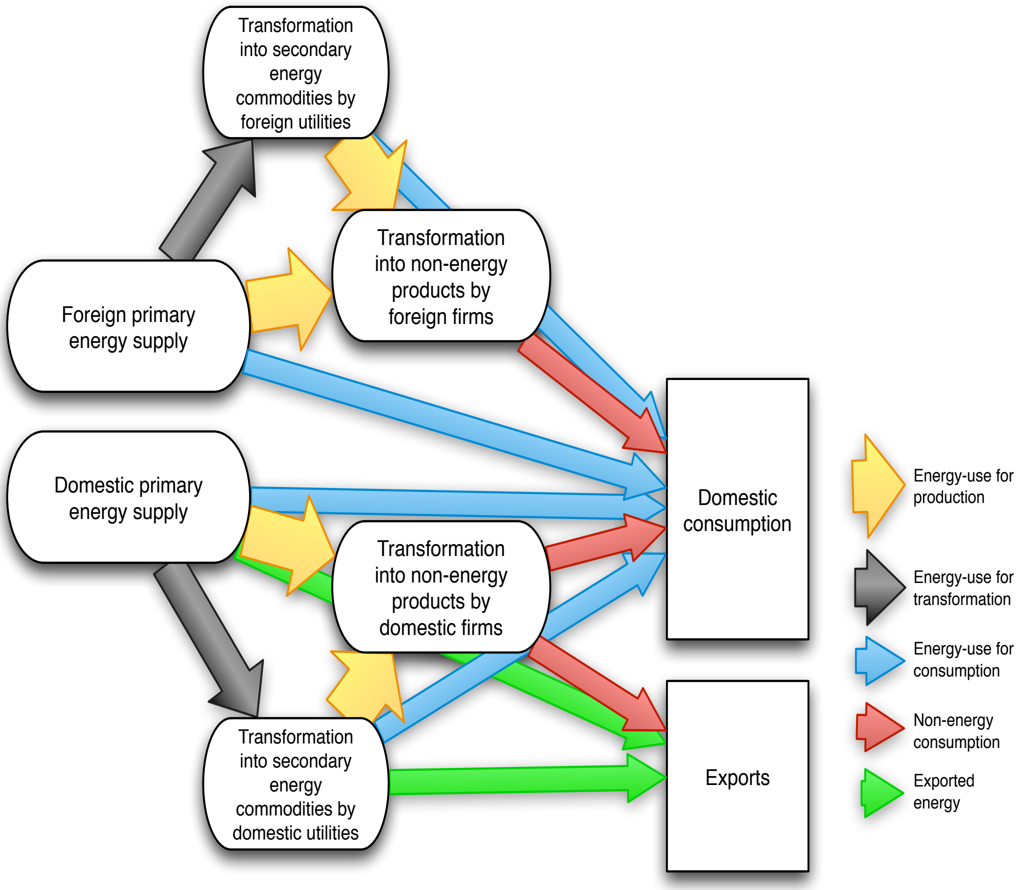
Smith intended the above maxim, which comes from his discussion on the mercantile system, as a self-evident truth implying an obvious preference against government policies that attend to the interests of producers while sacrificing the interests of consumers. It serves also to focus the discussion on the relationship between energy consumption and economic growth. Chapter 3 analysed changes in the relationship between energy use and economic production. It revealed that key drivers of China's recent energy boom were a structural shift toward production of energy intensive sectors beginning in 2002, a decline in the rate of improvement in energy efficiency, and dramatic growth in the scale of production. But Smith's words make it clear that production patterns are not fundamental drivers of the energy use. Druckman and Jackson (2009) make a similar point in relation to GHG emissions: "the responsibility for carbon dioxide (CO2) emissions from economic activity lies with people's attempts to satisfy certain functional needs and desires". Chapter 1 demonstrated that in an open economy the energy used in production need not be equivalent to the energy embodied in consumption. The central objective of this chapter is to discover to what extent recent changes in China's consumption are responsible for the rapid growth in energy use in China since 2002.

The relationship of energy use to consumption (and other categories of final expenditure) is conceptually different to the relationship of energy use to production. This chapter therefore asks what is the best way to characterise energy use in consumption. Establishing a relationship between energy use and consumption raises the question of how that relationship evolves as the economy develops. Addressing that question draws on the experiences of developed countries at earlier stages of economic development. Comparing these observations with China's contemporary experience not only helps answer the question of how the relationship between energy use and consumption evolves through economic development, but also provides context to when asking whether China's experience has been peculiar or familiar? To quantify the impact of changing consumption patterns on energy use, input-output structural decomposition analysis (IO-SDA) techniques introduced in Chapter 2 are employed. In this chapter, the IO-SDA is applied separately to three categories of final expenditure: rural household consumption, urban household consumption and provision of government services. The chapter concludes by discussing some implications for China's energy future, an issue also taken up in the concluding chapter.

Energy-use in consumption

What is meant by energy-use in consumption? Chapter 2 explained two broad methods of conceptualising energy use: direct and embodied energy use. Energy use in consumption is best conceptualised as embodied energy use, explained as "the amount of energy required to deliver a product to final demand" (Miller & Blair, 2009). This includes the direct energy use of non-Chinese producers whose products are consumed by Chinese consumers, and excludes the direct energy use of Chinese producers whose products are consumed by non-Chinese consumers. Chapter 3 presented a basic, illustrative energy flow diagram to depict the concept of direct energy use. Here, that diagram is adjusted to depict embodied energy.

Figure 4.1: Adjusted energy flow diagram



In the adjusted energy flow diagram presented in Figure 4.1, total embodied energy use is represented by the sum of all arrows pointing to domestic consumption. It includes energy embodied in domestic consumption of raw fuels (the blue arrows connecting domestic and foreign primary energy supply to domestic consumption); energy embodied in domestic consumption of secondary fuels (the blue arrows connecting secondary energy commodities of domestic and foreign utilities to domestic consumption); and energy embodied in domestic consumption of non-energy products (the red arrows connecting transformation into non-energy products by domestic and foreign firms to domestic consumption). It does not include any of the arrows pointing to exports. The diagram in Figure 4.1 does not show energy flows from foreign primary energy, utilities or firms, to domestic utilities or firms even though such transactions occur. The exclusion is for visual simplicity only, and the diagram is not intended to be a complete representation of material flows in the economy, only to elucidate the concept of embodied energy.

Chapter 2 detailed the IO methodology required to calculate embodied energy and explained the reliance on IO tables. The final use part of the two most recent IO tables (2002 and 2007), adjusted to show primary fuel consumption in consistent physical units, shows clearly the importance of considering embodied energy when analysing the relationship between energy and consumption.

Table 4.1: Direct use of energy in China (2002)

(Petajoules)	Coal	Petroleum and natural gas	Coke	Electricity and Heat Power	Total
Intermediate use	24,835	8,869	916	1,048	**35,668**
Final use	3,286	1,986	462	172	**5,906**
Rural households	1,141	119	16	52	1,328
Urban households	550	858	76	85	1,569
Government services	0	0	0	0	0
Investment	0	0	0	0	0
Change in inventories	-231	42	-19	0	-208
Exports	1,826	968	389	35	3,218
Imports	236	4,184	14	8	4,442
Other	-1,231	71	136	0	-1,023
Total Output	**26,654**	**6,742**	**1,501**	**1,212**	**36,108**
Domestic Final Use	**1,460**	**1,018**	**73**	**137**	**2,688**

Total Output = Intermediate use + Final use – Imports + Other
Domestic Final Use = Final use – Exports
Source: Author's calculations

Table 4.2: Direct use of energy in China (2007)

(petajoules)	Coal	Petroleum and natural gas	Coke	Electricity and Heat Power	Total
Intermediate use	43,883	14,136	1,788	1,710	**61,517**
Final use	2,386	2,934	361	314	**5,995**
Rural households	1,389	344	9	107	1,850
Urban households	575	1,745	81	154	2,555
Government services	0	0	0	0	0
Investment	0	0	0	0	0
Change in inventories	-703	-190	-195	0	-1,088
Exports	1,125	1,035	465	52	2,678
Imports	1,097	8,786	50	15	9,949
Other	-1,505	0	-24	0	-1,528
Total Output	**43,668**	**8,284**	**2,075**	**2,009**	**56,035**
Domestic Final Use	**1,261**	**1,899**	**-104**	**261**	**3,317**

Total Output = Intermediate use + Final use – Imports + Other
Domestic Final Use = Final use – Exports
Source: Author's calculations

In 2002, China's total output of energy was around 36,000 PJ (Table 4.1). Total output is calculated as the sum of all energy used directly by producing sectors (intermediate use) and all energy used directly as a final use good (by households, government consumption, investment in fixed assets, change in inventories, and exported energy), minus imported energy and adjusted for survey errors (the 'other' column in China's IO tables). In 2007 total output was 56,035 PJ (Table 4.2) (around 1.5 times the 2002 level). Including net imports of energy, China's total energy supply in 2007 was 63,306 PJ (calculated from Table 4.2). Fully 97 per cent of that energy was used for the production of intermediate goods.

The analysis in Chapter 3 focused on the intermediate-use energy: the energy used by firms to produce other goods. That type of analysis when applied to the consumption side would typically conclude that households' total energy consumption was around 7 or 8 per cent of the national total energy consumption (total rural household consumption plus total urban household consumption divided by total energy output). This would be misleading since it ignores embodied energy implicit in the opening quotation in this chapter. Once all of the 'intermediate use' energy is attributed to some 'final consumer', the results are quite different.

These figures tell us that proper attribution of intermediate uses of energy is crucial to an accurate understanding of energy consumption.

Justification for consumption focus

As argued in Chapter 1, energy embodied in consumption and energy-use for production are not equivalent and are independently determined. Chapter 3 justified a focus on final energy use by producers, pointing to the dominance of producers as final users of energy, the fact that technological progress is a major determinant of the embodied energy intensity of goods and that such progress is a producer-side issue, and by pointing out that for the related area of GHG emissions, country emissions are counted with respect to their occurrence within that country's borders, not with respect to their use as a factor of production for a product consumed by that country's residents.

But these arguments are incomplete. Environmental concerns have spurred interest in questioning whether environmental improvements in rich countries constitute actual reductions in the global level of GHG emissions, or whether they are accounting illusions due to shifting GHG-emitting activity off-shore: simply "indicators of increased ability of consumers in wealthy nations to distance themselves from the environmental degradation associated with their consumption" (Rothman, 1998). The argument underpinning research on environmental issues can be similarly applied to energy analysis: changes in the energy intensity of production may be due to real changes in the way our production systems meet global demand, or they may be due to changes in where things are produced. If the objective is to understand the energy needs of Chinese people, attention should focus on the total energy embodied in Chinese consumption. Moreover, understanding the relationship between energy use and consumption is important and useful because consumption is relatively well understood theoretically. Consumption patterns at different stages of development have been well studied and aggregate consumption levels are the subject of extensive quantities of data. Realistic expectations of energy demand requires a clear understanding of the relationship between consumption and energy use.

Energy and consumption during economic transformation

Total energy use is ultimately a function of aggregate demand, and understanding energy flows in the Chinese economy must include this concept. Since patterns of consumption evolve as the economy develops, expectations of total energy embodied in China's consumption should take into consideration changes in the energy-intensity of consumption (that is, the total amount of energy required to produce one unit worth of final consumption goods) and changes in the structure of consumption itself. Finally, understanding consumption trends enables the development of nuanced expectations about total embodied energy demand. The logic of this argument can be presented as six propositions:

(1) Aggregate energy use is related to final consumption; (2) the relationship between energy use and final consumption is not constant over time; (3) the relationship between energy use and final consumption is dependent on consumption structure and production processes; (4) as economies develop, consumption structure changes; (5) China has experienced a fundamental consumption-side transformation over the past 30 years; and (6) China's economic transformation has substantially altered the relationship between aggregate energy use and final consumption.

The logic underpinning proposition (1), that aggregate energy use is related to final consumption, is directly related to Input-Output Analysis (IOA), which was explained thoroughly in Chapter 2. Proceeding on the assumption that the reader will accept the first proposition as having been demonstrated, consider the second: that the relationship between aggregate energy use and final consumption is not constant. Stating the proposition formally, if aggregate energy use is proportional to final consumption, through some calculable 'total energy intensity of demand' coefficient, that coefficient is variable. The absolute quantity of final consumption may change, and through the total energy intensity of consumption, aggregate energy demand will be affected, however, changes in the level of total consumption should not affect the energy intensity coefficient. In contrast, changes in the consumption bundle will affect the energy intensity coefficient.

In Chapter 1 an illustrative non-linear energy-GDP relationship was presented. This was done in the context of interpreting GDP as total domestic output, but the exact same illustration applies if GDP is taken to mean total expenditure, one component of which is consumption. Since different products have different embodied energy intensities, a rebalancing of the relative share of products in the overall consumption bundle will alter the total energy intensity of demand.

A second way in which that intensity can change is if production processes change. Even if final consumption remains constant in all respects, production processes may change over time. That change may be biased toward more or less use of energy. These two factors form the standard ‘structural’ and ‘technological’ effects that are the focus of many decomposition analyses. They are both focused on changes to the total energy intensity of demand, asserted to be variable by the second proposition. Together with the ‘quantity’ effect, they are the main categories for decomposing change in total embodied energy consumption.

The demonstration in Chapter 1 that total energy intensity of demand is variable simultaneously establishes the third proposition: that the relationship between energy use and final consumption is dependent upon both consumption structure and production processes.

The demonstration of the first three propositions has largely relied on referring to arguments established earlier in this thesis. Demonstrating the next three propositions requires new discussion and analysis. Subsequent sections are devoted to this. Demonstrating the fourth proposition, that consumption structure changes as the economy develops, largely relies on discussion of the theoretical development literature. The fifth proposition, that China’s consumption patterns have changed dramatically over recent decades, is empirical and will be demonstrated with reference to the most recently available Chinese consumption data. The final proposition, that changes in China’s consumption structure have impacted total embodied energy consumption in China, is analytical. This will be demonstrated with reference to the existing SDA literature and through new application of SDA techniques. Having demonstrated the continuing influence of changes in consumption patterns over energy demand the chapter will end with a discussion of major influences on China's recent and near-future consumption patterns.

Economic development and patterns of consumption

There is no theoretical link between government consumption patterns and stages of economic development. However, household consumption patterns are strongly linked to development levels and growth rates. The argument that consumption structure is dependent upon economic development therefore focuses on the relationship of economic development to household consumption, both rural and urban.

The relationship between a consumer's expenditure on some particular good and that consumer's income is known as an Engel Function: $x\left(\bar{p},w\right)$, where x is demand for the good, $\bar{p}$ indicates constant prices, and w is the consumer's wage. The derivative with respect to wages for a particular good (l) gives the wealth expansion path, expressed: $\partial x_l\left(p,w\right)/\partial w$ (Mas-Colell, Whinston, & Green, 1995). Only if the wealth expansion path of all goods are equal can an increase in household consumption have no impact on relative consumption shares. Even assuming very few product categories, such as food, other goods, and services, it is implausible to expect the income expansion path of each product to be equal. If the consumption basket is divided into larger numbers of discrete products the variety of income expansion paths should be expected to grow.

In 1857 Ernst Engel published the first formal observation that consumption patterns depend on levels of wealth (Houthakker, 1957). In his study of production and consumption in Saxony, "he formulated an empirical law concerning the relation between income and expenditure on food… [stating] that the proportion of income spent on food declines as income rises" (Houthakker, 1957). In the post-World War II era, when many rich countries were establishing development plans, there was interest in the question of whether consumption patterns followed predictable trends as countries moved from conditions of poverty to conditions of wealth. Houthakker (1957) contributed to that effort, examining household survey data across many countries to analyse the relationship between expenditure on particular groups of items and total expenditure (controlling for household size). He considered four groups of items: food, clothing, housing and ‘others’. He found that although considerable variation existed across countries, the coefficient for food was uniformly less than one, confirming Engel’s law; the coefficient for clothing was almost uniformly between one and 1.5, classifying clothing as a ‘moderate luxury’; the coefficient for housing was mostly less than one but the divergence across countries and regions was too great to make any stronger conclusion than the observation that housing is a necessity, confirming Schwabe’s law; and the coefficient for the ‘miscellaneous’ items were almost uniformly greater than 1.4, implying that goods other than the three main categories considered are of greater luxury value.

Maslow formalised the evolution of individual human preferences in what has come to be known as “Maslow’s hierarchy of needs” in two papers on motivation theory (1943 and 1943). He described people as

> A perpetually wanting animal; the appearance of a need rests on prior situations, on other prepotent needs; needs or desires must be arranged in hierarchies of prepotency. (Maslow, 1943, p. 91)

In aggregate economic terms, this translates into consumption profiles of countries with predominantly very poor people being dominated by consumption of necessities; as the number of people able to meet necessity consumption increases, the consumption profile shifts toward basic goods, then toward luxuries, and positional goods. It can be reasoned that the consumption profile is linked more directly to the share of population at certain income levels, rather than the national GDP per capita.

It would be too strong to conclude that an ordered list of consumption preferences, applying across people, countries and time, could ever be constructed. As mentioned, Houthakker’s findings included considerable variation across countries, and even regions of the same country. Consumption possibilities are not constant over time, so that although necessity goods are relatively stable, luxury and positional goods are subject to variable perceptions and valuation. While a car may be a luxury good desired by Beijing’s present-day middle class, by the time Guizhou has a substantial middle class the personal car may have lost its status in favour of an urban apartment in the vicinity of a public transport hub. Already

China’s *nouveau riche* exhibit preferences for positional goods such as designer label clothing and accessories to lifestyle and experiential goods, such as holidays.

There is substantial evidence that nation’s consumption profile, the aggregate result of individual consumption preferences, exhibits some broadly predictable variations as the economy develops, though precise predictions or ordering is not easy. This context establishes that the recent changes in China’s consumption profile, which will be discussed empirically in the next section, are not unusual – rather, they conform to the general experience of other, already developed countries.

China’s consumption transformation

The fifth proposition of the argument in this chapter claims that China has experienced a transformation of consumption patterns over the last 30 years. This section investigates that claim empirically, and separately for rural and urban households and government consumption. Figure 4.2 shows the level of GDP by expenditure for each of the main domestic consumer categories (fixed capital formation, households, government and changes in inventory). Figure 4.3 shows the same data calculated as relative shares of consumption by the different categories in the consumption identity. The most important feature to be observed in Figure 4.3 is the fall in the relative importance of household consumption, and the rise in the relative importance of investment (fixed capital formation).

In 1978, at the beginning of the reform period, household consumption accounted for 49 per cent of total consumption, with rural households accounting for 30 per cent and urban households accounting for 18 per cent. At that time, investment accounted for just 30 per cent of consumption. In the first years after 1978, rural households increased their share of total consumption slightly, peaking at 33 per cent, mostly offset by changes in inventories. Household consumption peaked in relative importance in 1981-1982 at 53 per cent. Over the next two decades, to 2000, household consumption fell moderately in relative terms to 48 per cent of total consumption despite the constant rise in the elative importance of urban households, which grew from just 18 per cent to 32 per cent of total consumption over the two decades. The modest decline in the relative importance of household consumption was offset by the modest growth in the relative importance of investment, which grew from 30 per cent in 1978 to 35 per cent by 2000.

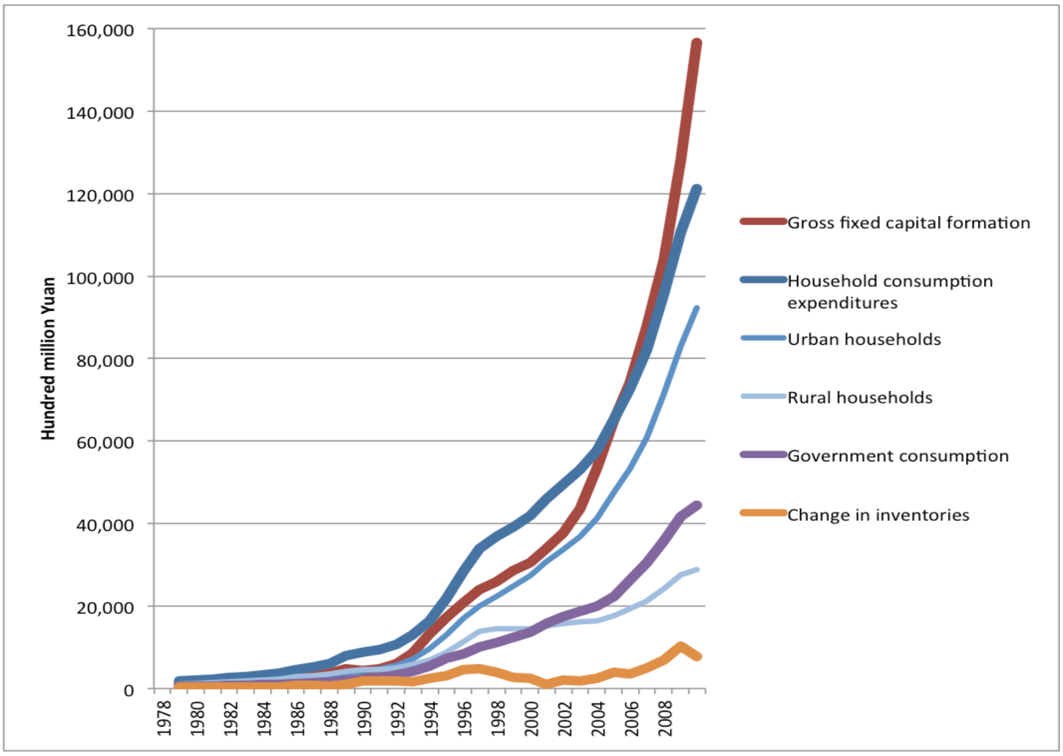
Since 2000, the relative importance of household consumption and investment has changed dramatically, with the share of total consumption due to investment increasing by 12 percentage points over 9 years, to a peak of 47 per cent, while household consumption fell 11 percentage points to a low of 37 per cent. The decline in the relative importance of household consumption was evident in both rural and urban households: while rural households occupied a diminishing share of total consumption since 1982, urban households had been increasing almost constantly until 2001, peaking at 32 per cent of total consumption and falling to 28 per cent by 2009.

According to Perkins (2010), the falling share of household consumption in GDP is consistent with the rapid growth experience of other Asian countries, including Japan, Korea and Taiwan. However in China's case household consumption has fallen from a level already around 15 per cent lower than was experienced by those countries. In Japan, Korea and Taiwan, the fall levelled off when GDP per capita reached around $10,000 in purchasing power parity terms. Whether this pattern repeats in China is yet to be seen.

What has driven the dramatic transformation of China's consumption profile over the last decade? Naturally, the level of expenditure in all categories (except changes in inventories) has increased. It is the relative rates of growth that have resulted in the changes to the overall expenditure profile. While urban households have driven a boom in household consumption, especially since 2003, 2002 began a much larger boom in fixed capital formation in China. Between 2000 and 2009, China's annual growth in fixed capital formation has averaged 18 per cent in nominal terms: a doubling time of less than four years. At this growth rate, China's fixed asset investment should have surpassed eight times the 2000 level around the middle of 2011.

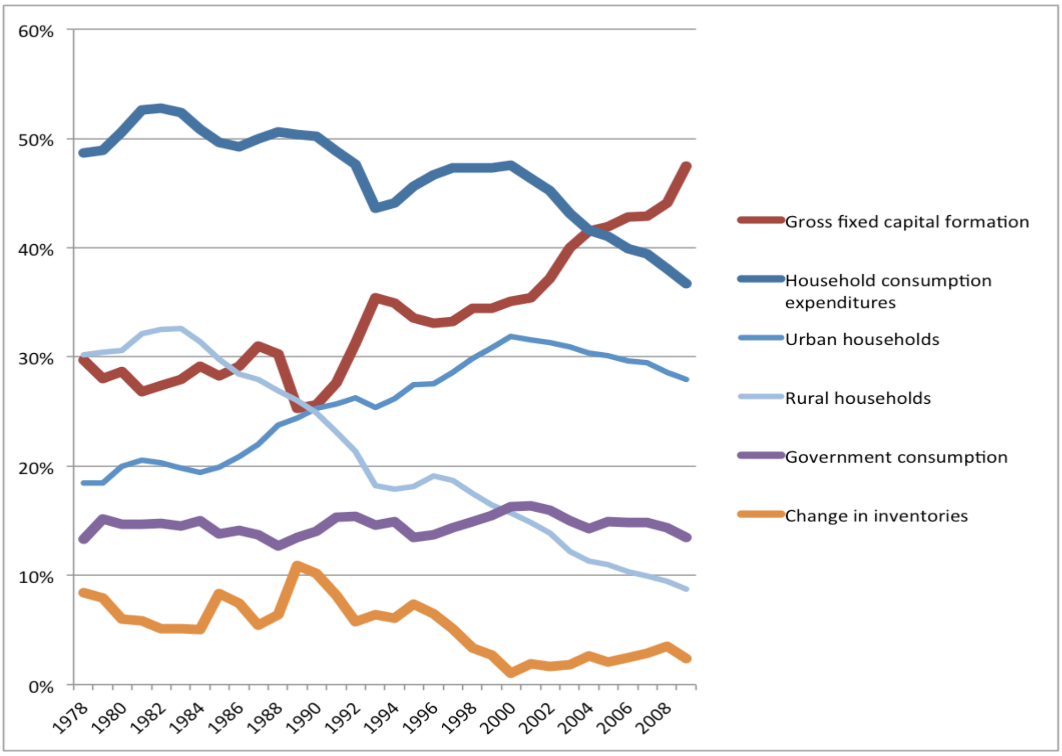
That China's expenditure profile has undergone a major transformation in the last decade is undeniable. The next section looks more deeply into this question – considering household consumption specifically – to examine whether the consumption patterns within households has also changed.

Figure 4.2: Components of GDP by expenditure (hundred million yuan)



Source: NBSC (2011, pp. 2-18)

Figure 4.3: Relative shares of components of GDP by expenditure (per cent)



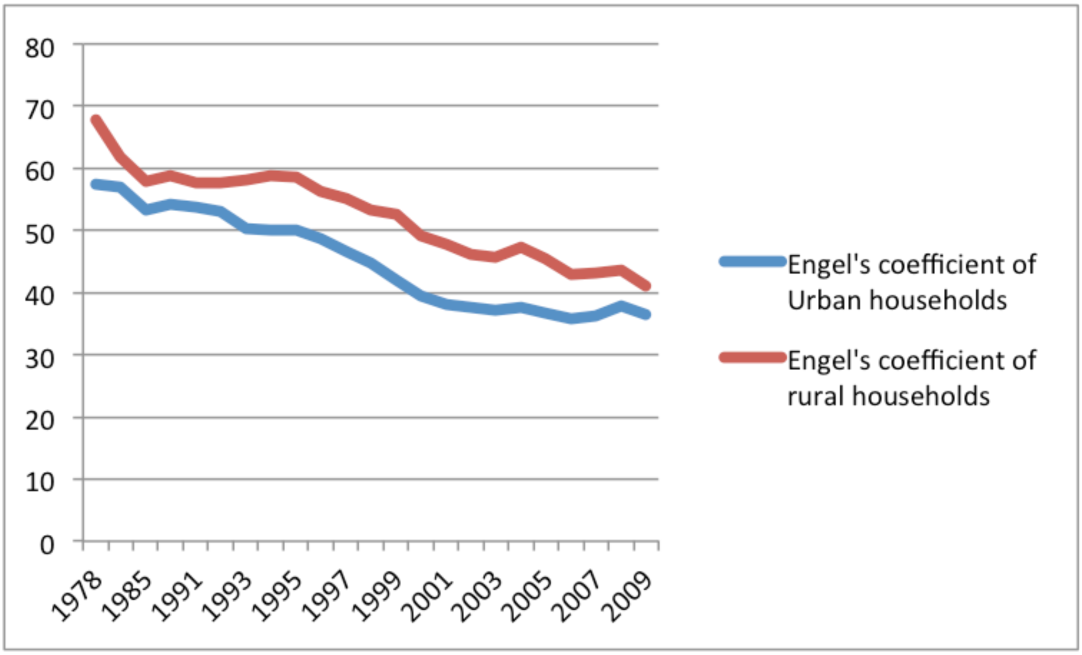
Source: Author's calculations based on data from NBSC (2011, pp. 2-18)

China's household consumption patterns

Engel functions can be described both for aggregate consumption and for consumption of specific products or product groups. When different product groups exhibit divergent Engel functions and wealth expands significantly, consumption not only increases, but the pattern of consumption is transformed.

The significant expansion of household consumption in China is evident from Figure 4.2 but to observe changes in the pattern of consumption, additional data are required. One simple measure used to demonstrate the changing consumption profile is the Engel coefficient, which measures food expenditure as a share of total expenditure. Figure 4.4 shows that for both rural and urban households in China, the Engel coefficient has declined steadily since the beginning of the reform era, with urban households consistently spending a slightly smaller portion of total expenditure on food.

Figure 4.4: Engel coefficients of Chinese urban and rural households (1978-2009)



Source: NBSC (2011, pp. 10-2)

The Engel coefficients are indicative of a change to China's household consumption patterns. The high frequency of data available increase the usefulness of Engle coefficients compared with some other indicators, however, they do not give any indication of changes in the portion of household expenditure outside of the food category.

One source of data that details complete household expenditures by consumption category are IO tables. The most suitable IO tables for the purposes of confirming the presence of a consumption transformation are the higher frequency, less detailed IO tables. China has produced 17 sector IO tables for the years 1997, 2000, 2002, 2005 and 2007. There are also IO tables for the years 1992 and 1995, however the sectors in those tables do not correspond with the those of the later tables, so the 1992 and 1995 tables are not used here. The five IO tables come from *China Statistical Yearbooks* (2002, 2005, 2007, 2009, 2010). Tables 4.3 and 4.4 present data as shares of total rural and urban household consumption for the year in question.

The most useful visualisation of these changes can be achieved by aggregating the data into three consumption groups: food, manufactured goods and services. Food includes both the ‘agriculture, forestry, animal husbandry & fishery’ sector as well as the ‘manufacture of foods, beverage & tobacco’ sector. Services include the five sectors listed last in Table 4.3, and manufactured products include the remaining sectors.

Figure 4.5 shows the transformation of consumption patterns in both rural and urban households over the past decade clearly. Food expenditure has fallen from around 60 per cent of rural household expenditure in 1997 to less than 40 per cent by 2007, and from around 40 per cent of urban household expenditure, to just 25 per cent. The difference has largely been due to an increase in the portion of household expenditure directed to services, with rural households directing just 21 per cent of total expenditure to services in 1997, but 42 per cent in 2007, and urban households directing 28 per cent of expenditure to services in 1997 and 49 per cent by 2007. The share of expenditure on manufactured goods has not changed nearly so much, declining by 4 and 7 per cent over the decade for rural and urban households, respectively, with the entire decline occuring between the years 2000 and 2002. While rural households have only just begun to spend a larger share of their income on services than food, urban households passed that point before 2002.

Table 4.3: Rural household consumption shares

(per cent)	**1997**	**2000**	**2002**	**2005**	**2007**
Agriculture, Forestry, Animal Husbandry & Fishery	38	32	30	26	21
Mining	0	0	0	0	0
Manufacture of Foods, Beverage & Tobacco	21	20	15	17	18
Manufacture of Textile, Wearing Apparel & Leather Products	6	6	4	4	5
Other Manufacture	2	3	2	2	1
Production and Supply of Electric Power, Heat Power and Water	1	1	1	1	2
Coking, Gas and Processing of Petroleum	0	0	0	0	1
Chemical Industry	3	4	3	3	3
Manufacture of Nonmetallic Mineral Products	1	1	1	1	0
Manufacture and Processing of Metals and Metal Products	1	1	0	1	0
Manufacture of Machinery and Equipment	6	8	4	6	6
Construction	0	0	0	0	0
Transport, Storage, Post, Data Transmission, IT Services & Software	2	3	3	5	5
Wholesale and Retail Trades, Hotels and Catering Services	7	6	9	8	14
Real Estate, Leasing and Business Services	6	8	14	12	10
Financial Intermediation	2	3	3	3	3
Other Services	3	4	10	11	11

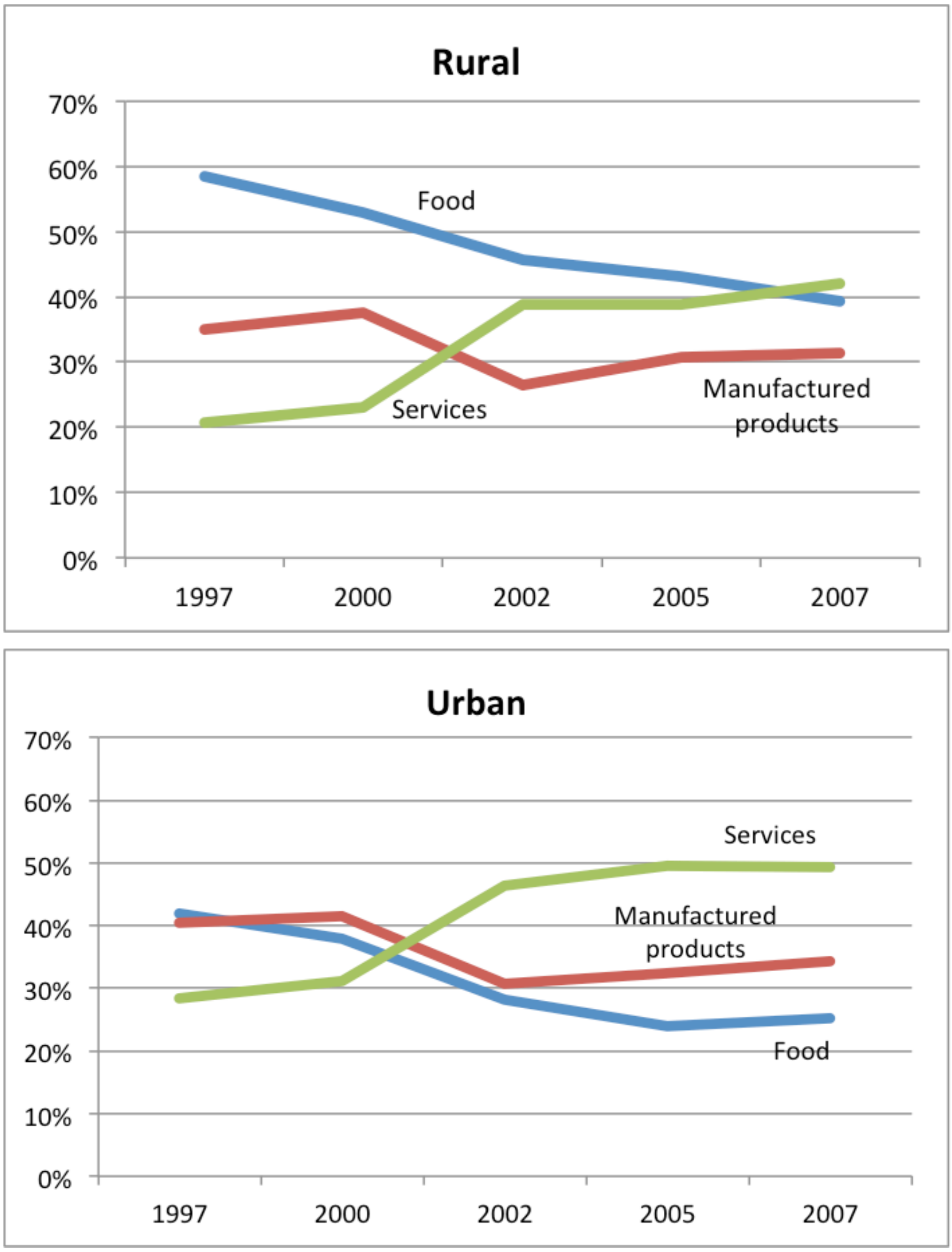
Source: Author's calculations based on data from NBSC (2002, 2005, 2007, 2009, 2010)

Table 4.4: Urban household consumption shares

(per cent)	**1997**	**2000**	**2002**	**2005**	**2007**
Agriculture, Forestry, Animal Husbandry & Fishery	20	18	15	11	8
Mining	0	0	1	0	0
Manufacture of Foods, Beverage & Tobacco	22	19	13	13	17
Manufacture of Textile, Wearing Apparel & Leather Products	11	9	7	7	7
Other Manufacture	4	4	3	3	3
Production and Supply of Electric Power, Heat Power and Water	1	2	3	3	3
Coking, Gas and Processing of Petroleum	1	1	1	1	1
Chemical Industry	2	4	3	3	2
Manufacture of Nonmetallic Mineral Products	2	2	1	1	0
Manufacture and Processing of Metals and Metal Products	1	1	1	1	0
Manufacture of Machinery and Equipment	7	8	6	8	7
Construction	0	0	0	0	1
Transport, Storage, Post, Data Transmission, IT Services & Software	3	4	4	8	6
Wholesale and Retail Trades, Hotels and Catering Services	9	9	13	12	14
Real Estate, Leasing and Business Services	6	6	9	8	9
Financial Intermediation	3	4	3	6	5
Other Services	7	8	18	16	16

Source: Author's calculations based on data from NBSC (2002, 2005, 2007, 2009, 2010)

Figure 4.5: Rural and urban household consumption shares



Source: Author's calculations

Government consumption in China

Almost all (around 95 per cent) of government consumption is directed to the "other services" sector (see Table 4.5). While the level of government consumption has increased, especially since 2004, it has stayed between 13 and 15 per cent of total consumption expenditure since 1978 (NBSC, 2011, pp. 2-18). It should be noted that China's IO tables use special definition of government expenditure. Since the government is such a pervasive actor in China's economy, most government activities are treated in the tables as a normal part of the supply process. Government owned firms, for instance, are treated as normal firms, and their purchases are not included in government consumption. Only government expenditure on final service delivery is included in government consumption in China's IO tables. Since this is the data source being used here, that is the definition that applies in this chapter.

Table 4.5 establishes that there is no major story to be told regarding transformation of government consumption.

Table 4.5: Government consumption shares (per cent)

	1997	2000	2002	2005	2007
Agriculture, Forestry, Animal Husbandry & Fishery	0	0	1	1	1
Transport, Storage, Post, Data Transmission, IT Services & Software	0	0	2	2	5
Real Estate, Leasing and Business Services	7	10	1	0	2
Financial Intermediation	0	0	0	0	1
Other Services	93	90	97	96	92

Source: Author's calculations

Impact of China's consumption transformation on energy

The previous sections of this chapter have discussed the evidence that aggregate energy demand exhibits a variable relationship to final consumption which is dependent on the consumption structure; that as economies develop the consumption structure changes; and that China has experienced just such a change in its consumption structure as it has developed since the beginning of the reform period. The next section will demonstrate that the fundamental transformation of China's consumption structure has substantially altered the relationship between aggregate energy demand and final consumption. This proposition relies on the combination of changing consumption patterns and diverse embodied energy intensities, as demonstrated in Chapter 1. As mentioned above, this chapter analyses three functional relationships: $E_{(RH)}, E_{(UH)}, E_{(G)}$, namely, energy as a function of rural household consumption, urban household consumption, and government consumption.

Chapter 2 argued that the best methodology for analysing the impact of changing consumption patterns on energy demand is structural decomposition analysis (SDA). As with the analysis of the relationship between China's production structure and energy demand presented in Chapter 3, the first step is to define an energy identity. Only slight modifications to the identity proposed in Chapter 3 are required for application to the current problem:

$$E^t = \sum_j \sum_i E^t_{j,i} = \sum_j \sum_i \frac{E^t_{j,i}}{C^t_{j,i}} \cdot \frac{C^t_{j,i}}{C^t_j} \cdot \frac{C^t_j}{P^t_j} \cdot P^t_j \tag{4.1}$$

Where, E^t is the total quantity of energy embodied in consumption in year t, $E^t_{j,i}$ is the energy embodied in consumption of sector i by consumer group j in year t, $C^t_{j,i}$ is the value of sector i by consumer group j in year t, C^t_j is the total value of consumption by consumer group j in year t, and P^t_j is the total population of consumer group j in year t. The three consumer groups are rural households, urban households and government. The population of the government consumer group is taken as the total population of China.

The right hand side represents the embodied energy intensity of each sector, the share of each sector in total consumption, the scale of total consumption per capita, and the population. As with the Production energy identity, the Consumption energy identity makes clear that the issue is one of sustainable development. People desire greater consumption (accepting a broad definition of "consumption"), but higher values of E^t are problematic for the reasons discussed in Chapter 1. The sustainable development challenge is to achieve higher values of C^t, but lower values of $\sum_j \sum_i \frac{E^t_{j,i}}{C^t_{j,i}} \cdot \frac{C^t_{j,i}}{C^t_j}$, that is, greater consumption, but restricted or lowered energy use.

Following the multiplicative LMDI approach used in Chapter 3, the change in embodied energy consumption between years is decomposed according to the following general decomposition equation:

$$D_{tot} = \sum_j D_{j_{tot}} = \sum_j \frac{V_j^T}{V_j^0} = \sum_j D_{x_i}^j D_{x_s}^j D_{x_q}^j D_{x_p}^j \tag{4.2}$$

given the following definitions:

D_{tot} is the total effect: the ratio of total embodied energy consumption in year T to year 0

V_j^T is total embodied energy consumption in year T for consumer group j

V^0 is total embodied energy consumption in year 0 for consumer group j

$D_{x_i}^j$ is the intensity effect for consumer group j

$D_{x_s}^j$ is the structural effect for consumer group j

$D_{x_q}^j$ is the quantity effect for consumer group j

$D_{x_p}^j$ is the population effect for consumer group j.

Setting aside terminology indicative of consumer groups (for simplicity), each of the decomposition factors are estimated according to the following equation:

$$D_{x_k} = \exp\left(\sum_i \frac{\left(V_i^T - V_i^0\right) \Big/ \left(\ln V_i^T - \ln V_i^0\right)}{\left(V^T - V^0\right) \Big/ \left(\ln V^T - \ln V^0\right)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \right) \tag{4.3}$$

The biggest challenge of SDA, compared to IDA, is the relatively more complex data requirement. Embodied energy is not reported in statistical tables, and must be calculated from IO tables, energy balance tables and price index tables. Because of the reliance on IO tables, SDA for China is restricted to considerations of five-year intervals (or very few sectors). Existing literature has examined changes between China's IO tables up to 2002, though recent literature focuses on energy related GHG emissions rather than energy consumption per say (see for example, Peters et al. (2007)). The next section gives a brief overview of the results related to consumption and embodied energy demand found in the literature (including the related literature on GHG emissions), and then extends the analysis up to 2007.

Embodied energy intensity of sectors

According to the energy identity presented in Equation (4.1) the three points at which consumption impacts energy use are the embodied energy intensity of consumption goods, the relative share of consumption goods in total consumption, and the magnitude of total consumption. The results of IOA provide the energy intensity of each sector. Here a modified version of the 2002 IO table is used in order to make it compatible with the 2007 IO table, as discussed in Chapter 2. There are 138 non-energy sectors and four energy sectors. Table 4.6 shows the seven non-energy sectors with the highest and lowest embodied energy intensities in 2002. Given the major discrepancy between the embodied energy intensity of different sectors, changes in the consumption profile will clearly have a major impact on energy use, as indicated in Chapter 1.

Table 4.6: Seven most and least energy intensive sectors (2002)

	Energy intensity in 2002 (GJ / 10,000 RMB)
1. Urban public traffic (098)	1,455
2. Transport via pipeline (101)	1,415
3. Rolling of non-ferrous metals (062)	1,361
4. Manufacture of metal products (063)	1,040
5. Smelting of non-ferrous metals and manufacture of alloys (061)	922
6. Timber and bamboo harvesting and transport (002.2)	817
7. Manufacture of medicines (046)	745
132. Manufacture of alcohol and wine	79
133. Forestry (002.1)	77
134. Social security (128)	74
135. Real estate (113)	64
136. Processing of aquatic products (016)	59
137. Processing of petroleum and nuclear fuel (037)	58
138. Banking, security, other financial activities (111)	58

Source: Author's calculations

Expanding the general embodied energy identity

The general energy identity presented in Equation (4.1) can be written in an expanded form, identifying the consumer groups used in the current analysis:

$$E^t = \sum_j \sum_i E^t_{j,i} = \sum_i E^t_{RH_i} + \sum_i E^t_{UH_i} + \sum_i E^t_{G_i} \tag{4.4}$$

This specific and expanded energy identity says that total energy consumption in a given year is equal to the energy embodied in rural household consumption of all sectors, urban household consumption of all sectors, and government expenditure on all sectors (all in the same given year). Following the logic of this expansion, the next section will first consider the relative importance of each consumer group before providing a detailed analysis of each of the consumer groups in turn, applying SDA to each individually.

Overview: relative energy use by three main consumer groups

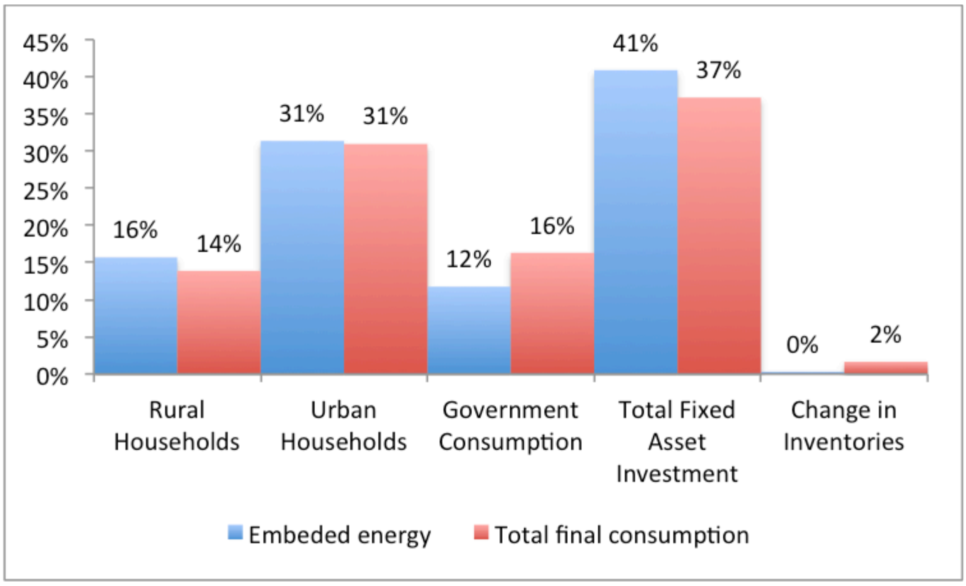
When interpreting the three principal consumption-energy relationships it is useful to be aware of the context relating each consumer group to the others and to China's total energy production, the quantity of energy used by China's producers (the subject of analysis in Chapter 3) and the quantity of energy embodied in trade. The total energy requirements matrix derived through the IOA process explained in Chapter 2 shows the total energy consumption due to each consumer group. The values are reported as shares of total energy used for Chinese domestic consumption for ease of interpretation. The total domestic use is taken to be the sum of all energy inputs to goods consumed by rural and urban households, by government in the provision of services and for investment in fixed assets. Changes in inventories are included because they affect the total values, but the thesis does not offer any discussion of results associated with changes in inventories. Exports and imports are not counted toward total domestic consumption but are dealt with separately in Chapter 5.

From Figure 4.6 we can see that in 2002, households accounted for 45 per cent of the total consumption (14 and 31 to rural and urban households, respectively) and 47 per cent of total embodied energy use (16 and 31 per cent to rural and urban households respectively), making rural household consumption marginally more energy intensive than urban household consumption. Government consumption was clearly the least energy intensive, with government accounting for 16 per cent of consumption but only 12 per cent of embodied energy use. Given the results presented in Table 4.5 that showed the majority of government expenditure to be directed to the services sector, this should not be surprising. The final expenditure category, investment in fixed assets, accounted for both the largest share of total consumption (37 per cent) and the largest share of total embodied energy use (41 per cent).

Adding together rural and urban household consumption from Figure 4.7, it can be seen that combined household consumption generated 40 per cent of total final consumption (10 and 30 per cent for rural and urban households, respectively) and 45 per cent of the total energy demand for all domestic consumption in 2007 (13 and 32 per cent for rural and urban households, respectively). The household consumption results in 2007 were down slightly from their levels in 2002. As with 2002, government consumption was the least energy intensive in 2007, accounting for 15 per cent of total final consumption and just 12 per cent of embodied energy. Again, as with 2002, investment accounted for the largest share of total final consumption and the largest share of embodied energy: 43 and 45 per cent respectively. The share of embodied energy in investment increased moderately compared with the share in 2002, changing from 41 to 45 per cent of total embodied energy: equal to the combined share from rural and urban households.

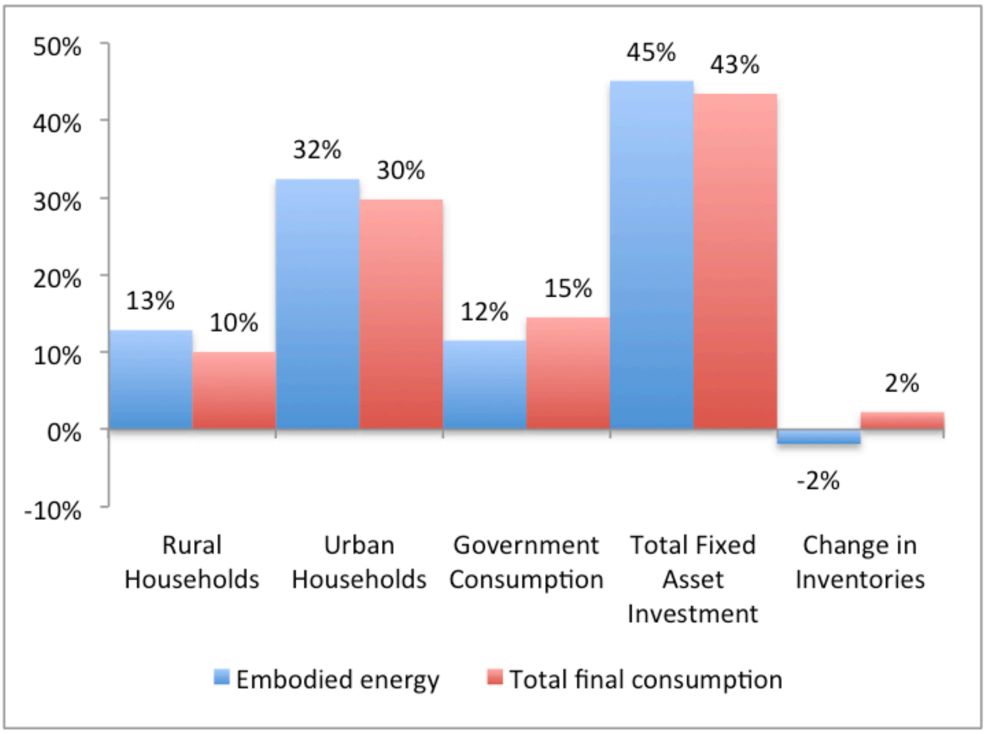
The differences between the four energy relationships, $E_{(RH)}, E_{(UH)}, E_{(G)}, E_{(I)}$, are deeper than simply embodied energy per unit of output. One additional difference is in the types of fuels from which energy is derived. The four main fuel categories are coal, petroleum and natural gas, coke and non-thermal electricity. As discussed in Chapter 2, differences across the four principal fuel groups are important for economic, social and environmental reasons.

Figure 4.6: Share of total final consumption and total embodied energy (2002)



Source: Author's calculations

Figure 4.7: Share of total final consumption and total embodied energy (2007)



Source: Author's calculations

The differences in relative importance of each fuel type to each consumer group in 2002 are summarised in Table 4.7 while Table 4.8 provides the same information for 2007. Rural households are revealed as deriving the largest share of energy from coal with almost two thirds of their energy use coming from coal in 2002. Although this coal dependence diminishes somewhat by 2007 in favour of petroleum and natural gas, energy embodied in rural household consumption was still mainly derived from coal, with almost 60 per cent coming from that fuel source. Investment in fixed assets is also revealed as coal dependent, deriving more than half its energy needs from coal in 2002. As with rural households, investment dependence on coal diminished over the five years, with petroleum and natural gas supplying almost as much by 2007, but coal was still the source of 47 per cent of energy embodied in fixed asset investments.

Table 4.7: Primary fuel shares in total embodied energy by consumer group, 2002 (per cent)

	Coal	Petroleum & gas	Coke	Electricity
Rural households	65.9	26.4	2.6	5.1
Urban households	39.7	50.9	3.9	5.4
Government	29.4	63.8	2.6	4.3
Investment	52.2	34.9	7.4	5.5

Source: Author's calculations

Table 4.8: Primary fuel shares in total embodied energy by consumer group, 2007 (per cent)

	Coal	Petroleum & gas	Coke	Electricity
Rural households	58.4	33.3	2.4	6.0
Urban households	29.5	61.3	3.8	5.4
Government	26.0	66.2	3.2	4.5
Investment	47.5	38.8	7.9	5.8

Source: Author's calculations

Both urban households and government consumption were predominantly intensive in petroleum and natural gas, with almost two thirds of total embodied energy used for government consumption coming from petroleum and gas, and over half the embodied energy used for urban household consumption being derived from that fuel in both time periods. Coke and non-thermal electricity were less important fuel sources for all consumer groups.

In all consumer groups the portion of embodied energy derived from coal in 2007 was 3 to 10 per cent lower than in 2002, with petroleum and natural gas accounting for virtually all of the proportionate increase. The relative importance of coke and non-thermal electricity remained relatively constant across all the consumer groups, but the shift away from coal toward petroleum and natural gas is both significant and important.

The low relative importance of electricity as a source of embodied energy in the consumption profile of all consumer groups in both time periods is due to the focus on primary energy sources in the methodology of the analysis in this thesis. Electricity produced from coal is counted as coal consumption. Primary electricity includes only that produced from nuclear, hydro, solar, wind or other non-thermal generation techniques. Thermal electricity (that produced from coal, petroleum, gas and coke) is considered simply as a transmission mechanism for the primary fuel commodities. This approach can be a limitation in some regards since it obscures the extent of electrification in energy transmission. However, the thesis is not focused on questions of electrification so this limitation is not a concern here.

This section has provided some context for the relative magnitudes of consumption, embodied energy intensity and fuel ratios of the four main consumer groups. The next section explores the relationship between consumption and energy in more detail, for each of the groups in turn.

Energy use and rural household consumption

Households consume energy as both an embodied component of non-energy goods (for instance, the energy used to produce food purchased by households) and directly, as an energy commodity (for instance, the coal bricks purchased for cooking purposes). Rural households' direct energy in 2002 was 1,328 PJ, or 1.70 PJ per million people. In contrast, the IOA results show rural households' total energy consumption in the same year was 2,846 PJ, or 3.64 PJ per million people, more than double that (see Table 4.1). The large discrepancy was due to the high proportion of energy embodied in rural household consumption of non-energy goods: 53 per cent of total rural household energy consumption (1,519 PJ, or 1.94 per million people) was embodied in non-energy goods. Table 4.9 shows the breakdown of direct, embodied and total consumption of each fuel type and of aggregate energy for rural households in 2002.

Table 4.9 shows that the proportion of direct versus embodied energy consumption varied considerably across the four fuel types. A relatively large proportion of rural household coal consumption was consumed directly (almost two thirds). In contrast, only one fifth of coke consumed by rural households was consumed directly: 79 per cent was embodied in rural household consumption of non-energy goods with the largest share being embodied in farming (001) products. Petroleum and natural gas consumption was even more skewed toward embodied consumption, with 84 per cent being embodied in non-energy goods, with animal husbandry (003) and farming (001) products and road transport (097) being the main avenues of petroleum and natural gas embodiment. A larger portion of rural household consumption of electricity and heat power was direct consumption (36 per cent), although even here the majority of rural household consumption was embodied in non-energy goods, with farming (001) products again having the largest share. Table 4.10 presents the equivalent figures for 2007.

By 2007, rural households' direct energy consumption was 1,850 PJ or 2.54 PJ per million people (almost 50 per cent greater than in 2002 in per capita terms, but only 40 per cent greater in absolute terms). The results of IOA show rural households' total energy consumption in the same year was 3,413 PJ, or 4.69 PJ per million people, meaning that 46 per cent of energy consumed by rural households in 2007 was embodied in non-energy goods and services. The decline of almost 10 per cent relative to 2002 levels was due to rural households' direct consumption of energy having grown faster (both at a faster rate, and by a larger increment) than the growth of embodied energy. Importantly, while direct coal consumption increased by a similar amount to direct consumption of petroleum and natural gas, the latter grew at an average rate of 24 per cent per year (a doubling period of less than three years), significantly higher than the 4 per cent annual growth in direct consumption of coal.

Table 4.9: Rural household direct versus embodied energy use (2002)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct consumption (PJ)	1,141	119	16	52	1,328
(PJ / million people)	1.46	0.15	0.02	0.07	1.70
Embodied consumption (PJ)	734	633	59	92	1,519
(PJ / million people)	0.94	0.81	0.08	0.12	1.94
Total consumption (PJ)	1,875	752	75	144	2,846
(PJ / million people)	2.40	0.96	0.10	0.18	3.64

Source: Author's calculations

Table 4.10: Rural household direct versus embodied energy use (2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct consumption (PJ)	1,389	344	9	107	1,850
(PJ / million people)	1.91	0.47	0.01	0.15	2.54
Embodied consumption (PJ)	604	792	71	96	1,563
(PJ / million people)	0.83	1.09	0.10	0.13	2.15
Total consumption (PJ)	1,992	1,137	80	203	3,413
(PJ / million people)	2.74	1.56	0.11	0.28	4.69

Source: Author's calculations

Table 4.11: Share of rural household energy use embodied in non-energy goods

(per cent)	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
2002	39.2	84.2	78.9	63.9	53.4
2007	↓ 30.3	↓ 69.7	↑ 88.5	↓ 47.2	↓45.8

Source: Author's calculations

Structural decomposition analysis

Rural household total energy consumption increased from 2,846 PJ in 2002 to 3,413 PJ in 2007. The change can be represented with the following expression:

$$D_{tot} = \frac{V^{2007}}{V^{2002}} = \frac{3,413}{2,846} = 1.20 \tag{4.5}$$

Separating the direct energy consumption from the embodied energy consumption produces the following results:

$$D_{tot}^{d} = \frac{1,850}{1,328} = 1.39 \tag{4.6}$$

$$D_{tot}^{e} = \frac{1,563}{1,519} = 1.03 \tag{4.7}$$

The average annual growth rates of rural household direct, embodied and total consumption of energy are 6.8, 0.6 and 3.7 per cent, respectively, equating to doubling times of 7, 122 and 19 years. The change in rural household consumption of embodied energy can be decomposed into changes in energy intensity (D_i), consumption patterns (D_s) and per capita consumption levels (D_c) and population (D_p), such that:

$$D_{tot} = \frac{V^{T}}{V^{0}} = D_i D_s D_c D_p \tag{4.8}$$

where $D_x,\ x = i,s,c,p$ are given by the formula established in Equation (4.3). Interpreting the values of D_x is relatively simple. A value of 1 implies zero impact. A value between 0-1 implies the factor contributed to a decline in embodied fuel consumption (for example: 0.80 implies a 20 per cent decline) and a value greater than 1 implies that factor contributed to an increase in embodied fuel consumption (for example: 1.10 implies a 10 per cent increase).

The results of the SDA are presented in Table 4.12. The first row presents estimates of the intensity effect: the amount by which rural household consumption of embodied energy would change if consumption patterns had remained constant, and only the production processes were allowed to change. The result is an overall intensity effect of 0.76, which indicates a considerable energy-saving technological change over the period, resulting in a 24 per cent reduction in energy embodied in rural household consumption over the period. This is a promising result from an air pollution and climate change point of view, especially since the technological effect was even greater on embodied coal consumption, pushing rural household consumption of embodied coal down by almost 40 per cent. The very low intensity effect on coal resulted in rural household consumption of embodied coal actually decreasing, while consumption of all other embodied fuels increased.

Table 4.12: SDA - Rural households

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.64	0.84	1.44	0.92	**0.76**
Consumption Pattern: D_s	1.06	1.20	1.03	1.05	**1.12**
Per capita consumption: D_c	1.30	1.30	1.29	1.30	**1.30**
Population: D_p	0.93	0.93	0.93	0.93	**0.93**
Total: D_{tot}	**0.83**	**1.23**	**1.79**	**1.17**	**1.03**
Error:	*0.00*	*-0.01*	*0.01*	*0.00*	*0.00*

Source: Author's calculations

Turning to the second row of SDA results, changes in the consumption pattern (the structural effect), which shows that rural households' consumption bundle in 2007 contained more energy intensive products than the 2002 bundle, resulting in an estimated 12 per cent increase in embodied energy consumption. The shift in consumption patterns moved furthest toward petroleum and natural gas intensive products, with the other fuels all registering moderate increases of between three and six per cent. The consumption pattern resulted in a considerable move toward petroleum and natural gas, partly due to the increase in consumption of products from three sectors: wholesale and retail trade (108), education (126) and catering services (110). Rural households spent almost nine per cent of their total expenditure in 2007 on retail products, compared with less than five per cent in 2002. While this sector was not very energy intensive, the substantial increase in expenditure resulted in the quantity of petroleum and natural gas embodied in rural consumption of retail products increasing from 22 to 52 PJ. Similarly, the share of total rural household expenditure on education rose from three per cent in 2002 to six per cent in 2007, resulting in embodied petroleum and natural gas levels rising from 14 to 29 PJ. The shift in expenditure on catering services was not as substantial as the other two sectors, but catering services were a more energy intensive sector. While its expenditure share rose less than two per cent, the impact on embodied petroleum and natural gas was an increase of 30 PJ. The embodied energy, energy intensity, and rural household consumption levels of the wholesale and retail trade sector, the education sector and the catering services sector are summarised in Table 4.13.

The next two rows, per capita consumption and population, are almost constant across all fuel types. This is because the data are not sector-specific. The results show that the increase in per capita consumption of rural households resulted in an approximately 30 per cent increase in embodied consumption of all fuel types. The decline in China's rural population in recent years has resulted in downward pressure on rural household consumption of embodied energy equivalent to an estimated 7 per cent decline between 2002 and 2007. It will be seen in the next section that the population effect is largely the result of the urbanisation of China: as the rural population falls the urban population has grown. In effect, the decline in rural household consumption of embodied energy associated with population changes merely reflects an accounting shift of consumption as people move from rural areas to urban areas.

The fifth row of Table 4.12 shows the total effect. It is the multiple of the intensity, consumption pattern, per capita consumption level and population effects. The summarised results reported here may appear not to equate perfectly but this is due to rounding at the second decimal point. The total effect of changes in rural household consumption combined with changes in production processes varied substantially across the four fuel groups. The substantial improvements in coal intensity combined with a moderate shift toward coal-intensive products in the rural household consumption bundle resulted in a very moderate increase in the quantity of coal embodied in rural household consumption: just 5 per cent. In contrast, the increase in embodied coke was almost 80 per cent, though the relative insignificance of coke as a fuel source meant that this large relative increase contributed very little to the increase in total energy embodied in rural household consumption.

The sectors that had the largest impact on petroleum and natural gas consumption have already been discussed in this section. The relatively restrained increase in rural household consumption of embodied coal appears to be due largely to three other sectors: farming (001), manufactured of other foods (021)) and real estate (113). In 2002, rural households consumed around 400 billion RMB worth of farming sector output, embodying approximately 104 PJ of coal. By 2007, rural household consumption of farming sector products had fallen to 290 billion RMB embodying approximately 61 PJ of coal. The coal intensity of the farming sector fell from 26 GJ per 10,000 RMB to 21 over the five-year period, while the total energy intensity of the sector fell from 48 to 43 GJ per 10,000 RMB. While the technological effect in the farming sector was modest it was combined with the largest relative reduction in rural household consumption of all sectors, falling from 21 to 12 per cent of total rural household consumption. The decline in expenditure share for the farming sector was almost double the decline of the share for the animal husbandry sector (003), which recorded the second greatest reduction in relative expenditure by rural households, falling from almost 12 per cent of rural household consumption in 2002 to 7 per cent in 2007. This change in consumption patterns combined with less energy-intensive production in the farming sector was an important contributor to rural households' overall decline in embodied coal consumption.

The second sector responsible for a large share of the growth in rural household consumption of embodied coke was the manufacture of other foods (021)[1]. In 2002, rural households consumed around 29 billion RMB of products from that sector (just 1.5 per cent of total rural household consumption), embodying approximately 34 PJ of coal. By 2007 they consumed 53 billion RMB of 'other manufactured food' products (rising to 2 per cent of rural household expenditure), but the coal embodied in that consumption fell to 12 PJ. The decline was due to a substantial reduction in coal intensity of the sector, falling from 116 GJ per 10,000 RMB to just 23, while total energy intensity of the sector fell from 183 to 36 GJ per 10,000 RMB.

[1] This sector is a disaggregated component of the "other food processing and manufacturing (13019) sector reported in the 2002 IO tables, which recorded rural household expenditure of around 75 billion RMB. The RMB 29 billion figure comes from disaggregating the sector into five sectors: (016), (017), (018), (020) and (021) according to the method outlined in Chapter 2. The values were then converted into 2007 prices.

Finally, rural household consumption from the real estate sector in 2007 embodied 61 PJ of energy less than it did in 2002 (40 PJ of which was coal). Though the real estate sector was not very energy intensive in 2002, embodying just 39 GJ of energy per 10,000 RMB of output (22 of which derived from coal and 14 of which derived from petroleum and natural gas) it was still responsible for considerable energy savings. By 2007, the energy intensity of the real estate sector fell to 14 GJ per 10,000 RMB (5 from coal and 7 from petroleum and natural gas). The result in relation to coal embodied in rural household consumption of the real estate sector was a fall from 52 to 12 PJ over the 2002 to 2007 period.

These results are summarised in Table 4.13. They show that well-targeted energy efficiency gains can have a substantial impact, even if they occur in sectors that were not energy intensive to start with.

Table 4.13: Key sectors embodying energy in rural household consumption

	Coal	Petroleum and natural gas	Coke	Electricity	Value of Consumption (Billion RMB)
Farming (001)					
2002					407 B RMB
Embodied consumption (PJ)	104	66	11	16	
Intensity (GJ / 10,000 RMB)	26	16	3	4	
2007					291 B RMB
Embodied consumption (PJ)	61	43	8	12	
GJ per 10,000 RMB	21	15	3	4	
Manufacture of other foods (021)					
2002					29 B RMB
Embodied consumption (PJ)	34	15	1	3	
Intensity (GJ / 10,000 RMB)	116	51	5	11	
2007					53 B RMB
Embodied consumption (PJ)	12	5	1	1	
Intensity (GJ / 10,000 RMB)	23	10	1	2	
Wholesale and retail trade (108)					
2002					81 B RMB
Embodied consumption (PJ)	23	22	2	4	
Intensity (GJ / 10,000 RMB)	26	24	2	4	
2007					206 B RMB
Embodied consumption (PJ)	23	71	4	3	
GJ per 10,000 RMB	11	35	2	1	
Real estate (113)					
2002					239 B RMB
Embodied consumption (PJ)	52	32	4	5	
Intensity (GJ / 10,000 RMB)	22	14	2	2	
2007					227 B RMB
Embodied consumption (PJ)	12	15	2	3	
Intensity (GJ / 10,000 RMB)	5	7	1	1	
Catering services (110)					
2002					67 B RMB
Embodied consumption (PJ)	26	23	1	2	
Intensity (GJ / 10,000 RMB)	39	35	2	4	
2007					128 B RMB
Embodied consumption (PJ)	41	54	2	4	
Intensity (GJ / 10,000 RMB)	32	42	2	3	
Education (126)					
2002					67 B RMB
Embodied consumption (PJ)	24	14	2	3	
Intensity (GJ / 10,000 RMB)	35	20	3	5	
2007					147 B RMB
Embodied consumption (PJ)	20	87	2	3	
Intensity (GJ / 10,000 RMB)	14	59	2	2	

Source: Author’s calculations

Energy use and urban household consumption

There are both important similarities and differences in the pattern of energy consumption for urban households compared with rural households (see Tables 4.14, 4.15 and 4.16). As with rural households, the majority of energy use (both direct and embodied) derives from coal or petroleum and natural gas, with coke and non-thermal electricity providing far smaller shares. A second similarity is that a declining majority of energy consumption was embodied in non-energy goods, though the share was higher for urban than rural households and the decline was less, falling from 72 to 70 per cent, compared with 53 to 46 per cent for rural households.

A third similarity is that the growth in direct consumption of petroleum and natural gas and non-thermal electricity and heat power outstripped the growth in embodied consumption of those fuel sources. This is most likely related to the growing ownership of private cars and motorbikes that run on liquid fuels, the spread of electricity to homes in rural areas and increased ownership of home appliances across the country. The average annual growth rate of direct petroleum and natural gas consumption in rural and urban households was 24 per cent and 15 per cent, respectively (doubling times of just under 3 and 5 years). Direct consumption of petroleum and natural gas by households can be expected to continue to grow as the number of middle-class households increases, as the prices of cars fall, and as China continues to build more roads.

Despite these few similarities, there are important differences between the rural and urban household consumption relationships with energy. Most obviously, the total energy consumed on a per capita basis by urban households was around three times larger than by rural households and consumption of energy embodied in non-energy goods by urban households was around four times the level of rural households. Both ratios fell only slightly over the five years.

In contrast to rural households, urban households did not directly consume substantial amounts of coal: less than a quarter of urban household coal consumption was consumed directly, compared with more than two thirds for rural households. In 2002 rural households consumed 30 per cent more ‘direct coal’ per capita than urban households, although the reverse was true for embodied coal consumption, with urban households consuming almost four times as much coal embodied in non-energy goods per capita as rural households.

While rural households' energy profile was dominated by coal, urban households consumed a higher portion of petroleum and natural gas: 50 per cent in 2002 and 61 per cent by 2007 (compared with less than one third for rural households). On a per capita basis, urban households' direct consumption of petroleum and natural gas was more than seven times greater than direct consumption by rural households in 2002, and was still more than five times higher by 2007 despite rapid growth in rural households (rural household direct petroleum and natural gas consumption grew at an average rate of almost 24 per cent per year between 2002 and 2007, while the equivalent growth rate for urban households was 15 per cent).

Table 4.14: Urban household direct versus embodied energy use (2002)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct consumption (PJ)	550	858	76	85	1,569
(PJ / million people)	1.10	1.71	0.15	0.17	3.12
Embodied consumption (PJ)	1,711	2,041	146	225	4,123
(PJ / million people)	3.41	4.06	0.29	0.45	8.21
Total consumption (PJ)	2,261	2,899	222	310	5,692
(PJ / million people)	4.50	5.77	0.44	0.62	11.34

Source: Author's calculations

Table 4.15: Urban household direct versus embodied energy use (2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct consumption (PJ)	575	1,745	81	154	2,555
(PJ / million people)	0.97	2.94	0.14	0.26	4.30
Embodied consumption (PJ)	1,922	3,452	243	304	5,920
(PJ / million people)	3.24	5.81	0.41	0.51	9.97
Total consumption (PJ)	2,497	5,197	324	458	8,475
(PJ / million people)	4.20	8.75	0.55	0.77	14.27

Source: Author's calculations

Table 4.16: Share of urban household energy use embodied in non-energy goods

(per cent)	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
2002	75.7	70.4	65.8	72.5	72.4
2007	↑ 77.0	↓ 66.4	↑ 74.9	↓ 66.4	↓ 69.9

Source: Author's calculations

Structural Decomposition Analysis

Urban household total energy consumption increased from 5,692 PJ in 2002 to 8,475 PJ in 2007. The change can be represented as:

$$D_{tot} = \frac{V^{2007}}{V^{2002}} = \frac{8,475}{5,692} = 1.49 \tag{4.9}$$

Separating the direct energy consumption from the embodied energy consumption produces the following expressions:

$$D_{tot}^{d} = \frac{2,555}{1,569} = 1.63 \tag{4.10}$$

$$D_{tot}^{e} = \frac{5,920}{4,123} = 1.44 \tag{4.11}$$

Urban households can be seen to have increased both direct and embodied consumption of energy considerably faster than rural households, though the difference was greater for embodied consumption.

As seen in the previous section, the change in urban household consumption of embodied energy can be decomposed into changes in energy intensity (D_i), consumption patterns (D_s) and per capita consumption levels (D_c) and population (D_p), such that:

$$D_{tot} = \frac{V^{T}}{V^{0}} = D_i D_s D_c D_p \tag{4.12}$$

where D_x are given by the formula established in Equation (4.3).

The results of the SDA are presented in Table 4.17. As before, there are both important similarities and differences between the patterns of energy use by urban households *vis-à-vis* rural households.

Table 4.17: SDA - Urban Households

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.63	0.83	1.27	0.92	**0.75**
Consumption Pattern: D_s	1.02	1.17	1.02	1.04	**1.10**
Per capita consumption: D_c	1.45	1.46	1.42	1.44	**1.45**
Population:	1.17	1.18	1.16	1.17	**1.17**
D_{tot}	**1.09**	**1.66**	**2.15**	**1.61**	**1.40**
Error:	-0.03	-0.03	-0.04	-0.05	-0.03

Source: Author's calculations

The intensity effect on energy embodied in urban household consumption was even greater (further from a value of 1) than the effect on energy embodied in rural household consumption, driving a 25 per cent decrease in urban household embodied energy use. As with rural households, the impact was greatest on coal, and the only fuel with an intensity effect greater than 1 was coke. Although the intensity effect resulted in a 37 per cent decrease in embodied coal consumption by urban households, the structural, consumption and population effects meant that the actual change in the quantity of coal embodied in urban household consumption was a 9 per cent increase.

A similar pattern can be seen across the other fuels, with the intensity effect restraining growth, but being overwhelmed by the structural, consumption and population effects, resulting in actual increases in the embodied consumption of all fuels, most substantially of coke.

Since the intensity effect is not part of the behaviour of households, but relates to the production processes of various sectors, the key sectors where the intensity effect had the greatest impact on urban household consumption of energy were the same as those discussed in relation to rural households. While certain sectors had much more substantial improvements in energy efficiency, such as transport via pipelines (101), manufacture of cement, lime and plaster (050), and manufacture of brick, stone, and other building materials (052), output from these sectors was not consumed by households, so their impact on household energy use was only indirect, due to their use as inputs to other sectors.

The sector recording the greatest reduction in energy intensity (excluding sectors whose output was not consumed by households) was urban public traffic (098). The energy intensity of the sector fell by almost 1,000 PJ, but because it is still a very energy-intensive sector and urban households spent a higher share of their expenditure on it in 2007 than in 2002, the total energy embodied in urban household consumption of urban public traffic increased more than the amount embodied in any other sector (see Table 4.19).

As with rural households, the consumption bundle of urban households in 2007 contained more energy intensive products than in 2002, resulting in a 10 per cent increase in embodied energy consumption. The effect was most pronounced in relation to goods intensive in petroleum and natural gas. The sectors recording the largest increase in their share of urban household consumption were wholesale and retail trade (108), health (127), manufacture of automobiles (074.1) and insurance (112). Consumption of each of these sectors embodied higher quantities of energy in 2007 than 2002. Details of the wholesale and retail trade sector were provided in relation to rural household consumption in the previous section and will not be repeated in related to urban household consumption. Details of the other three sectors in relation to urban household consumption are provided in Table 4.19.

The growing wealth of urban households pushed up energy use much faster than the prosperity gains of rural households, resulting in a 45 per cent increase in energy embodied in urban household consumption, compared to a wealth effect of 30 per cent for rural households. The simple implication of this result is that as China continues to urbanise and more Chinese people enjoy the rapid wage growth available in urban areas, the wealth impact on energy demand will continue to grow.

Table 4.18: Total and per capita growth rates of energy consumption

	Average annual growth rate (per cent)	Doubling time (years)
Rural households		
Collectively	4.2	16.7
Per capita	5.7	12.3
Urban households		
Collectively	5.8	12
Per capita	2.3	30.3

Source: Author's calculations

Table 4.19: Urban household energy consumption embodied in key sectors

	Coal	Petroleum and natural gas	Coke	Electricity	Value of Consumption (Billion RMB)
Manufacture of automobiles (074.1)					
2002					24
Embodied consumption (PJ)	17	12	3	3	
Intensity (GJ / 10,000 RMB)	71	49	12	11	
2007					151
Embodied consumption (PJ)	4	4	1	1	
GJ per 10,000 RMB	31	35	10	6	
Urban public traffic (098)					
2002					31
Embodied consumption (PJ)	9	547	1	2	
Intensity (GJ / 10,000 RMB)	30	1,751	4	7	
2007					87
Embodied consumption (PJ)	16	1,229	4	5	
GJ per 10,000 RMB	19	1,414	4	5	
Insurance (112)					
2002					10
Embodied consumption (PJ)	2	5	0	0	
Intensity (GJ / 10,000 RMB)	25	48	2	4	
2007					120
Embodied consumption (PJ)	25	95	4	6	
GJ per 10,000 RMB	21	79	3	5	
Health (127)					
2002					164
Embodied consumption (PJ)	60	56	5	9	
Intensity (GJ / 10,000 RMB)	37	34	3	5	
2007					430
Embodied consumption (PJ)	154	149	16	22	
GJ per 10,000 RMB	36	35	4	5	

Source: Author's calculations

By necessity, the population effect for urban households was approximately the reverse of the population effect for rural households, since it is predominantly the result of rural to urban migration. While population changes pushed consumption of embodied energy by rural households down by seven per cent, it pushed up the consumption by urban households by 17 per cent. The asymmetry is likely due to the urban population growing at a rate faster than the rural population shrank, since China's total population has also been growing. Comparing the growth rates of embodied energy consumption across all households with those on a per capita basis shows the importance of the population effect (Table 4.18). As the rural population has declined in China, the collective growth rate is lower than the per capita growth rate, although as the urban population has increased, collective growth rate is substantially higher than the per capita growth rate.

Energy use and government services

Government consumption as defined for the purposes of China's IO tables was relatively minor and relatively stable, both in value terms and in terms of energy use. Figures 4.6 and 4.7 reveal total energy embodied in government consumption to be just 12 per cent of all total embodied energy consumed domestically in China. The share was constant in both 2002 and 2007. Table 4.20 shows the quantity of each fuel and the fuel share of energy used for government services in 2002 and 2007. The importance of petroleum and natural gas relative to other fuels in the production chain supplying government services can be seen: petroleum and natural gas supplied almost two thirds of all the energy embodied in government consumption (a higher share than for any other consumer group). These important features of the energy profile of government services are due to the fact that almost all of government consumption is in the service sectors since, by definition, only final provision of government services is counted.

Table 4.20: Embodiment of fuels in government services (2002 and 2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
2002					
(PJ)	626	1360	55	91	2,132
(per cent of total)	29.4	63.8	2.6	4.3	
2007					
(PJ)	809	2,061	100	141	3,112
(per cent of total)	26.0	66.2	3.2	4.5	

Source: Author's calculations

Structural decomposition analysis

Energy embodied in government services increased from 2,132 PJ in 2002 to 3,112 PJ in 2007. The change can be represented with the following expression:

$$D_{tot} = \frac{V^{2007}}{V^{2002}} = \frac{3{,}112}{2{,}132} = 1.46 \tag{4.13}$$

As government services do not include the direct purchase of any primary fuel commodities, this cannot be split into direct and embodied energy consumption: it is all embodied energy. The average annual growth rate of energy embodied in government consumption was 8 per cent per annum, equating to a doubling time of 9 years. As with rural and urban households, the change in energy embodied in government consumption can be decomposed into changes in energy intensity (D_i), consumption shares (D_s), per capita consumption levels (D_c) and population (D_p), such that:

$$D_{tot} = \frac{V^T}{V^0} = D_i D_s D_c D_p \tag{4.14}$$

where D_x are given by the formula established in Equation (4.3). The results of the SDA are presented in Table 4.21. The first row presents estimates of the intensity effect: the amount by which energy embodied in government services would change if service provision had remained constant and only the production processes were allowed to change. The result: is an overall intensity effect of 0.83, which indicates technological changes have resulted in a significant reduction in the energy embodied in sectors consumed by government. As with the intensity effects recorded for households, the impact was greatest on coal consumption while only coke embodied in government consumption rose due to technological effects.

Table 4.21: SDA – Government services

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.76	0.85	1.06	0.91	**0.83**
Consumption Structure: D_s	1.05	1.11	1.06	1.04	**1.09**
Per capita consumption: D_c	1.58	1.57	1.58	1.58	**1.57**
Population:	1.03	1.03	1.03	1.03	**1.03**
D_{tot}	**1.29**	**1.51**	**1.82**	**1.54**	**1.46**
Error:	*0.00*	*0.00*	*-0.01*	*-0.01*	*0.00*

Source: Author calculations

As seen earlier (see Table 4.5), government services have not undergone any major structural transformations since at least 1997. The estimated structural effect supports that finding, with relatively modest changes in each fuel being attributed to shifts in the consumption structure. Similarly, Figure 4.3 showed the share of government services in total GDP had remained constant, between 13 and 15 per cent of GDP: expenditure on government services essentially increased in line with GDP.

The consumption effect, which estimates the impact of per capita changes in government services on energy use, indicates an increase of 57 per cent over the five years. In the absence of any change to energy intensity, to the structure of government consumption, or to the population level, this would have resulted in energy use for government services reaching 3,347 PJ in 2007, equating to an average annual growth rate of 9.4 per cent, which is very near China's real GDP growth rate over the last decade. The fourth row estimates the effect that China's population growth had on energy used for government services. As China's population growth is restrained as a matter of policy, this effect was relatively modest, contributing an average annual growth rate of half a per cent to the increase in energy for government consumption over the period.

The final row (excluding estimated errors) estimates the total effect that changes to production and consumption of government services had on fuel consumption. These results are similar to those for household consumption: coke consumption increased by the greatest proportion, but from such a low base that it contributed relatively little to overall energy use. Petroleum and natural gas use increased by a greater amount than coal use. Electricity and heat power used for government services increased by a substantial proportion, as did the amount used for urban household consumption, but the amount used by rural households increased by a much more modest amount. This pattern is most likely due to the higher share of electricity intensive products in government and urban consumption than rural consumption, namely, of services rather than food.

In government consumption in particular, services dominated the consumption structure. Significant amounts of energy were embodied in government consumption of only five sectors, though two stand out as substantially more energy-using than the other three. The two are public management and social organisation (135) and urban public transport (098), while the other three sectors are education (126), health (127) and management of public facilities (123).

By far, the largest amount of energy used for government services was embodied in the public management and social organisation (135) sector. This is exclusively a government consumption sector: it is not used as an input to any other sector and is not consumed by any other category of consumer. The only discrepancy between government consumption of the sector and total output and total domestic consumption is a very small amount of imports and exports and a slightly larger amount of reporting errors. Public management and social organisation accounted for around half of all expenditure on government services, although the share fell from 55 per cent to 45 per cent between 2002 and 2007. Although the share of total government consumption directed to the sector declined, the level of expenditure increased by almost 400 billion RMB, with the result that total energy embodied in government consumption of this sector increased by a relatively large proportion.

The high petroleum and natural gas intensity of the urban public transport (098) sector has already been discussed. Although the sector attracted less than 2 per cent of total government expenditure, that share of government expenditure generated almost as much energy demand as the share directed to public management and social organisation, making it the sector generating the second highest level of energy demand due to government service provision.

Education (126) attracted the second highest share of government consumption, accounting for around a fifth of all government services expenditure, rising slightly over the last decade to 747 billion RMB in 2007 (almost double the household expenditure on education in that year). The very low (and improving) energy intensity of this sector resulted in only moderate energy demand relative to the high level of expenditure.

Energy use for government health (127) expenditure increased by a greater proportion than energy use for expenditure on any other government services, rising from 148 PJ to 432 PJ from 2002 to 2007. While the health sector had relatively low energy intensity (79 GJ per 10,000 RMB in both periods) government expenditure on this sector grew dramatically. As a share of total government expenditure it almost doubled, from 8.8 per cent in 2002 to 15.5 per cent in 2007, attracting an extra 357 billion RMB, raising government health expenditure to a level 25 per cent higher than household health expenditure.

Management of public facilities (123) is the final sector for which government expenditure generated significant energy demand. The energy use for government consumption on management of public facilities was relatively constant over the period, falling by just 8 PJ to 127 PJ by 2007. The decline was due to a modest increase in the level of expenditure (a slight reduction in the share of total government expenditure) combined with a reasonable improvement in energy intensity, both in relation to coal and (more significantly) in relation to petroleum and natural gas.

Table 4.22: Government energy consumption embodied in key sectors

	Coal	Petroleum and natural gas	Coke	Electricity	Value of Consumption (Billion RMB)
Urban public transport (098)					
2002					28
Embodied consumption (PJ)	8	491	1	2	
Intensity (GJ / 10,000 RMB)	30	1,751	4	7	
2007					51
Embodied consumption (PJ)	9	715	2	3	
GJ per 10,000 RMB	19	1,414	4	5	
Management of public facilities (123)					
2002					54
Embodied consumption (PJ)	22	108	3	3	
Intensity (GJ / 10,000 RMB)	40	200	5	6	
2007					77
Embodied consumption (PJ)	18	103	3	4	
GJ per 10,000 RMB	23	134	4	5	
Education (126)					
2002					385
Embodied consumption (PJ)	136	78	10	19	
Intensity (GJ / 10,000 RMB)	35	20	3	5	
2007					747
Embodied consumption (PJ)	152	147	17	32	
GJ per 10,000 RMB	20	20	2	4	
Health (127)					
2002					187
Embodied consumption (PJ)	69	64	5	10	
Intensity (GJ / 10,000 RMB)	37	34	3	5	
2007					544
Embodied consumption (PJ)	195	189	20	27	
GJ per 10,000 RMB	36	35	4	5	
Public management and social organisation (135)					
2002					1,172
Embodied consumption (PJ)	298	504	25	44	
Intensity (GJ / 10,000 RMB)	25	43	2	4	
2007					1,566
Embodied consumption (PJ)	322	575	35	54	
GJ per 10,000 RMB	21	37	2	3	

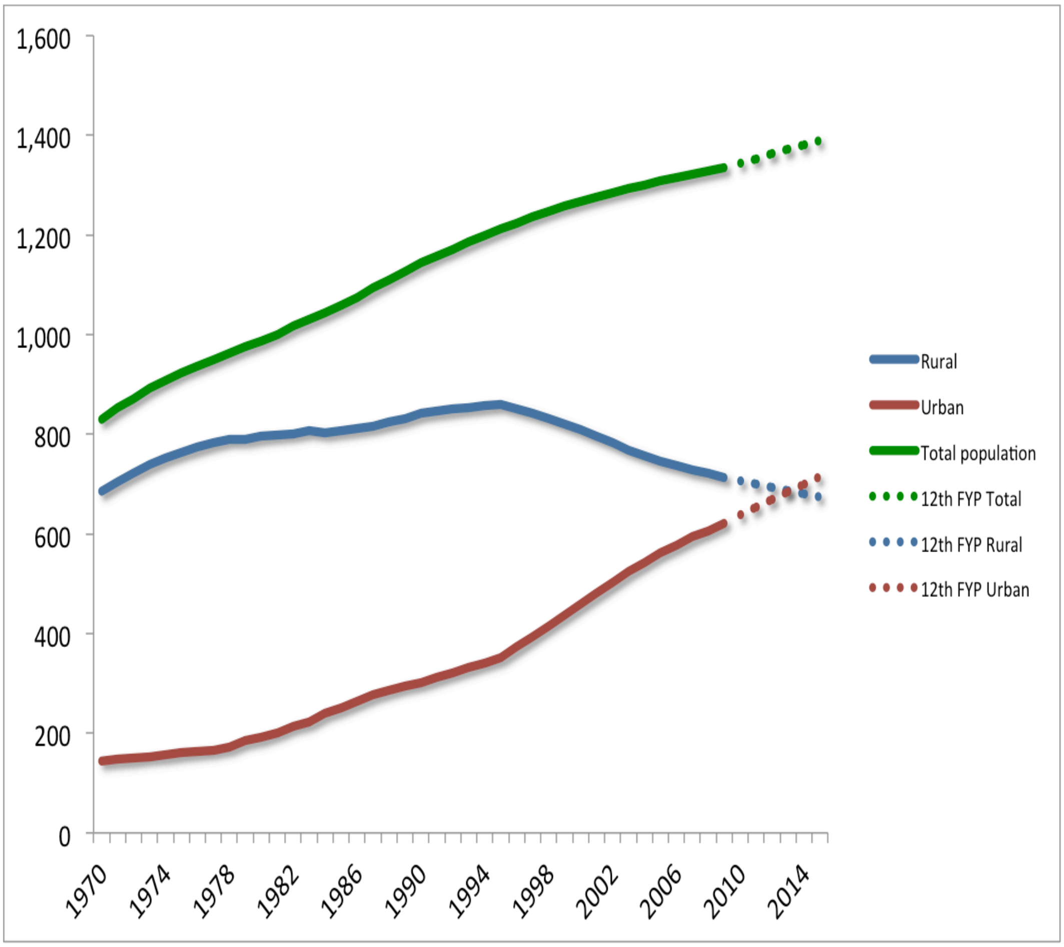
Source: Author's calculations

Implications for China's energy future

The discussion and analysis in this chapter have important implications for China's energy future. Figures 4.6 and 4.7 show that combined rural and urban household consumption was ultimately responsible for around 45 per cent of energy use in China between 2002 and 2007. While rural households' energy use barely changed between 2002 and 2007, urban household energy use was 45 per cent higher in 2007 than it was in 2002. The rapid growth in urban household energy use appeared to be the result of growing per capita consumption combined with a growing population and a shifting consumption bundle.

Figure 4.8 shows China's rural and urban population levels since 1970 up to the latest available year, 2009, then depicts the population levels targeted under China's 12th Five-Year Plan. Although urbanisation has resulted in a falling rural population and rapid growth of the urban population, there is still a long way to go before China approaches the urbanisation rate of most developed economies. In the 12th Five-Year Plan, China has targeted a total population of no greater than 1.39 billion people with an urbanisation rate of 51.5 per cent by 2015 (Xinhua, 2011). Meeting these targets would equate to an urban population growth of 94 million people over five years, while the rural population would shrink by almost 40 million people. This level of change is very close to the 92 million additional urban residents and 55 million fewer rural residents recorded between 2002 and 2007, implying that the population effect on household energy use over the 12th Five-Year Plan period would likely be similar to the population effect estimated in this chapter. In level terms, this equates to a *ceteris paribus* increase in household energy consumption of around 700 PJ due to population changes over five years. At the present rate of urbanisation, China's urban population will reach 70 per cent of the total population in 2025. In China's long march to urbanisation, the population effect alone ensures that household consumption will remain a strong driver of energy use in China for at least the next two decades.

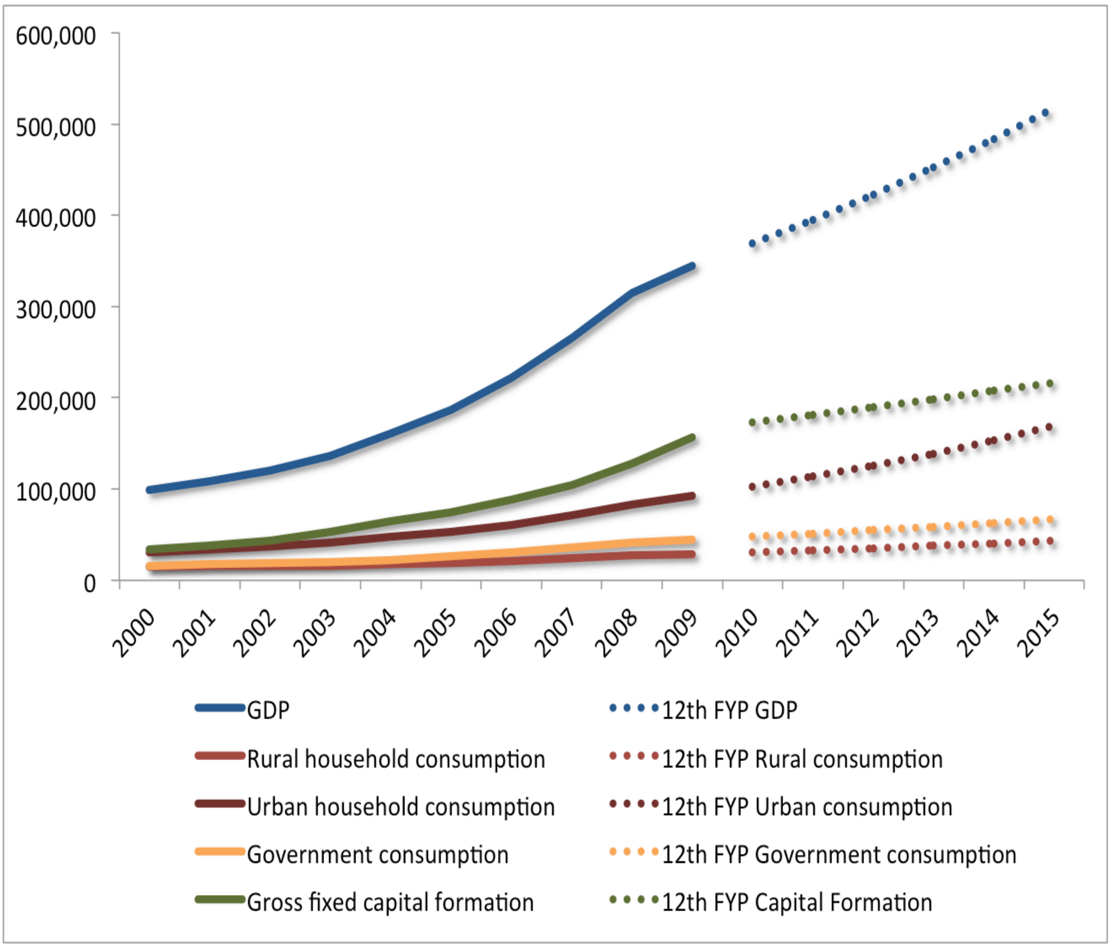
Figure 4.8: Population in China, 1970-2015 (millions of people)



Source: NBSC (2011, pp. 3-1) and Author's calculations based on Xinhua (2011)

Two important targets in the 12th Five-Year Plan relate to GDP growth and the consumption share of GDP. The Plan calls for GDP to grow by seven per cent annually, and the consumption share of GDP to grow by an unspecified amount. Interpreting the target of 'higher consumption share of GDP' as an annual increase in the consumption share of GDP at a rate of one percentage point per year, leads to a consumption rate of 42 per cent by 2015. Assuming government consumption and net exports retain their relatively constant share of GDP at 17 per cent, the investment share of GDP must fall to 41 per cent. The ratio of urban to rural household consumption per capita has remained relatively constant, between 3.6 and 3.7 since 2000 (NBSC, 2011, pp. 2-17). Assuming that ratio continues to stay constant the total rural and urban household consumption targeted by the 12th Five-Year Plan can be calculated. These results are depicted in Figure 4.9.

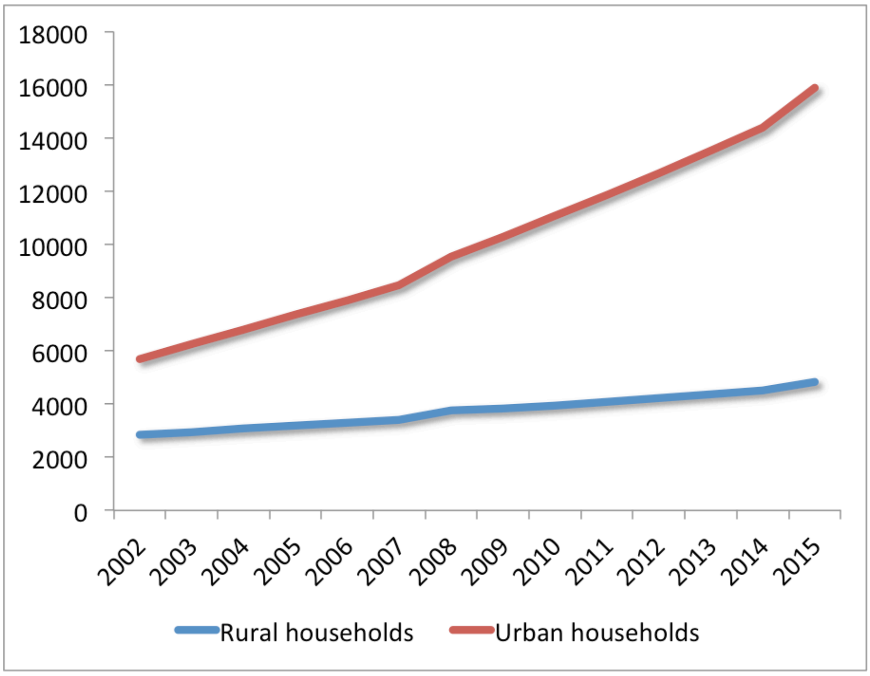
Figure 4.9: GDP by expenditure under the 12th Five-Year Plan (100 million RMB)



Source: NBSC (2011, pp. 2-17) and Author's calculations based on Xinhua (2011)

The final target in the 12th Five-Year Plan necessary to draw implications for China's energy future is the energy consumption per unit of GDP: this is targeted to be reduced by 16 per cent by 2015 compared with the 2010 level. Assuming a constant rate of improvement allows the projection of IOA results from 2007 on an annual basis to 2015 in accordance with the targets established under China's 12th Five-Year Plan. Those results are presented in Figure 4.10. It is clear from Figure 4.10that China's targets under the 12th Five-Year Plan imply that urban household energy consumption will grow at a higher rate than it did under the 2002-2007 period, while rural household energy consumption will continue to grow at around the 2002-2007 rate.

Figure 4.10: Estimated rural and urban household energy use under 12th Five-Year Plan conditions: 2002-2015 (PJ)



Source: Author's calculations

Whether the reality of China's household energy consumption between 2010 and 2015 will match the scenario depicted in Figure 4.10 depends on how closely China achieves its targets of GDP growth, population growth, urbanisation and energy intensity and whether the ratio of urban to rural per capita consumption remains constant. Changes to the consumption bundle will also cause deviations between reality and this scenario, but the results of the SDA presented in this chapter suggest those changes will be relatively modest. If, for instance, China's GDP growth exceeds 7 per cent annually, the energy embodied in household consumption will be higher than this scenario indicates. If China fails to increase the consumption share of GDP, the level will be less.

One aspect of the scenario demands attention. The total estimated energy embodied in household consumption in 2015 under this scenario is 20,717 PJ; almost double the 11,888 PJ estimated for 2007. This chapter has shown that household in China are responsible for around 45 per cent of China's total energy consumption. The implication is that if China hits the 12^{th} five-year plan targets identified here, a 45 per cent share of Chinese energy consumption could almost double between 2007 and 2015.

Conclusion

China is undergoing a major transformation in both the scale and the pattern of its consumption. Two overwhelming forces are driving this: China's lightning-speed urbanisation and the steady growth in consumption levels. The change in China's consumption profile in recent years has been dominated by the explosion of urban household consumption and the growth of manufactured goods as a share of all household consumption (relative to the share of food). The discussion in this chapter has shown that China's transformation is not peculiar in its nature given the historical context of other nations. China's transformation may be larger and faster, but it has so far followed a familiar direction.

The results presented in this chapter demonstrate that household consumption is one of the main long-term drivers of China's energy use and will likely remain so for several decades.

The changes in China's consumption profile have important implications not only for the aggregate level of energy demand but also for the fuel mix required to produce consumption bundles. Coal dominates the rural household energy profile, especially direct consumption of coal. But since 2002 rural household consumption patterns have shifted substantially away from coal toward petroleum-intensive products. In contrast, urban households do not consume large quantities of energy directly: their energy profile is dominated by the consumption of products that embody petroleum. As with rural households, the shift in urban household consumption patterns has been toward products embodying petroleum. A similar trend toward consumption of the output of petroleum-intensive sectors appeared in the provision of government services. If China is successful in its 12th Five-Year Plan's ambition of increasing the consumption share of GDP, the shift in energy needs toward petroleum at the expense of coal will likely accelerate[2].

Consumption is a relatively small part of China's GDP (relative to investment and trade). This is consistent with the structure of expenditure in other 'rapid-catch-up' economies. An implication of this finding is that consumption is not currently the

[2] One interesting aside with implications for resource exporting countries such as Australia is that China's production processes appear to have become more coke-intensive, although the increase in coke use is not tied to a shift in consumption patterns.

largest driver of energy use. However, urbanization is one of the key features of the Chinese economic transformation. Urban per capita incomes have grown faster than rural per capita incomes even while urban populations have exploded and rural populations shrunk. The continued urbanization will see greater emphasis on consumption of products embodying petroleum and lesser emphasis on direct consumption of cheap, dirty coal. The higher energy needs of urban households relative to rural households combined with the long process of urbanisation that China has yet to face mean this is one factor that will continue to drive substantial energy consumption well into the future.

In considering the implications for China's energy future, a scenario based on the 12th Five-Year Plan was developed in this chapter. Under that scenario, energy embodied in household consumption in China would be expected to almost double by 2015 compared with 2007, a growth rate of around 10 per cent. In watching to see how the reality of China's energy consumption deviates from the scenario, it will be useful to consider deviations from each of the targets used to build the scenario. In particular, if GDP growth exceeds 7 per cent per annum, the expectations for energy embodied in consumption will need to be revised upward.

To continue the analysis of China's energy boom that began in 2002 and to see the energy impact of one of the second key demand side drivers of China's economy, the next chapter looks at the relationship between energy use and investment.

Chapter 5. Energy and investment

The relationship between energy use and investment (fixed asset accumulation) in China is complex, interesting and important. It is important because investment accounts for a large share of the derived energy demand in China. It is interesting because investment in China presents a number of puzzles for economists: China's investment is a larger share of GDP than in most other countries and is larger than many economists seem to believe is appropriate given China's economic conditions. And it is complex because apart from changes to the energy intensity of investment in different sectors due to improvements on the production side, the level and composition of investment are the result of at least three interrelated but separately motivated groups: government, firms and households.

The argument in the thesis begins with the presumption that the relationship between economic growth and total energy use is the aggregate of several non-linear relationships, and that these relationships can be individually understood in the context of economic theory. This is the second of the three chapters that treat energy use as a function of aggregate demand. The previous chapter addressed the relationship of energy use to domestic consumption, concluding that consumption patterns in China are a substantial driver of China's growing energy use but that consumption patterns did not offer a full explanation of the very rapid rise in energy use between 2002 and 2005. This chapter turns to the relationship between energy use and investment. How is the investment profile in China changing? Can investment explain the rapid growth in energy consumption beginning in 2002? To what extent is the underlying trend of growing energy use driven by investment? And what implications do the answers to these questions have for China's energy future?

Energy-use in investment

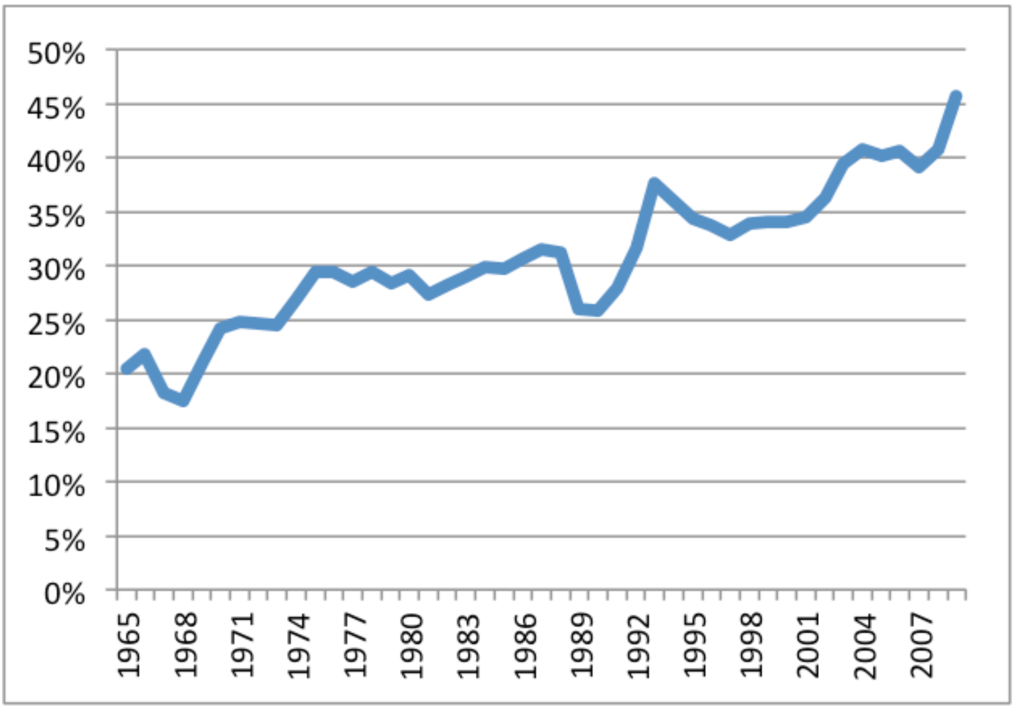
What is meant by energy-use in investment? Energy-use in investment carries essentially the same meaning as energy-use in consumption. As with energy-use in consumption, the focus is on embodied energy. In this case, rather than delivering a product to final demand, energy-use in investment is the amount of energy required to deliver investment to productive use: the creation of fixed assets. Investment in a machine in the manufacturing sector would include all the energy required to produce the machine (including all the energy required to provide the raw materials) and deliver it to its operational state.

The 'direct use of energy' table presented in Chapter 2 reports that no energy is used in investment. This is because only expenditure on fixed assets is counted toward investment; there is therefore no expenditure on direct energy use since energy is not a fixed asset. As this chapter confirms (as in the previous chapter), measuring only the direct-use of energy fails to capture some of the most important drivers of energy demand.

Justification for investment focus

In the previous chapter it was argued that to understand the energy needs of Chinese people requires a focus on the total energy embodied in Chinese consumption. The argument was predicated on the concept of embodied energy that treats energy use as a derived demand, dependent upon aggregate demand. While Chapter 4 analysed energy embodied in household consumption and government services, those constitute only a fraction of aggregate demand. Chapter 4 showed that of all the components of domestic demand, investment had grown the most rapidly, growing at an average annual rate of 18 per cent between 2000 and 2009. Investment in China has been responsible for an increasing share of GDP. The best indicator available to demonstrate this point is fixed assets investment as a share of GDP (Barnett & Brooks, 2006). By this measure, gross fixed capital formation has become a substantially more important part of the Chinese economy, increasing from around 20 per cent in 1965, to 29 per cent in 1978, to 36 per cent in 2002 and 49 per cent in 2009 (Figure 5.1). The impact of investment on energy demand is clearly important and requires particular treatment in this analysis.

Figure 5.1: Gross fixed capital formation (per cent of GDP) (1965-2009)



Source: World Bank (2011)

In 2002 energy embodied in fixed asset investments accounted for around 41 per cent of energy embodied in final expenditure and by 2007 the share had risen to 45 per cent (see Figures 4.6 and 4.7).

Energy and investment during economic transformation

Part of aggregate energy demand is a function of fixed asset investment, and understanding energy flows in the Chinese economy needs to include this element. If it is accepted that patterns of investment are not constant, then expectations of total energy embodied in investment should take into consideration changes in the nature of the energy-intensity of investment and changes in the structure of investment itself. The logic of this argument can be presented as a series of six propositions.

(1) Aggregate energy demand is related to investment; (2) that relationship is not constant; (3) the relationship between energy and investment is dependent on the investment structure; (4) as economies develop, the investment structure changes;

(5) China has experienced a fundamental transformation in investment over the past 30 years; and (6) that fundamental transformation has substantially altered the relationship between aggregate energy demand and investment.

The first three of these propositions follow identical reasoning to the equivalent propositions in Chapter 4 relating to energy and consumption. Aggregate energy demand is related to investment, through some calculable 'total energy intensity of investment' coefficient, which is variable. These propositions are perfectly analogous to the arguments presented in the previous chapter. The fourth proposition, however, needs new evidence. Why should the structure of investment be dependent upon economic development? The next section draws on general economic principles to demonstrate the variation in the structure of investment over the development process.

The fifth proposition is empirical: that China has experienced a fundamental investment transformation over the past 30 years, and will be demonstrated with reference to the most recently available Chinese investment data. The final proposition is analytical: that China's investment transformation has altered the relationship between aggregate energy demand and investment. Demonstrating this proposition will rely on the same IOA and SDA techniques used to demonstrate the equivalent proposition in Chapter 4. Demonstrating these six propositions is sufficient to show that energy demand has a non-linear relationship with investment in China and will contribute one more piece of the energy-economy puzzle. The results of the analysis contribute to understanding how China's growing energy use is related to investment in fixed assets and, as will be seen, can be interpreted as explaining to some extent the boom in energy use from 2002.

Economic development and patterns of investment

Understanding how the relationship between energy consumption and fixed asset investment changes as an economy develops requires some general understanding of the relationship between fixed asset investment and economic growth. Research on the determinants of investment has not received the same level of attention that determinants of consumption and production have received (Adda & Cooper, 2003). Accordingly, there is substantial disagreement in the literature about the relationship between investment and economic growth (Herrerias & Orts, 2010).

Part of the challenge stems from the fact that different types of investors have different motivations for investment. Consequently, the relationship between investment and economic growth is best understood as an aggregate of the relationships that several categories of investors have with economic growth. The three most important categories of investors are households, government and enterprises.

Of the three, theoretical understanding of the determinants of investment by firms is strongest. The fundamental model that explains investment by firms is the neoclassical model of investment (Mankiw, 2003). According to that model, investment depends on the marginal product of capital, the interest rate, and the rate of capital depreciation. Since the marginal product of capital and the depreciation rate vary across sectors and are heavily impacted by the broad stages of economic development discussed in Chapter 3, the structure of investment by firms is also related to the stage of economic development[1]. The evolution of the investment structure through the process of economic development was reasoned as early as Adam Smith:

> According to the natural course of things, therefore, the greater part of capital of every growing society is, first, directed to agriculture, afterwards to manufactures, and last of all to foreign commerce (Smith, 1776, p. 274).

But Smith was also aware that the ‘natural course of things’ was not necessarily the actual course of things (Fiaschi & Signorino, 2003). China’s case is particularly unusual since there are major distortions in the determinants of China’s investment patterns such as the heavy influence of the state in the banking system and the relationships between managers in state-owned enterprises and government officials (Pettis, 2011). Perhaps the most that can be generalised is that in a free market economy with an efficient financial sector and an impartial bureaucracy, investment follows expected relative rates of return. The rates of return in a given sector, if the market is functioning well, ought to reflect the productivity gains from investment in that sector and be determined as the equilibrium of demand and

[1] To see that this is the case, consider the marginal products of manufacturing and intellectual capital in the US. The marginal product of manufacturing capital is not much higher than the depreciation rate, so there is very little investment in manufacturing in the US, while the marginal product of intellectual capital far exceeds the depreciation rate, directing US investment away from manufacturing and toward intellectual property. This conforms to the post-industrial stage of economic development characterizing the US economy.

supply for investment. This minimal generalisation may even be sufficient to explain China's high rate of investment: Sun et al. (2011) showed that China has experienced a consistently high rate of return to capital, and that this can explain a large share of the high rate of investment.

In contrast to investment by firms, household investment is not strongly affected by sectoral variations in the marginal product or depreciation rate of capital. Household investment in fixed assets is largely restricted to housing or real estate. Naturally, not all household savings are in real estate (much is directed to firms through stock markets and so on) but the accumulation of fixed assets by households generally occurs in this one sector. The aggregate household demand for real estate is determined primarily by expected household income, expected interest rates and the population (Mankiw, 2003). China's rapid urbanisation obviously exerts massive upward pressure on the demand for urban housing, as do the rising wages of Chinese people. The natural consequence is both rising property prices[2] and large-scale investment in construction of residential buildings. The pace and (until late 2011) seeming inevitability of rising house prices, largely due to the sheer numbers of people looking to move to China's cities, has meant that housing has been seen as a reliable source of capital gains. Partially as a consequence, construction of housing far outstrips occupancy rates. This is an unusual feature of China's property market and affects the amount of investment in construction, with important implications for energy use that will be discussed below.

The last of the three types of investor is the government. Government motivation for investment is quite different to that of either the firm or the household. While government investment is usually (ideally) subject to some form of commercial cost benefit analysis, the benefits of interest are generally social benefits rather than private benefits. Political ideology is also hugely important as a determinant of investment, making any general theory of government investment elusive. Government fixed asset investment usually focuses on infrastructure, utilities and essential services such as schools and hospitals. While there are some differences in infrastructure needs at different stages of development (Lin, 2010), the existence of a 'set path' is much weaker in 'catch up economies': the least developed

[2] China's property prices began to fall in late 2011, in response to government policies targeting that outcome.

countries today would aim to invest in a broad spectrum of infrastructure and essential services, likely focusing on areas of local scarcity, with no set path related to development. Governments do not first invest in roads, then schools and hospitals and only then invest in communications and internet infrastructure (Rodrik, 2007). This is evident in the juxtaposition of deep mobile phone penetration with limited access to clean water in many places around the world. The level of government fixed asset investment in any given year may also be partly a tool of macroeconomic management of which the aim may be smoothing aggregate demand. The underlying theory is that when private investment lags, public investment should rise to maintain employment, but when private investment booms, public investment should retreat to avoid crowding-out effects. Since there is no strong theoretical link between levels or structure of government investment in fixed assets and stages of economic growth, the best strategy for ascertaining patterns in a particular country is a combination of empirical analysis and consideration of public statements of intent by the government in question.

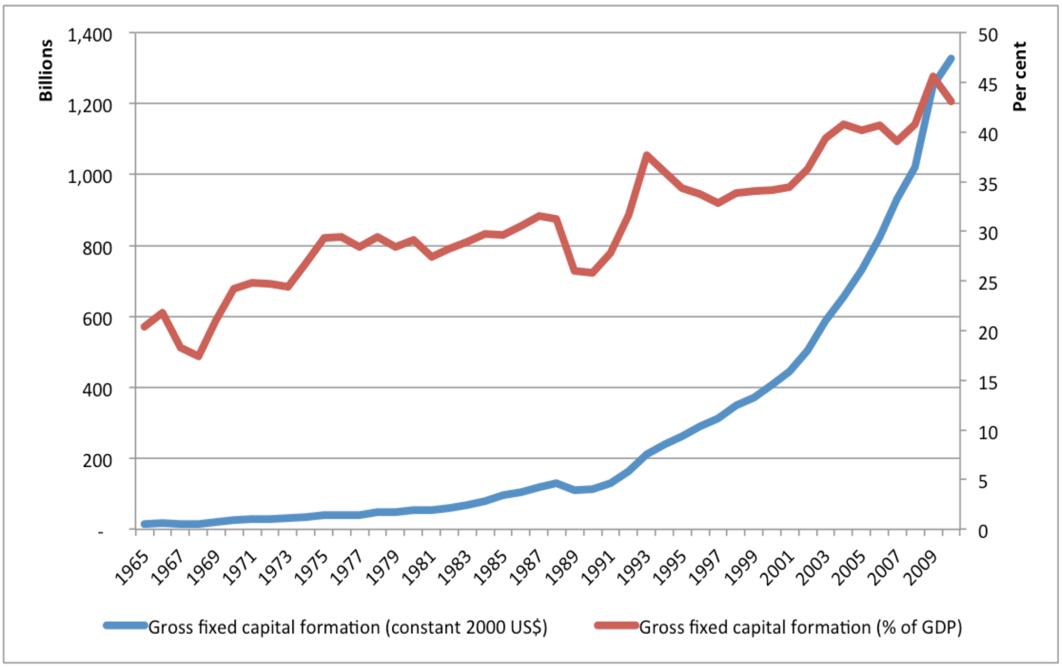
In aggregate then, the impact of economic development on investment is primarily one of scale: as the economy grows, so investment grows. Only investment by firms would be expected to follow a pattern of broad structural transformation as the economy develops. Household investment remains in housing at all stages of development, and government investment remains focused on the provision of infrastructure and essential services, subject to the political ideology of the government in question. How does China's recent investment pattern fit this general story? The next section considers this question empirically.

China's investment transformation

The fifth proposition in the argument at the beginning of this chapter is an empirical claim that China has experienced a fundamental investment transformation over the last 30 years. Characterising China's recent investment patterns is the first step toward analysing the link between fixed asset investment and aggregate energy use. The aspects of China's investment transformation most pertinent to its energy use are the quantity, structure and energy intensity of investment.

The most obvious characteristic of Chinese investment is its very rapid growth. Figure 5.2 shows investment both in terms of the quantity and as a share of GDP dating back to 1965. The feature of Figure 5.2 most relevant here is the increase in investment as a share of GDP in the years 2001 to 2004, when investment rose from 34 per cent of GDP to 41 per cent. A second increase occurred between 2008 and 2009 when China's 4 trillion RMB stimulus package and very weak global demand resulted in investment rising from 41 to 46 per cent of GDP in one year. That short-term increase is already being reversed but the result is that the value of investment in 2010 was more than triple the 2000 value.

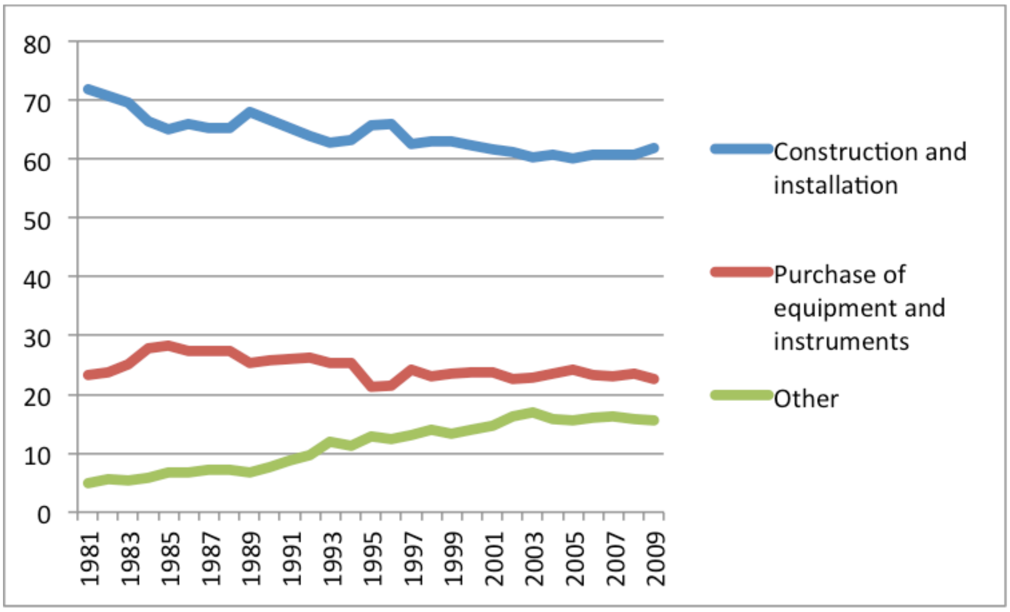
Figure 5.2: China's gross fixed capital formation, level and share of GDP (1965-2010)



Source: World Bank (2011)

In an environment of such rapid investment growth it would be highly surprising if all forms of investment were growing at an equal rate. Figure 5.3 shows the three broad types of investment spending and creation of new assets at the sectoral level. As would be expected, there has been a steady change in the structure of investment in China. The share of investment in construction and installation has fallen from more than 70 per cent in 1981 to around 60 per cent now. Most of the relative decline in investment in construction and installation has been matched by a relative increase in the 'other' category of investment.

Figure 5.3: Structure of investment



Source: NBSC (2010, pp. 5-4)

Because these categories are quite broad, and because the 'other' category is of increasing importance although little clarity, the official definition of each of these categories provided by the NBSC explanatory notes is reproduced here:

> (1) Construction and installation (work volume of construction and installation) refers to the construction of houses and buildings and the installation of various kinds of equipment and instruments. They include construction of houses; equipment foundations, industrial kilns and stoves, and metal structure work; preparation works and temporary works for project construction, and clearing up works post project construction; pavement of railways and roads, drilling of mines and putting up of oil pipes; construction of water conservancy; construction of underground air-raid shelters and construction of other special projects; value of equipment for heating, sanitation, ventilation, lighting, gas, painting, etc. that are covered by the budget of housing projects; laying out of various pipelines (for steam, compressed air, petroleum, tap water and sewage) and wiring and cabling for electric power and for communications; installation of various machinery and equipment; testing operation for pre-testing the quality of installation projects, and land and other development work conducted by real estate developers for commercialized housing. The value of equipment installed is itself not included in the value of installation projects.
>
> (2) Purchase of equipment and instruments refers to the total value of equipment, tools, and instruments purchased or self-produced which come up to the cut-off point for fixed assets by

> the construction units or investing enterprises or institutions. Equipment, tools and instruments purchased or self-produced for new workshops by newly established or expanded units are categorized as “purchase of equipment and instruments” no matter whether they come up to the cut-off point for fixed assets.
>
> (3) Other expenses refer to expenses arising during the construction or purchase of fixed assets other than those mentioned above. (NBSC, 2010, pp. Ch5-Explanatory Notes)

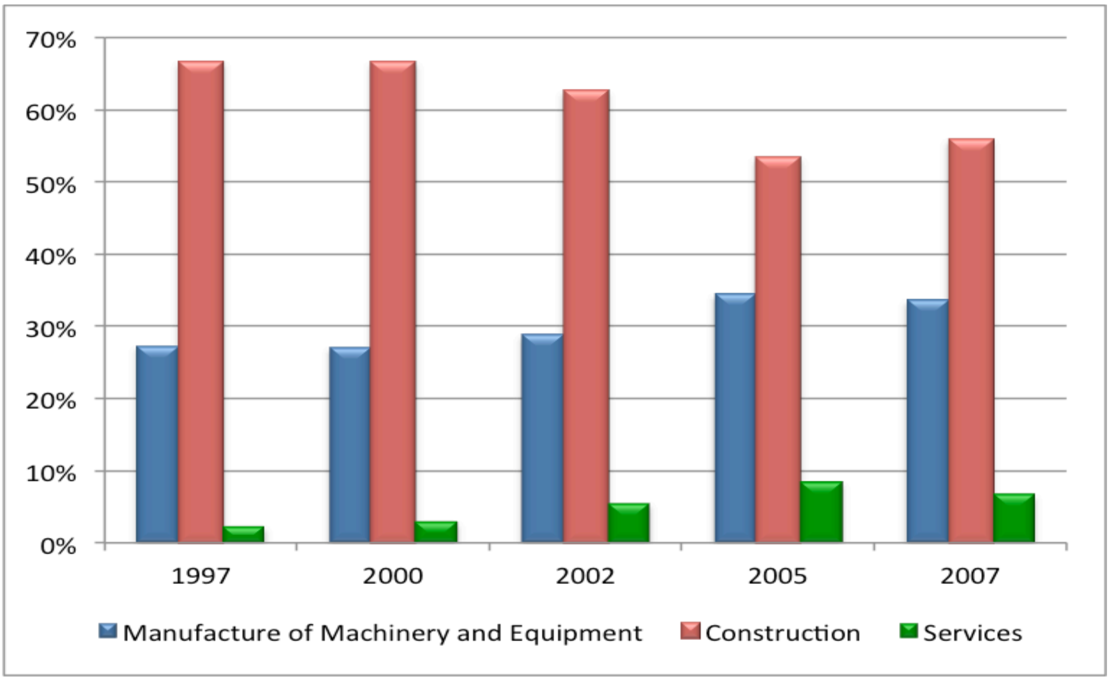
A slightly more detailed breakdown of the sectoral destination of investment funds is available from China’s IO tables. The final-use part of the 17 sector IO tables available for 1997, 2000, 2002, 2005 and 2007 show that over the period 1997 to 2007, two sectors account for around 90 per cent of total investment: construction and the manufacture of machinery and equipment (see Table 5.1). The data from Table 5.1 are summarised in Figure 5.4, showing the share of total fixed capital formation due to the two dominant sectors and the group of services sectors combined. The agriculture sector and the ‘other manufacture’ sector are not included in Figure 5.4 since they are negligibly small relative to other sectors. While the data from the IO tables provide additional information, particularly with regard to the details of the ‘other’ categorisation in Figure 5.3, it does not change the general story: the construction sector attracted the overwhelming majority of Chinese investment over the past decade, attracting 67 per cent in 1997 and 2000 and falling to 56 per cent by 2007. Most of the remaining investment went to machinery and equipment, which accounted for 27 per cent in 1997 and 2000, rising to 34 per cent by 2005. Almost the whole modest decline in the relative share of investment funds going to the construction sector has been due to an increase in investment in the manufacture of machinery and equipment, and an increase in investment in the services sector. Both sectors attracted around 6 per cent more of China’s total investment in 2007 than in 1997.

Table 5.1: Gross fixed capital formation by sector (1997-2007)

(100 billion yuan) (per cent of total)	1997	2000	2002	2005	2007
Agriculture, forestry, animal husbandry & fishery	5,938 (2.4)	7,240 (2.2)	7,727 (1.8)	14,119 (1.8)	10,672 (1.0)
Other manufacture	1,970 (0.8)	2,189 (0.7)	2,595 (0.6)	6,214 (0.8)	19,632 (1.9)
Manufacture and processing of metals and metal products	1,703 (0.7)	2,166 (0.7)	3,216 (0.7)	8,834 (1.1)	9,530 (0.9)
Manufacture of machinery and equipment	68,738 (27.3)	88,229 (27.0)	125,818 (28.8)	266,361 (34.5)	355,016 (33.7)
Construction	167,473 (66.6)	216,877 (66.5)	272,754 (62.5)	412,394 (53.3)	588,466 (55.8)
Transport, storage, post, IT, computer services & software	583,581 (0.2)	771,846 (0.2)	1,976 (0.5)	11,461 (1.5)	14,974 (1.4)
Wholesale and retail trades, hotels and catering services	3,267 (1.3)	3,722 (1.1)	9,548 (2.2)	17,869 (2.3)	18,821 (1.8)
Real estate, leasing and business services	1,869 (0.7)	5,044 (1.5)	11,427 (2.6)	3,330 (0.4)	34,063 (3.2)
Other services	0 (0.0)	0 (0.0)	1,261 (0.3)	2,066 (0.3)	3,185 (0.3)
Total	**251,542**	**326,238**	**436,321**	**773,048**	**1,054,359**

Note: Eight sectors had zero gross fixed capital formation in every year and have been excluded from the table. These are: mining; manufacture of foods, beverage & tobacco; manufacture of textile, wearing apparel & leather products; production and supply of electric power, heat power and water; coking, gas and processing of petroleum; chemical industry; manufacture of non-metallic mineral products; financial intermediation.
Source: Final-use part of IO tables, NBSC (2002, 2005, 2007, 2009, 2010)

Figure 5.4: China's key investment sectors (1997-2007)



Source: Author's calculations

Does this all demonstrate that China has experienced a 'fundamental transformation in investment'? One conclusion could be that construction and the manufacture of machinery and equipment account for nearly all of fixed asset investment and have done so for decades. However, this would be to dismiss some very important changes to investment in China. The largest change to investment in China since 1997 has been the sheer scale of that investment, which is arguably not a transformative feature in the sense of not representing a change in the nature of investment, but can be considered transformative in the context of the wider economy. The most notable way in which investment itself could be said to have transformed is the increasing dominance of manufacturing of machinery and equipment, rather than construction, and an increase in investment in services from a very low base as recently as 2000.

There may be some legitimate question as to whether 'transformation' is too strong a word to represent these changes, but it is clear that they are all important and substantial changes in the investment profile of China with serious implications for the relationship between fixed asset investment and energy use. In this chapter the term 'transformation' will be used, with the acknowledgement that a substantial portion of the transformation relates to a change in scale rather than form. The next section looks at the impact of that change on China's use of energy.

Impact of China's investment transformation on energy

The previous section presented discussed evidence for the first five propositions in the argument here: that aggregate energy demand exhibits a variable relationship to final consumption (a component of which is investment in fixed assets), that as economies develop patterns of investment in fixed assets change, and that China has experienced a transformation in its patterns of investment in fixed assets over the past thirty years. The final proposition, that this transformation has impacted China's use of energy, remains to be shown. This section demonstrates that impact using the logic established in Chapter 1 and the methodologies presented in Chapter 2: IOA and SDA. As with the analysis of the relationship between China's production structure and energy demand presented in Chapter 3, and the relationship between China's consumption structure and energy demand presented in Chapter 4, the first step is to define an energy identity for investment:

$$E^t = \sum_i E_i^t = \sum_i \frac{E_i^t}{I_i^t} \cdot \frac{I_i^t}{I^t} \cdot \frac{I^t}{P^t} \cdot P^t \tag{4.1}$$

Here, E^t is the total quantity of energy embodied investments in fixed assets in year t, E_i^t is the energy embodied in investments produced by sector i in year t, I_i^t is the value of investments in fixed assets produced by sector i in year t, I^t is the total value of investments in fixed assets in year t, and P^t is the total population in year t. The right hand side of Equation (4.1) represents the embodied energy intensity of each sector, the share of each sector in total investment, and the scale of total investment per capita and changes in the population. Therefore efforts to reduce the total energy required for investment in fixed assets could focus either on improving the total energy intensity of sectors, incentivising investment into low-energy-intensive forms of fixed asset accumulation, or reducing the quantity of total investment on a per capita basis. Population is not considered a policy lever in this context despite the Chinese government's substantial involvement in influencing population levels.

Following the multiplicative LMDI approach explained in Chapter 2, the change in energy embodied in investment between years is decomposed according to the following general decomposition equation:

$$D_{tot} = \frac{V^T}{V^0} = D_{x_i} D_{x_s} D_{x_q} D_{x_p} \tag{4.2}$$

given the following definitions:

D_{tot} is the total effect: the ratio of total energy embodied in investment in year T to year 0

V^T is total energy embodied in investment in year T

V^0 is total energy embodied in investment in year 0

D_{x_i} is the intensity effect

D_{x_s} is the structural effect

D_{x_q} is the quantity effect

D_{x_p} is the population effect.

Because of the limitations of China's IO data, year T is 2007 and year 0 is 2002.

Each of the decomposition factors $\left(D_{x_k}\right)$ are estimated according to the following equation:

$$D_{x_k} = \exp\left(\sum_i \frac{\left(V_i^T - V_i^0\right) \Big/ \left(\ln V_i^T - \ln V_i^0\right)}{\left(V^T - V^0\right) \Big/ \left(\ln V^T - \ln V^0\right)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right)\right) \tag{4.3}$$

The next section provides an overview of energy embodied in investment in China, based on IOA.

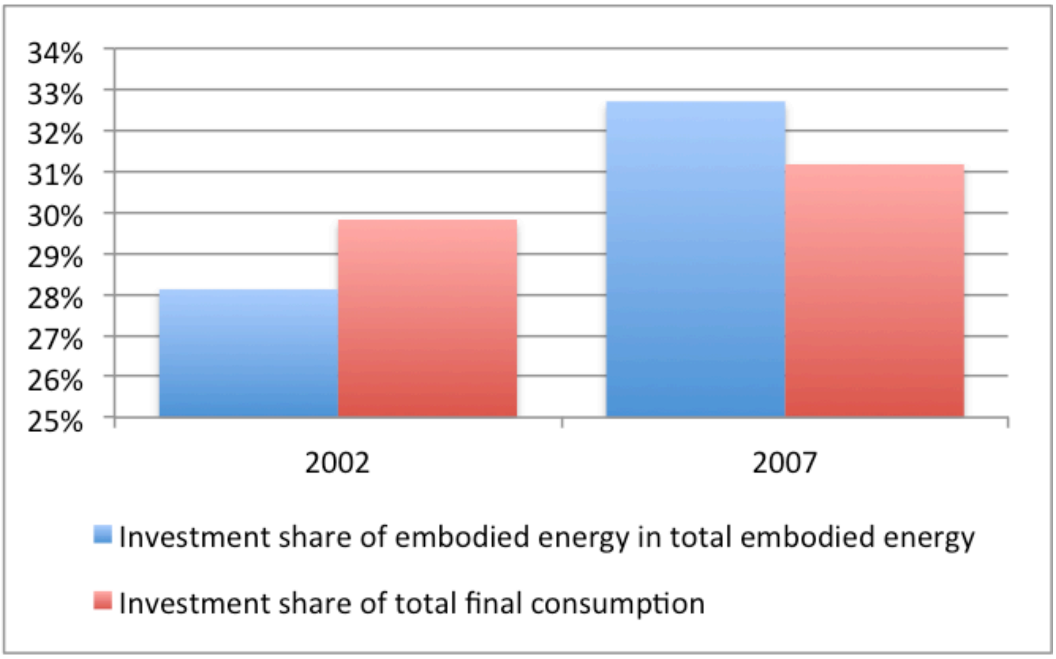
Energy use and investment in fixed assets

The importance of investment to China's economy was demonstrated in the first part of this chapter. This importance is clearly illustrated in Figure 5.1, which shows the rising share of investment relative to GDP, reaching 45 per cent in 2009. Figure 5.5 makes it clear that fixed asset investment is an even more important driver of embodied energy consumption than it is a driver of GDP.

The aggregate data in Figure 5.5 is presented in more detail in Table 5.2. Table 5.2 shows that Chinese investment derived most of its energy needs from coal: 52 per cent in 2002 and 48 per cent in 2007. Petroleum and natural gas provided the next largest share. The decline in relative importance of coal as a fuel source, with petroleum and natural gas becoming proportionately more important, is consistent with the results observed for both rural and urban households and government expenditure.

While coke accounted for less than 8 per cent of all the energy used to satisfy investment demand, investment in fixed assets was responsible for almost three quarters of China's total domestic demand for coke in 2007, up from around two-thirds in 2002. Investment in the construction sector was responsible for half the coke used for all Chinese investment in 2007, or 40 per cent of all the coke embodied in Chinese consumption.

Figure 5.5: Investment share of embodied energy and total final consumption



Source: Author's calculations

Table 5.2: Embodiment of fuels in fixed asset investment (2002 and 2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
		2002			
(PJ)	3,872	2,586	551	412	7,421
fuel share (per cent)	52.2	34.9	7.4	5.5	100
		2007			
(PJ)	6,229	5,090	1,034	757	13,111
fuel share (per cent)	47.5	38.8	7.9	5.8	100

Source: Author calculations

Structural decomposition analysis

Energy embodied in investment increased from 7,421 PJ in 2002 to 13,111 PJ in 2007. The change can be represented with the following expression:

$$D_{tot} = \frac{V^{2007}}{V^{2002}} = \frac{13{,}111}{7{,}421} = 1.77 \tag{4.4}$$

As investment in fixed assets does not include the direct purchase of any primary fuel commodities, total energy use cannot be split into direct and embodied energy components: it is all embodied energy. The average annual growth rate of energy embodied in investment was 12.1 per cent per annum, equating to a doubling time of 5.8 years. As usual, the change in energy embodied in investment can be decomposed into changes in energy intensity $\left(D_i\right)$, sectoral shares $\left(D_s\right)$, per capita investment levels $\left(D_q\right)$ and population $\left(D_p\right)$, such that:

$$D_{tot} = \frac{V^T}{V^0} = D_i D_s D_q D_p \tag{4.5}$$

where D_x are given by the formula established in Equation (4.3). The results of the SDA are presented in Table 5.3. The first row presents estimates of the intensity effect: the amount by which energy embodied in investment would change if investment had remained constant and only the production processes used in producing the investment goods were allowed to change. The result is an overall intensity effect of 0.86, which was the least substantial impact (closer to 1) of all intensity effects estimated in this thesis, including for rural and urban households, government consumption, and as will be seen in the next chapter, exports and imports. The weak intensity effect held across both coal and petroleum and natural gas, though the intensity effect on coke embodied in fixed asset investments was greater than the intensity effects on coke embodied in household or government consumption, or exports. As with the estimates for the other consumer groups, the intensity effect for fixed asset investment had the largest impact on coal, while there was only a minor impact on petroleum and natural gas embodied in fixed asset investments due to the intensity effect.

Table 5.3: SDA – Fixed asset investment

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.80	0.95	0.86	0.84	**0.86**
Investment structure: D_s	0.96	1.00	1.05	1.05	**0.98**
Per capita investment: D_c	2.03	2.03	2.03	2.02	**2.03**
Population:	1.03	1.03	1.03	1.03	**1.03**
D_{tot}	**1.61**	**1.97**	**1.88**	**1.84**	**1.77**
Error:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*

Source: Author's calculations

The second row of Table 5.3 shows the structural effect: the impact of changes in the allocation of investment across the 142 sectors. The relatively small structural effect (minor deviations from 1) is consistent with expectations: the structural effect across all fuel types was a very modest 2 per cent reduction. While the structural effect resulted in a small decrease in coal use, partly offset by a small increase in coke and electric and heat power, there was almost no impact on petroleum and natural gas use.

The fall in the share of investment expenditure on construction was the main structural change to China's investment patterns over the five years, with construction attracting a share of investment expenditure that fell from 66.5 per cent in 2002 to 55.8 per cent in 2007, a decline equal to 10.7 percentage points of investment expenditure. There was also a minor reduction in the amount of energy required to produce a unit value of construction, with the total energy intensity of the sector falling from 157 to 151 GJ / 10,000 RMB. Alongside the reduction in total energy input required was a substitution of petroleum and natural gas for coal, with the coal intensity of construction falling 8 GJ and the petroleum and natural gas intensity rising 4 GJ for every 10,000 RMB of output by the sector. Although construction attracted a declining share of total fixed asset investment over the five years this should not be taken as implying an absolute decline for the sector: investment expenditure on construction in 2007 was still 2.5 trillion RMB higher than in 2002.

At the 142-sector level, there are no other sectors that stand out as having attracted substantial shares of investment expenditure. Taken together however, the 29 manufacturing sectors that produced fixed assets in either 2002 or 2007 attracted an additional 10.4 per cent of investment funds in 2007 compared to their share in 2002, rising to 36.4 per cent of investment expenditure from 26.1 per cent in 2002 (see Appendix E for the list of key manufacturing secotrs, including sector name and line number).

Of those 29 manufacturing sectors the sector that witnessed the greatest rise was the manufacture of automobiles (074.1) which attracted almost 3 per cent more of investment expenditure in 2007 than in 2002, rising to 6.4 per cent, embodying 552 PJ in 2007 (more than double the energy embodied in investment in fixed assets manufactured by the automobile sector in 2002 despite the significant reduction in energy intensity of the sector). The sector that witnessed the second most substantial increase in the share of investment funds attracted was the manufacture of equipment for power transmission, distribution and control (078).

The 41 services sectors (196.1 to 135) combined increased their share of total investment in fixed assets from 5.3 per cent in 2002 to 6.7 per cent in 2007, though their combined energy use was just 246 PJ in 2002 and 283 PJ in 2007. The details of sector level energy use, value and intensity for the sectors discussed in this section are summarised in Table 5.4.

The population effect was without surprise. The estimated effect of population changes on energy use for investment was identical across all fuel types since population is not fuel specific. It was also identical to the estimated impact on energy use for government consumption, since population is not tied either to the government or investment. Naturally, the estimates discussed in Chapter 4 for rural and urban households were different, since rural and urban population growth is not the equivalent of total Chinese population growth: China’s rural population has shrunk while the urban population has grown more rapidly than the national rate. The rate of urbanisation is one of the key drivers of investment in the construction industry, the results of which, with respect to energy use, appear in Table 5.4.

The last of the SDA results to be considered is the quantity effect: the impact on energy use for investment due strictly to changes in the value of investment (in per capita terms). The quantity effect is constant across all fuel types because it is abstracted from the change in relative importance of sectors with divergent energy intensities. China's investment boom has driven energy embodied in investment up by 103 per cent in five years. In the absence of technological and structural effects, the increase in per capita investment would have more than doubled the energy used for fixed asset accumulation. Combining the population effect and per capita quantity effect to estimate the total quantity effect would result in a value of 2.09, or a 109 per cent increase over five years.

Although the investment boom had such a tremendous impact on energy use for investment, the intensity effect partially restrained the final impact, such that actual energy use for investment did not grow quite so dramatically, though a 77 per cent increase in energy use over five years can only be considered slow in relation to a 103 per cent increase. The energy boom had the least impact on coal use, which increased 61 per cent over the period, while petroleum and natural gas use very nearly doubled.

Figure 5.4 indicated that machinery and equipment attracted around a third of total investment. However 'machinery and equipment' is a composite sector, combining 30 of the 142 sectors analysed in this chapter. Similarly, the reference to 'services' in Figure 5.4 is a combination of 41 of the 142 sectors. At the 142-sector level, the only interesting sector in relation to investment is the construction sector. The increase in energy used for investment in the construction sector accounts for 65 per cent of the total increase in energy used for investment.

Table 5.4: Energy consumption embodied in key investment sectors

	Coal	Petroleum and natural gas	Coke	Electricity	Total
Manufacture of automobiles (074.1)					
2002					
Value of investment (Billion RMB)					171
Embodied consumption (PJ)	122	84	21	19	245
Intensity (GJ / 10,000 RMB)	71	49	12	11	144
2007					
Value of investment (Billion RMB)					673
Embodied consumption (PJ)	209	236	66	41	552
GJ per 10,000 RMB	31	35	10	6	82
Manufacture of equipment for power transmission, distribution and control (078)					
2002					
Value of investment (Billion RMB)					27
Embodied consumption (PJ)	21	15	4	3	42
Intensity (GJ / 10,000 RMB)	78	55	15	11	159
2007					
Value of investment (Billion RMB)					67
Embodied consumption (PJ)	117	131	31	30	310
GJ per 10,000 RMB	45	51	12	12	120
Construction (098)					
2002					
Value of investment (Billion RMB)					3,333
Embodied consumption (PJ)	2,895	1,734	339	260	5,227
Intensity (GJ / 10,000 RMB)	87	52	10	8	157
2007					
Value of investment (Billion RMB)					5,885
Embodied consumption (PJ)	4,640	3,302	553	420	8,915
GJ per 10,000 RMB	79	56	9	7	151
Combined manufacturing sectors (033-094)					
2002					
Value of investment (Billion RMB)					1,306
Embodied consumption (PJ)	856	701	200	135	1,892
Intensity (GJ / 10,000 RMB)	66	54	15	10	145
2007					
Value of investment (Billion RMB)					3,842
Embodied consumption (PJ)	1,486	1,563	466	318	3,834
GJ per 10,000 RMB	39	41	12	8	100
Combined services sectors (096.1-135)					
2002					
Value of investment (Billion RMB)					265
Embodied consumption (PJ)	101	121	10	14	246
Intensity (GJ / 10,000 RMB)	38	46	4	5	94
2007					
Value of investment (Billion RMB)					710
Embodied consumption (PJ)	82	170	14	17	283
GJ per 10,000 RMB	12	24	2	2	40

Source: Author's calculations

Implications for China’s energy future

The changing relationship between investment and energy use has important implications for China’s energy future. Figures 4.6 and 4.7 show that investment was responsible for 37 per cent and 43 per cent of China’s energy use in 2002 and 2007, respectively. The rapid growth of investment has been one of the key drivers of China’s rapidly growing energy use since 2002. Determining the implications of the analysis in this chapter for China’s energy future depends critically on expectations of future investment in China and the relationship between investment and energy use.

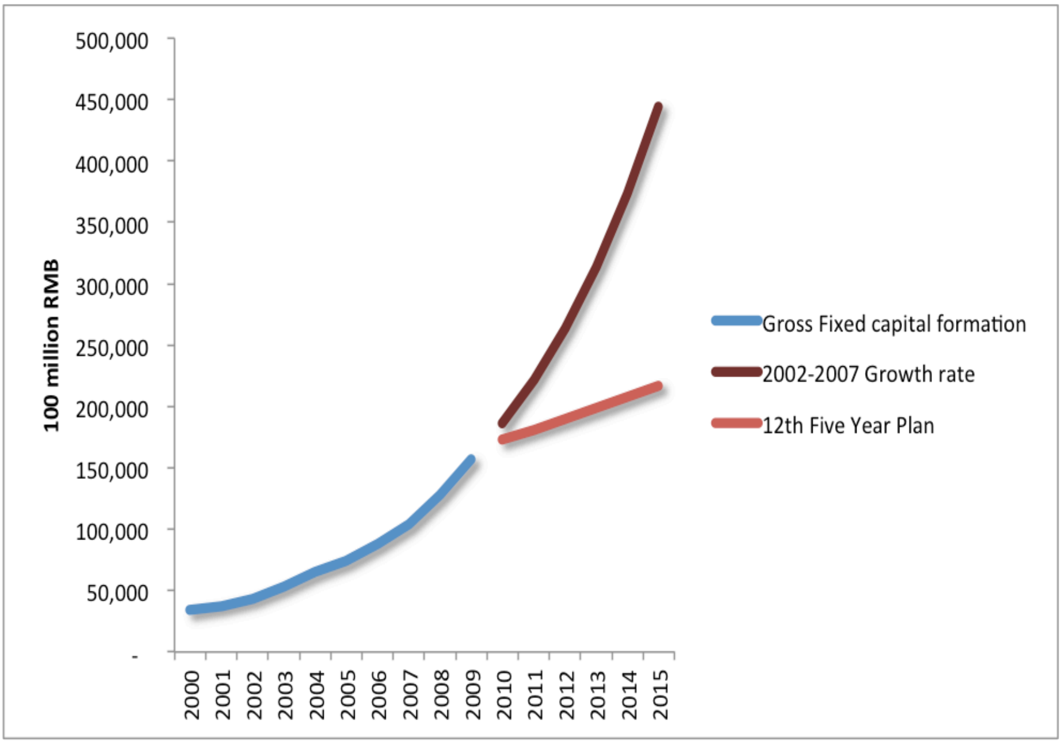
The results of IOA discussed in this chapter indicate that investment embodied 13,111 PJ of energy in 2007, when total investment expenditure was 10,395 billion RMB. There are two investments scenarios worthy of consideration in drawing implications for China’s energy future.

China’s 12th Five-Year Plan provides one case. Figure 4.9 depicts the implications of the 12th Five-Year Plan for gross fixed capital formation and other forms of expenditure. This Plan calls for annual GDP growth of 7 per cent, implying that GDP should reach 51,779 billion RMB by 2015. It also calls for an increase in the share of consumption in GDP. Assuming the consumption share of GDP increases at a rate of 1 percentage point per year entirely at the expense of the capital formation rate, the capital formation rate would fall from 48 per cent of GDP in 2009 to 42 per cent of GDP by 2015. These assumptions imply that investment will reach 21,691 billion RMB by 2015 if the 12th Five-Year Plan targets are met.

As outlined in Chapter 1, the 12th Five-Year Plan also calls for a 16 per cent reduction in energy intensity between the years 2011 and 2015. Making the assumption that this equates to a linear and uniform reduction in energy intensity from 2007, the energy intensity of investment would fall from 0.1261 PJ / 100 million RMB to 0.0996 PJ / 100 million RMB between 2007 and 2015. These figures imply a scenario where investment requires the consumption of 21,614 PJ of energy in 2015 – 65 per cent more than was required for investment in 2007.

The alternative scenario is based on the continuation of current trends. If investment in China were to continue growing at the average annual growth rate of investment that occurred between the years 2002 and 2007, it would reach 44,405 billion RMB by 2015. The average annual growth rate of investment between 2002 and 2007 is significantly lower than was the rate from 2007 to 2009, however those years were characterised by a deliberate government stimulus package that is unlikely to represent future conditions. This scenario depicts annual gross fixed capital accumulation double the amount called for under the 12th Five-Year Plan. The difference between the two is clearly illustrated in Figure 5.6.

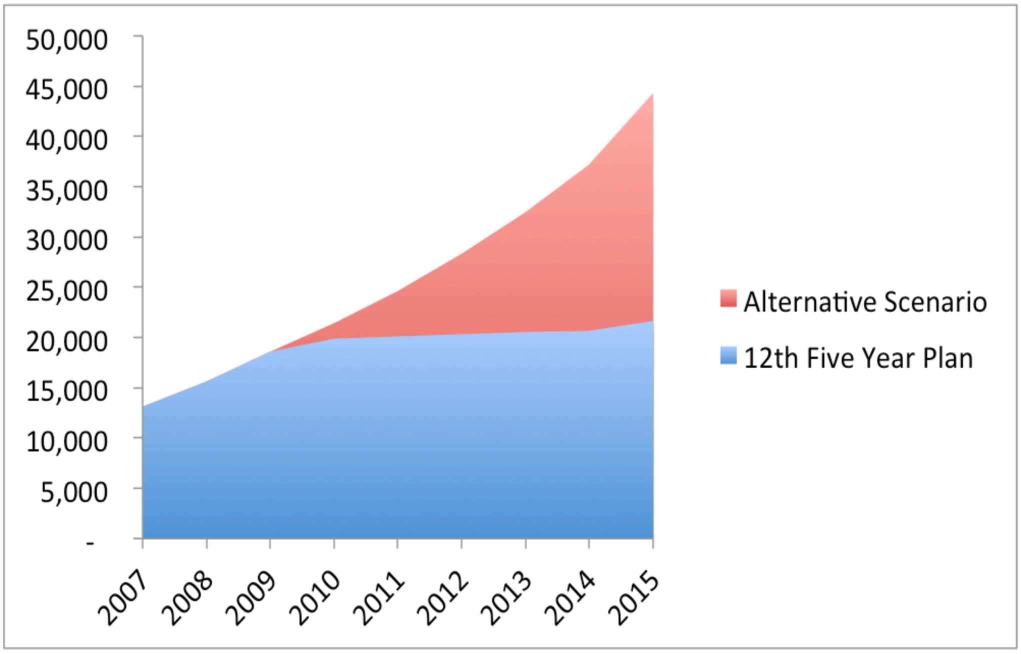
Figure 5.6: Two scenarios for gross fixed capital formation (2011-2015)



Source: Author's calculations

The 12th Five-Year Plan calls for a considerable deceleration of the investment growth rate. While it is relatively simple to create a basic scenario for the value of fixed capital formation, rationalising a scenario for the sectoral distribution of fixed capital formation, or changes to the energy intensity therein, is much more problematic. Therefore, a scenario based upon the assumption that the reductions in energy intensity called for by the 12th Five-Year Plan are realised uniformly and linearly over time is considered. The energy required by each of the two scenarios (the 12th Five-Year Plan scenario, and the alternative scenario) is presented in Figure 5.7.

Figure 5.7: Two scenarios for energy in gross fixed capital formation (PJ) (2011-2015)



Source: Author's calculations

The energy required for investment in 2015 under the 12th Five-Year Plan scenario is only 16 per cent higher than the amount required in 2009 (and 65 per cent higher than the quantity of energy required for investment in 2007). In contrast, the alternative scenario based on recent growth trends for investment and the same energy intensity assumptions as the 12th Five-Year Plan scenario, imply the energy needed by investment in 2015 will be 138 per cent higher than the amount required in 2009 (or 228 per cent higher than the amount required in 2007). Clearly, the growth path for investment will have tremendous implications for China's energy future. While neither of the two scenarios depicted are likely to eventuate, awareness of the energy implications of each hypothetical circumstance will provide an important analytical aid as the true trajectory of China's future investment patterns becomes known.

The analysis in this chapter shows that the energy intensity for investment fell by only 14 per cent between the years 2002 and 2007. This is less than the 12th Five-Year Plan calls for, and also less than the reduction in energy intensity from 2002 to 2007 in other expenditure categories. The implication of this analysis is that even the high (alternative) scenario presented in Figure 5.7 is low, in comparison with observations from the period 2002 to 2007. Close observation of China's investment trends will be important to see how China's energy requirements are likely to develop over the 12th Five-Year Plan period.

Conclusions

Investment is one of the most important drivers of the Chinese economy and one of the main sources of demand for energy use. It is therefore critically important to understand the relationship between investment and energy in the Chinese economy. China has experienced an investment boom over recent decades, even surpassing that of the other 'rapid-catch-up' Asian economies during their boom years. The majority of that investment has been in construction, although the amount of investment in machinery and equipment began approaching the construction levels after 2001 when China joined the WTO.

The impact of that rapid and uneven investment growth on China's energy use has been astounding. The energy embodied in investment increased by 75 per cent over five years, representing an average annual growth rate of 12.1 per cent. The results set out in this chapter also lead to a more specific conclusion: 29 manufacturing sectors (listed in Appendix E) appear to be the most responsible. Although the construction sector attracted more investment than these sectors, investment there did not expand at the rate of the 29 manufacturing sectors taken together. Additionally, while construction does not have a low energy intensity, neither does it have an especially high energy intensity. Were it not for a substantial reduction in the coal intensity of key sectors, the energy needs of investment in 2007 would have been double the amount that was needed in 2002.

Energy for investment, as with consumption, is dominated by coal, but, as with consumption, this is changing: the growth of petroleum and natural gas as sources of energy fuel for fixed asset investment has far outpaced the growth of coal. This is not due to a change in investment patterns, however. It is due to progress in coal efficiency relative to progress in oil and gas efficiency. This is evidenced by the difference in the intensity effects of investment across the four main fuel commodities: while the coal intensity of investment fell 20 per cent from 2002 to 2007, the oil and gas intensity fell just 5 per cent. The result was that while coal used for investment increased by 60 per cent over five years, petroleum and natural gas used for investment very nearly doubled.

This shift to an increasing reliance on oil and gas is a pattern discernible right across China’s economy. Aside from coal, oil and gas, the importance of investment for China’s use of coke, specifically, is even greater than its impact on energy use generally: investment was responsible for three quarters of the coke used in China and the construction sector was responsible for half the coke used in investment.

The analysis of the relationship between investment and energy use has implications for the role of investment in China’s energy future. Investment in construction embodied almost 9,000 PJ of energy in 2007, mostly from coal, oil and gas: equivalent to more than 10 per cent of all the energy embodied in China’s total economic output. Changes in the construction sector would clearly have major ramifications for both energy use and GHG emissions. Similarly, the 29 fast-growing manufacturing sectors have driven a large share of the growth in energy embodied in investment. How long will this continue? Given China’s most recent five-year plan, what might be expected from investment in China, and what are the implications for China’s energy future?

The final section of this chapter drew attention to three types of investor: households, government and firms. It demonstrated that firms have provided both the largest and the fastest growing share of investment in China. It also showed that even during the financial crisis of 2008-2009, when the government made a concerted and determined effort to increase investment, the impact was most notably only in the infrastructure and essential services sectors. The large reliance on self-raised funds for investment calls into question the central government’s ability to strongly influence the investment rate outside of sectors where it has relatively direct control. The takeaway message from that discussion is that investment in China may be driven more by the market than many people believe. While China continues to urbanise, the market incentives for continued investment in construction will remain: one report predicts an additional 350 million urban residents in China by 2025 (McKinsey Global Institue, 2009).

However, ongoing weak external demand, depending on whether it can be reversed soon or not, may change the economic incentives for investment in

China’s manufacturing sectors. If that became the case a significant component of the growth in demand for energy could dissipate. Of course, manufacturers would look for alternative markets and China’s own consumers have long attracted manufacturers from all over the world. Whether they are ready to replace the lost demand from China’s external markets remains to be seen. Even if China’s consumers do become a powerhouse of domestic demand in the near future, they will not displace investment in China. Investment as a driver of China’s growth has a long way to run, and the implications for China’s energy future are profound.

Chapter 6. Energy and trade

Introduction

Since China began its market reforms in 1978 it has become an increasingly important trading nation and trade has become an increasingly important part of China's GDP. In the years since joining the WTO in 2001, China experienced a surge in trade encompassing both exports and imports. How has China's post-WTO membership trade growth affected the economic growth – energy use relationship? China's export growth may be one of the most frequent economic stories told in recent decades (with the exception of the 2008 financial crash). To what extent has external demand driven China's energy use? Similarly, to what extent have imports 'mitigated' Chinese energy use?

Taken together, the two sides of China's post-2001 trade boom have resulted in an important shift in global production processes, with China coming to play a huge role in low-wage manufacturing. Has the transformation of the role of international trade in China's economy resulted in a shift in the location of global energy use? As Dong et al. (2010) point out; international trade separates consumption from production, introducing complications to the study of energy in the economy. It was shown in Chapter 4 that China's growing household consumption generated a steadily increasing demand for energy, both as an energy-fuel and as a factor of production for non-energy products, and in Chapter 5 that China's investment boom has driven a rapid expansion of energy use. However, the thesis has not yet explored the relationship between China's growing domestic demand and energy embodied in imports. China's energy intensity targets could effectively be met by importing large quantities of energy-intensive products without reducing China's actual energy requirements, only changing the location at which energy is used. That may soothe anxieties in China, but it would not address the challenges related to aggregate global energy use, especially GHG emissions.

This chapter addresses the role of trade in China's energy use, using the techniques introduced in Chapters 1 and 2: input-output analysis (IOA) and structural decomposition analysis (SDA). The results have substantial implications for China's role in the world as an energy-using nation.

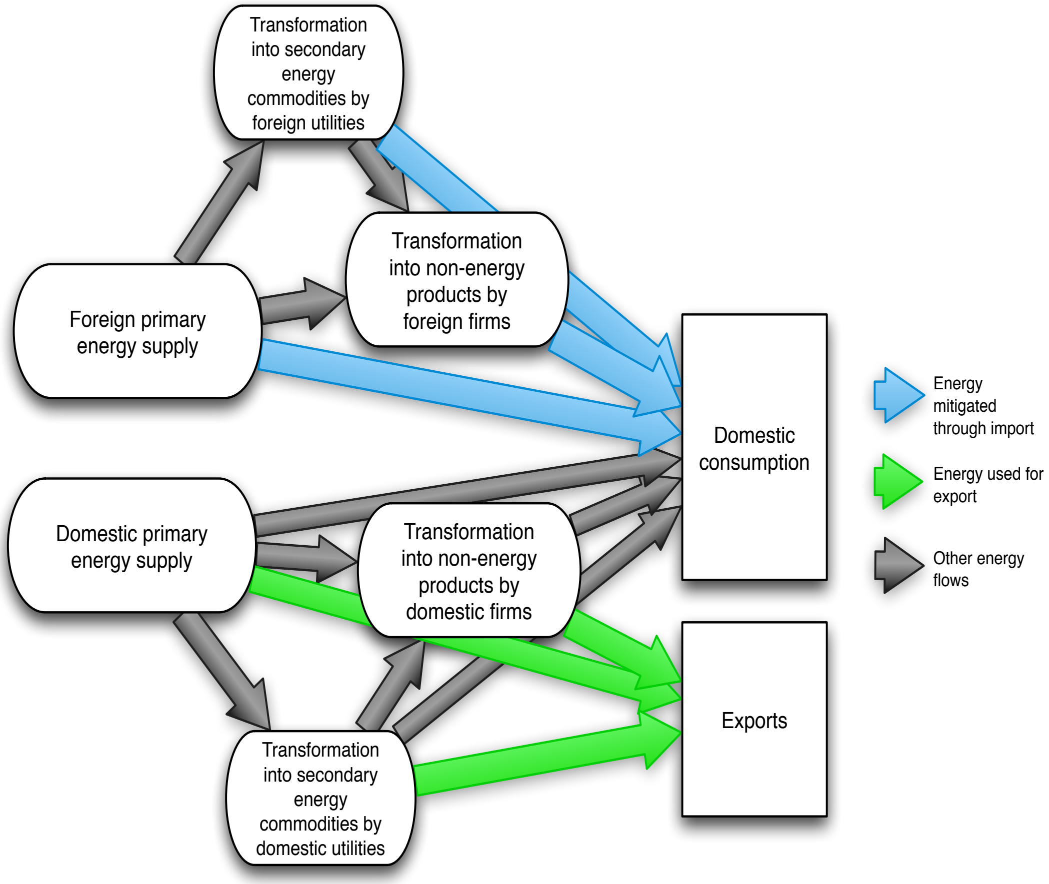
Energy-use in trade

What is meant by energy-use in trade? The answer to this question with respect to exports is very different from the answer with respect to imports. The concept of energy-use in exports is essentially the same as that of energy-use in consumption or investment (discussed in Chapters 4 and 5). It is the concept of embodied energy-use introduced in Chapter 2, explained as "the amount of energy required to deliver a product to final demand" (Miller & Blair, 2009, p. 401). However, in the case of energy embodied in exports the definition should be refined to read, 'the amount of energy required to deliver a product to export'.

The concept of energy-use in imports has a unique and non-intuitive meaning in the context of single-country IO analysis. As the name implies, single-country IO analysis relies on the IO tables of a single country. China's IO tables quantify the imported value of each sector, but they do not provide details on which countries were the exporting country, what the inter-industry transactions were in the exporting country, or who within China consumed what share of imports. It is therefore impossible to know the process by which imported goods were produced, and consequently impossible to estimate the energy embodied in imported goods without building a global, multi-regional IO model incorporating every trading country. The GTAP database is an effort to do just that, but GTAP covers only 57 commodities and the most recent year for which data is available is 2004. Additionally, GTAP is intended to be cross-sectional, so its application to questions of structural change is not ideal (GTAP, 2011). Therefore, rather than creating a separate time series of multi-regional IO tables covering all trading countries, careful interpretation of the import data in China's IO tables is preferred. The approach yields considerably useful information.

Applying the same methodology used to calculate energy embodied in consumption, investment and exports, energy 'embodied' in imports is best interpreted as a measure of mitigated domestic production. This approach is consistent with that used by Liu et al. (2010). An example is illustrative. In 2007 China imported some 15 million RMB of farming sector products. For China to produce that much farming sector output would require the use of 37 PJ of coal, 30 PJ of petroleum and natural gas, 5 PJ of coke and 7 PJ of electricity. By importing those goods, China mitigated the need to use those energy resources domestically. Whether the countries that produced the 15 million RMB of farming sector products used the same, more, or less energy in production is unknown so the energy embodied in imports cannot be accurately estimated. But the domestic energy-use mitigated can be estimated. In the case of 15 million RMB of farming sector output for 2007, 79 PJ of energy was mitigated. These concepts are depicted in the energy flow diagram for trade (Figure 6.1): all the green arrows represent transactions that result in the export (either direct or embodied) of energy, while all the blue arrows represent transactions that result in the import (either direct or embodied) of energy.

Figure 6.1: Energy flow diagram depicting simplified trade flows



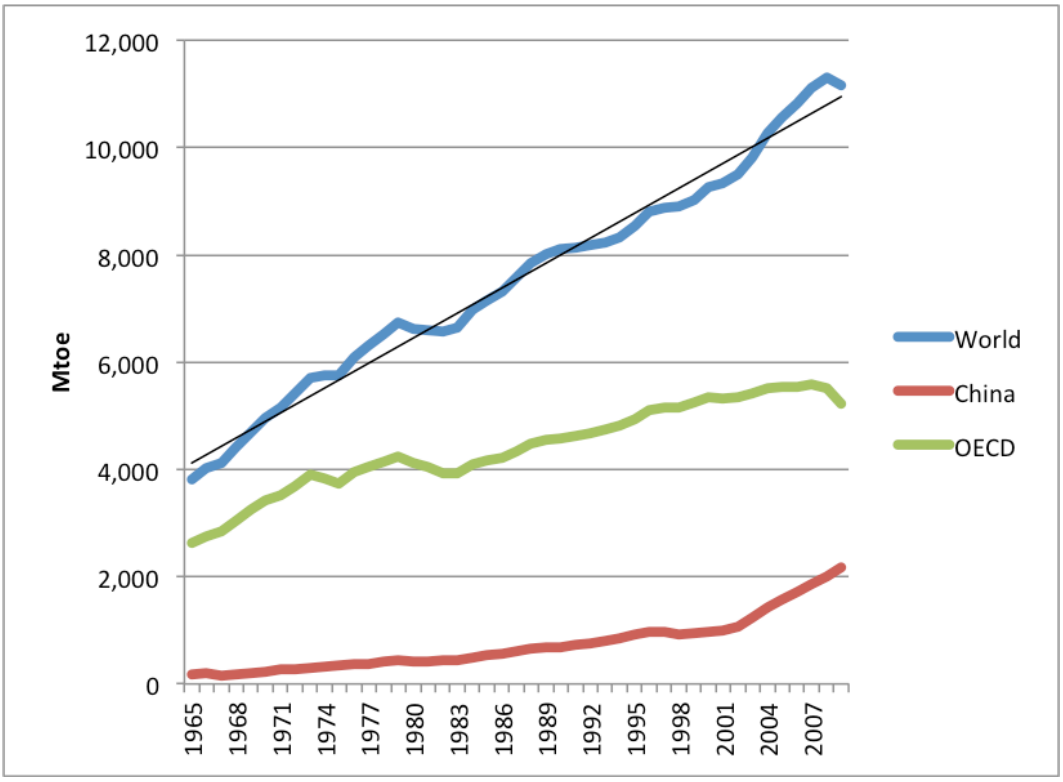
Justification for trade focus

With the interpretation described above, the balance between energy embodied in exports and energy mitigated through imports has a particular implication for

China's position in the global supply chain. *Ceteris paribus*, an increase in energy embodied in exports implies China is occupying a larger share of the energy-intensive parts of global production, and by extension, that the world is outsourcing energy-intensive activities to China. Conversely, an increase in energy mitigated through imports implies that China is outsourcing energy-intensive activities to the rest of the world, such that China decreases its contribution to the energy-intensive part of the production chain. The extent to which this is the case also has important implications in the area of international climate change negotiations: according to Peters and Hertwich (2008), "emissions embodied in trade may have a significant impact on participation in and effectiveness of global climate policies."

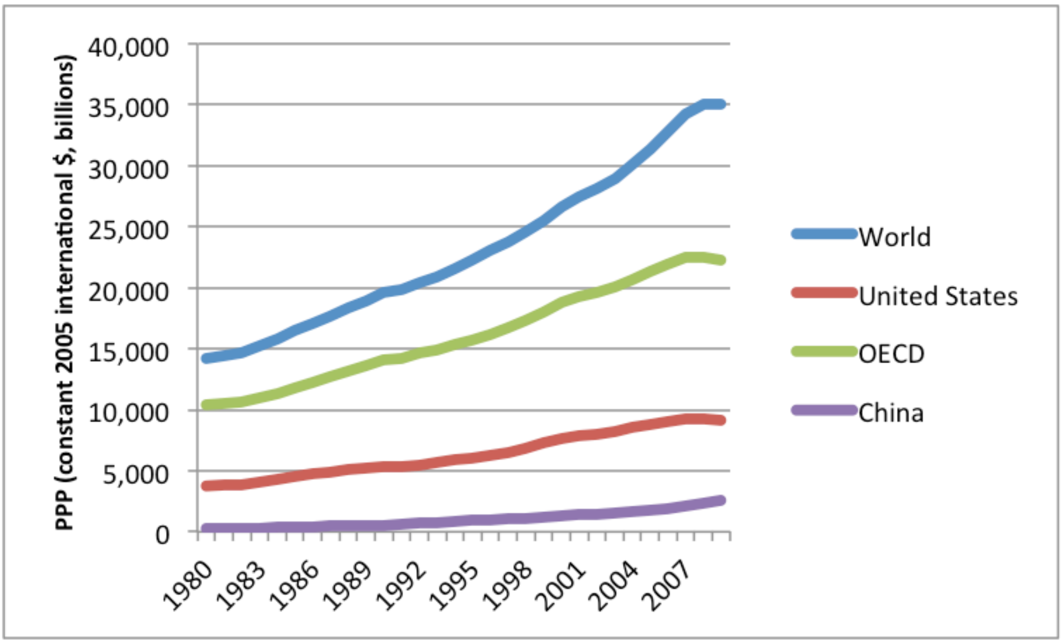
The plausibility of the hypothesis that China has moved to occupy a larger share of the energy-intensive parts of global production is clear from an inspection of global primary energy consumption trends. Figure 6.2 shows world, OECD and Chinese primary energy consumption since 1965. World primary energy consumption has scarcely deviated from the growth trend in the last 44 years, yet OECD primary energy consumption was at the same level in 2009 as it was in 1999. There was a small decline in OECD primary energy consumption post-2008 that was almost certainly due to the global financial crisis, but even prior to 2008 primary energy consumption had levelled in the OECD, with an average annual growth rate between 2000 and 2007 of just 0.6 per cent. At the same time as primary energy consumption in the OECD has apparently ceased to grow, world energy consumption has held to the long-term trend of 2.5 per cent average annual growth. The growth in primary energy consumption has come from non-OECD countries, notably China.

Figure 6.2: Primary energy consumption (1965-2009)



Source: BP (2010)

Figure 6.3: Household final consumption expenditure (1980-2009)



Source: World Bank (2011)

Yet neither the world nor the OECD experienced a corresponding decline in household final consumption expenditure (with the exception of the GFC from 2008 to 2010), nor has China experienced a corresponding increase in household final consumption expenditure (Figure 6.3).

The continual rise of global energy consumption, the levelling-off of OECD energy consumption and the rapid increase in Chinese energy consumption, combined with the steady growth trend of global, OECD and Chinese household final consumption expenditure, imply a shift in location of the production of goods consumed in the OECD to China that is likely to provide at least a partial explanation for the rise of Chinese energy use.

The relative balance of energy embodied in China's exports and energy mitigated through Chinese imports has important implications for interpreting China's energy boom: if China has large quantities of energy embodied in exports relative to the amount mitigated through imports, China's energy boom, in part at least, is simply due to the relocation of global production of energy-intensive products to China. As China's comparative advantage shifts, this is likely to change. Were those energy-intensive process to relocate again, China's energy use would fall but, *ceteris paribus*, there would be no impact on global energy use. Alternatively, if China has not increasingly become a net exporter of embodied energy, then the growth in demand for energy witnessed in China cannot be considered partly due to a geographical shift in global energy-intensive supply side activities, and must be considered as a gross increase in global energy needs caused by demand-side factors in China.

Energy and trade during economic transformation

A central theme of the thesis is non-linearity in the relationship between energy-use and economic growth. Chapter 3 argued that the production transformation experienced by China over the past 30 years has substantially altered the energy-economy relationship. Chapters 4 and 5 treated production as a function of demand, extending the argument to show that non-linear relationships between household, government and investment-driven demand were responsible for a large share of the non-linearity in the relationship between energy use and production. This chapter introduces the final element of the argument: trade. The changes in China’s trade patterns since the beginning of the reform period, but most especially since 2001 when China became a member of the WTO, have been a considerable source of non-linearity in the relationship between China’s energy use and economic growth.

The essential elements of this argument are contained in the following eight propositions: (1) energy use is determined by derived demand; (2) exports are a component of aggregate demand; (3) imports mitigate domestic production and energy-use required to satisfy demand; (4) the relationship between energy use and the components of aggregate demand is not constant; (5) as economies develop, trade patterns change; (6) China has experienced a transformation of its trade patterns since 1978 and an even greater transformation since 2001; (7) China’s trade transformation has substantially altered the relationship between energy-use and aggregate demand; and (8) China’s trade transformation has also substantially altered its role as an energy user in the global supply chain.

The first proposition, that energy use is determined by derived demand, is effectively the same initial proposition used in the arguments presented in Chapters 4 and 5 on the relationships of energy with consumption and investment. The logic of the proposition was expounded in Chapter 2.

The second proposition is trivial given an examination of the basic macroeconomic identity: $Y \equiv C + G + I + X - M$. The identity states that total output is equivalent to household consumption, plus government expenditure, plus investments, plus exports, minus imports. Exports can be treated in this context as simply another component of aggregate expenditure, equivalent in most respects to household consumption, government consumption and investment. The crucial respect in which exports differ from those other components of consumption is that it captures foreign consumption rather than domestic consumption.

The third proposition is a summary of the argument developed earlier in this chapter regarding the conceptualisation of imports in single country IOA. The fourth proposition, that the relationship between energy-use and the components of aggregate demand is not constant, is a restatement of the argument initially developed in Chapter 1 and used throughout this thesis, that there exists a calculable coefficient linking aggregate energy-use to aggregate demand, but that coefficient is not constant over time or across countries. The other four propositions remain to be demonstrated. The next sections address each of those four propositions in turn.

Economic development and patterns of trade

Patterns of international trade depend on key economic development parameters; this understanding has been central to trade theory since Ricardo (1817). Ricardo's model of international trade determined by comparative advantage was based on relative costs of production, or technological effects. Heckscher (1919) and Ohlin (1924) developed the main alternative model of international trade. The Heckscher-Ohlin theory emphases relative factor endowments as the determinants of international trade. According to Feenstra,

> The Ricardian model introduces us to the idea that technological differences across countries matter. In comparison, the Heckscher-Ohlin model dispenses with the notion of technological differences and instead shows how *factor endowments* form the basis for trade. (Feenstra, 2002, p. 1)

In reality, both technological differences (broadly defined) and factor endowments (also broadly defined) are important determinants of trade between nations. Both technological capacity and factor endowments contribute to the cost of production, and it is the cost of production that inevitably determines what gets made where, or in other words, patterns of trade.

Taking broad definitions of both technology and factor endowments, economic development can be described in large part as a change in a country's technological capacity and factor endowment. As a country develops investment in all forms of capital (physical, human, social etc), the nation's endowment of those factors, and technological capacity are expanded, raising the productivity of those factors. As asserted by the fifth proposition in the argument of this chapter, the country's external trading relations are inevitably affected by the process of economic development.

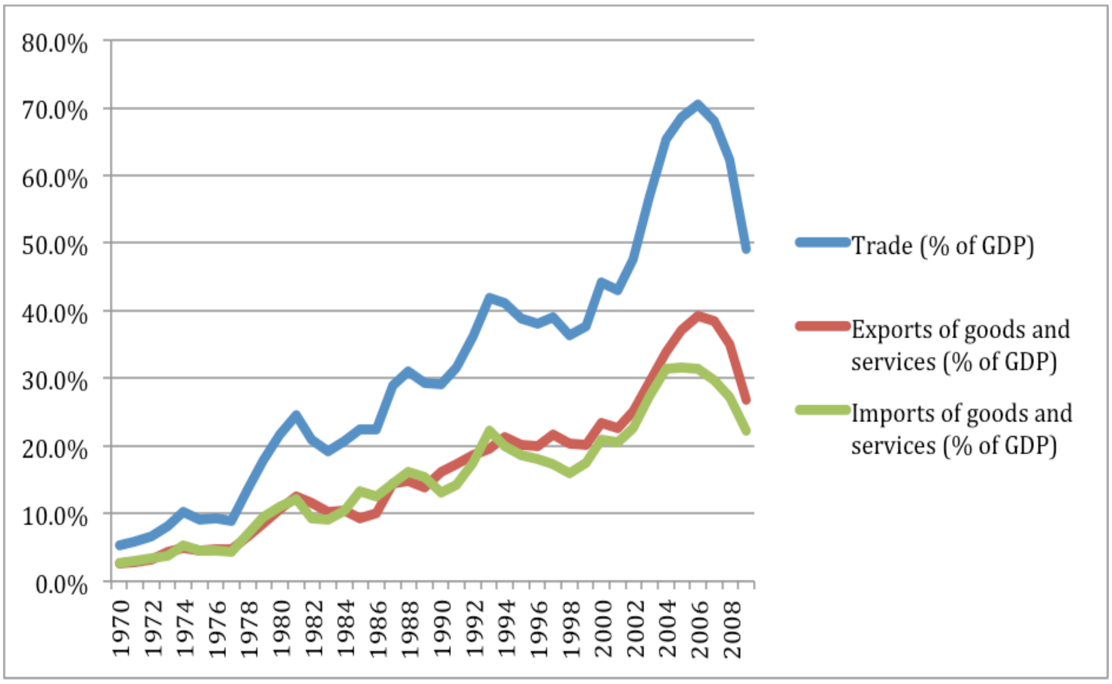
China's trade transformation

The sixth proposition asserts that China has experienced a transformation of its trade patterns since 1978, and an even greater transformation since 2001. The clearest indication of the truth of this statement comes from the rapid growth in China's trade relative to its GDP. Trade as a share of GDP grew from 5 per cent in

1970 to almost 14 per cent by the beginning of the reform period in 1978, then to 43 per cent in 2001: this is an almost constant arithmetic growth rate of approximately 1.2 percentage points per year.

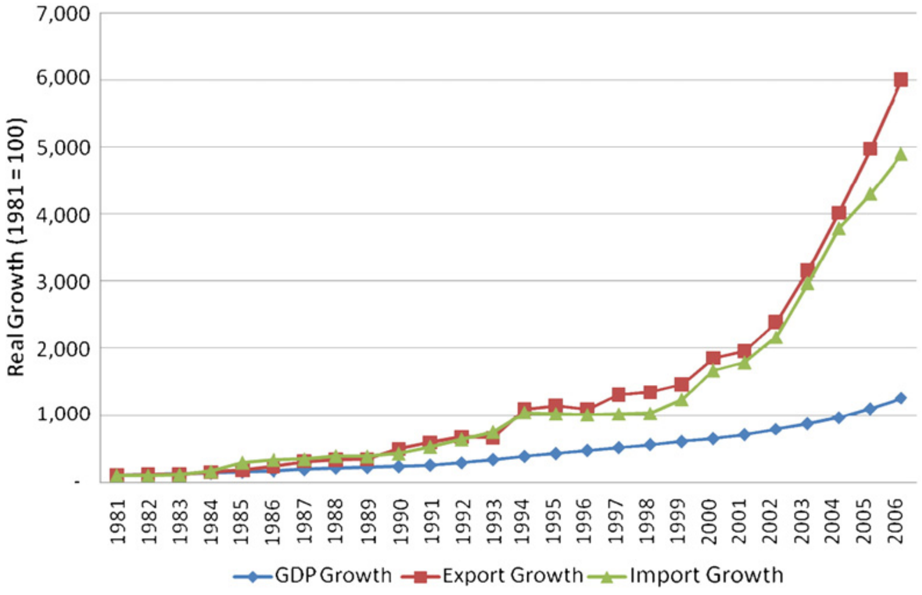
After China's entry to the WTO both imports and exports surged with trade as a share of GDP increasing by around 4.6 per cent each year until 2006 when trade peaked as a share of GDP at 71 per cent and exports reached almost 40 per cent (Figure 6.4). The global financial crisis interrupted this remarkable trend. Considering the period relevant to this study, in 2002 China's exports were 3.1 trillion RMB while imports were 2.7 trillion RMB (NBSC, 2002). By 2007 the values had risen to 9.6 and 7.4 trillion, respectively (NBSC, 2007) meaning China's total trade tripled in five years (in nominal terms). Promoting the export sector has been an abundantly successful development strategy for China over the past three decades: Garnaut argues that the "linking of markets has been a key to accelerated and sustained growth in China" (Garnaut, 2007, p. 1). Trade has become such an integral part of the Chinese economy that any study of energy in China's economy that did not pay particular attention to trade would not be complete.

Figure 6.4: Trade as per cent of China's GDP (1970-2009)



Source: World Bank (2011)

Figure 6.5: GDP, export and import indices: 1980=100 (1981-2006)



Source: Kahrl and Roland-Holst (2008)

Impact of China's trade transformation on energy

Having shown that the patterns of trade flows are not constant over time, but ather that they necessarily change as an economy develops and that China's trade flows have undergone such extensive changes in recent years that the term 'transformation' is applicable, it is now time to examine exactly what the impact of China's changing trade patterns has been on its energy use.

A small number of papers have studied energy embodied in China's trade in recent years, and some have studied the related issue of greenhouse gas emissions embodied in China's trade.

For instance Zhao and Hong (2008) estimate energy embodied in trade for the years 1997, 2000 and 2002. Their study covers 15 sectors but appears to be based on old data since they claim China's energy consumption in 2000 was 5.7 per cent lower than in 1997. They find that changes to exports led to an increase of 46 million TSE of energy consumption in China between 1997 and 2000, while changes to imports led to a decrease of 70 million TSE and changes to net exports resulted in 24 million TSE.

Kahrl and Roland-Holst (2008) use IO analysis to study energy embodied in China's trade for the years 2002 and 2004. They use the 122 sector IO table for 2002 as well as the 39 sector tables for 2002 and 2004. They assume that all sectors use imported content in equal proportions in order to 'net out' the imported content of exports. This process leads them to the conclusion that exports accounted for between 8 and 13 per cent of China's energy use in 2002, rising to between 13 and 19 per cent in 2004. The wide range in their estimates is due to their use of two separate IO tables for 2002. The 122 sector table contains substantially less aggregation bias than the 39 sector table, and generates results at the bottom of the estimation range, while the more aggregated, 39 sector table generates results at the top end of the estimation range.

Guan, Peters and Weber (2009) estimate the factors driving China's carbon emissions between 2002 and 2005 using SDA with China's 42 sector IO tables and assume imports are produced with Chinese technology (the same assumption is applied in this thesis). They find that emissions for Chinese production increased by 46 per cent between 2002 and 2005 and attribute half the increase to exports, in contrast to 36 per cent from investment, 7 per cent from government and 7 per cent from household consumption.

Yan and Young (2010) estimate carbon emissions embodied in China's trade from 1997 to 2007 but assume that imports are produced using US technology. They do not report the effects of trade on energy use since their interest is global carbon emissions.

Liu et al. (2010) estimate energy embodied in China's trade for the years 1992, 1997, 2002 and 2005. Their data contains 52 separate industries. Their approach is the most similar to that used in this thesis and their results are summarised below, with Table 6.1 showing energy embodied in exports and imports; Table 6.2 summarises the SDA results.

Table 6.1: Energy embodied in exports and imports (Liu et al., 2010)

	1992	*1997*	*2002*	*2005*
Exports	588.69	764.15	993.60	2,806.85
Imports	-579.80	-732.48	-944.60	-2,554.55
Net	8.89	31.67	49.00	252.30

Units: Exajouls (EJ) = 10^18
Source: Liu et al. (2010)

Table 6.2: SDA results (Liu et al., 2010)

	1992-1997	**1997-2002**	**2002-2005**
Direct primary energy efficiency	-86.4	-60.6	4.7
Primary energy consumption structure	-5.3	-4.7	0.3
Structure of intermediate inputs	-18.1	1.6	12.9
Structure of exports	3.9	3.1	1.8
Scale of exports	205.8	160.7	80.4
Total increment	100	100	100

Source: Liu et al. (2010)

The findings of Liu et al. (2010) indicate that from 1992 to 2005 China was a net exporter of energy and that the growth in energy embodied in exports was almost entirely due to the growth in the value of exports, though they identify a slight shift toward energy intensive sectors in each sub-period.

The rest of this section adds to this body of literature on the energy content of trade, focusing on the period since China's post-WTO membership trade boom. As with earlier chapters, structural decomposition analysis (SDA) is used to analyse the changing relationship between China's trade and its energy use. As usual the first step is to define a modified energy identity, in this case for the energy embodied in net exports:

$$E^{nx} = \sum_i \left(E_i^x - E_i^m\right) = \sum_i \left(\frac{E_i^x}{X_i} \cdot \frac{X_i}{X} \cdot \frac{X}{P} \cdot P - \frac{E_i^m}{M_i} \cdot \frac{M_i}{M} \cdot \frac{M}{P} \cdot P \right) \tag{6.1}$$

The notation depicting time is dropped from Equation (6.1) for simplicity but each term refers to the same single year. E^{nx} is the total quantity of energy embodied in net exports, i identifies the sector, E^x represents energy embodied in exports, X represents the value of exports, P is the population, E^m represents energy 'mitigated' through imports, and M represents the value of imports. Equation (6.1) says that energy embodied in net exports is equal to the energy intensity of each sector multiplied by each sector's share of exports multiplied by the total value of exports, minus the energy intensity of each sector multiplied by each sector's share of imports multiplied by the value of imports. While the production, consumption and investment energy identities are related to matters of sustainable development, the trade energy identity is also related to the geographic separation of production from consumption of energy-intensive products.

As with other chapters the change in embodied energy use between years is decomposed separately for energy embodied in exports and energy 'mitigated' through imports according to the following general decomposition equation:

$$D_{tot} = \sum_j D_{j_{tot}} = \sum_j \frac{V_j^T}{V_j^0} = \sum_j D_i^j D_s^j D_c^j D_p^j \tag{6.2}$$

given the following definitions:

D_{tot} is the total effect: the ratio of total embodied energy in year T to year 0

V_j^T is total embodied energy consumption in year T for imports and exports.

V^0 is total embodied energy consumption in year 0 for imports and exports.

D_i^j is the intensity effect for imports and exports.

D_s^j is the structural effect for imports and exports.

D_c^j is the quantity per capita effect for imports and exports.

D_p^j is the population effect for imports and exports.

Dropping terminology specifying exports or imports (for simplicity), each of the decomposition factors is estimated according to the LMDI equation:

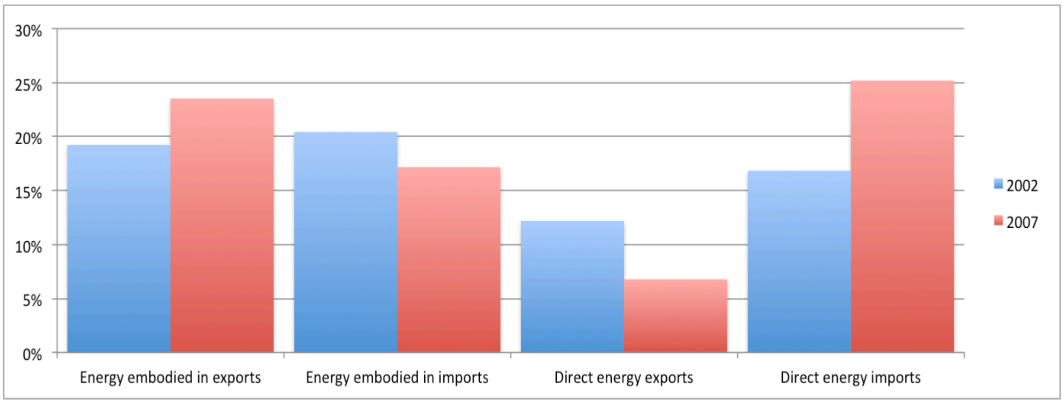
$$D_{x_k} = \exp\left(\sum_i \frac{\left(V_i^T - V_i^0\right) \big/ \left(\ln V_i^T - \ln V_i^0\right)}{\left(V^T - V^0\right) \big/ \left(\ln V^T - \ln V^0\right)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \right) \tag{6.3}$$

Overview: energy in imports and exports

China's total energy consumption, the amount of energy required to produce all of China's output in 2002, was approximately 36,000 PJ, rising to 56,000 PJ by 2007. However, the total final energy use, the amount of energy required to supply final consumption (including household, government, investment and exports after adjusting for changes in inventories) was considerably lower: 26,000 PJ in 2002 and 40,000 in 2007. Figure 6.6 summarises some of the key results of this chapter, in relation to total final energy use. The first pair of columns shows the energy embodied in exports of non-energy goods as a share of China's total energy consumption in the corresponding year. In 2002, non-energy exports accounted for 19 per cent of China's energy use for total final consumption, rising to almost 24 per cent by 2007. This is in contrast to energy mitigated through imports, which fell from 20 per cent in 2002 to 17 per cent in 2007. According to these estimations, China went from being a very minor net importer of embodied energy to being a moderate net exporter. In other words, in 2002 non-energy net trade flows allowed China to avoid a very small amount of energy use, but by 2007 non-energy net trade flows imposed an additional energy-use burden on China, accounting for around 6.4 per cent of China's energy use embodied in total final consumption, or 4.5 per cent of China's total energy use.

In direct energy trade, China was already a net-importer in 2002, but only moderately so: 12 per cent of China's energy use for final consumption was exported directly as energy-fuels (more than half as coal and almost one third as oil and gas) while imports provided 17 per cent of the energy required for total final consumption (12 per cent of total energy use in China), almost entirely in the form of petroleum imports.

Figure 6.6: Energy in trade flows relative to total final energy use



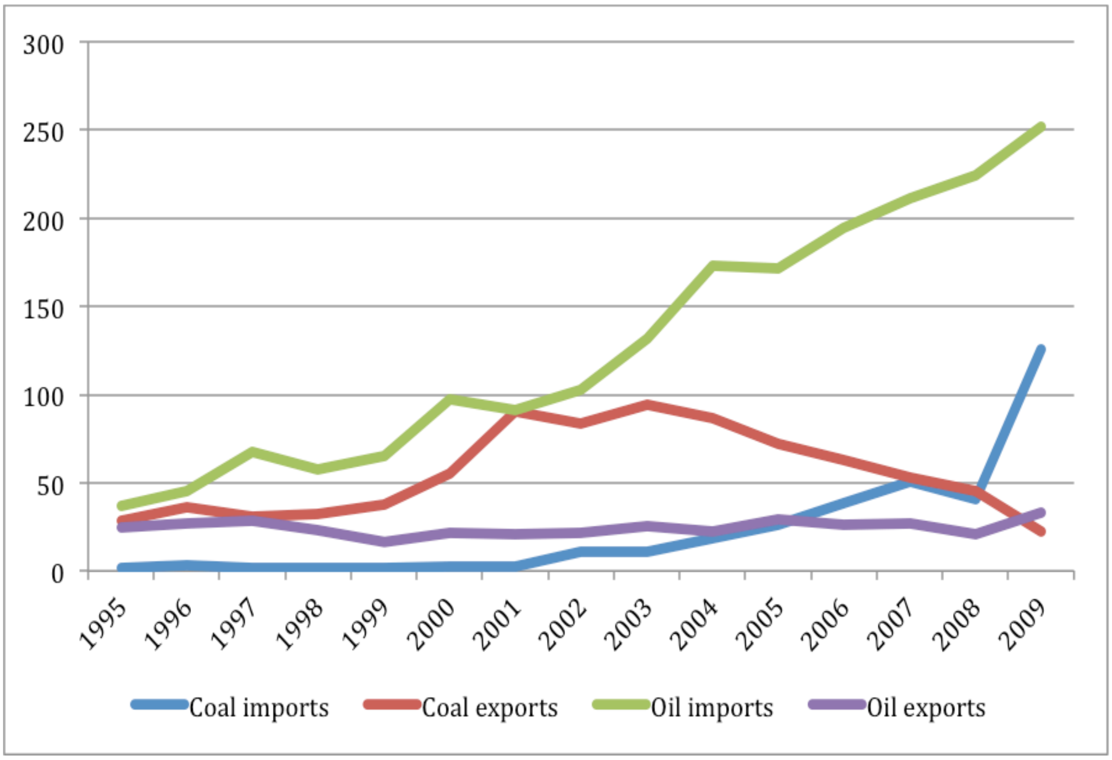
Note: Values are per cent of total final energy use (the sum of total energy use for all consumer groups)
Source: Author's calculations

The trends can be seen more clearly in Figure 6.7, the data for which come from the National Development and Reform Commission (NDRC)'s *Energy Data 2010*. While the units reported by the NDRC are not consistent with the IO analysis, the figure reveals the extent to which oil imports dominated other direct energy trade as well as how effectively the government contained coal exports, which peaked in 2003 at 94 Mt before falling back to just 22 Mt by 2009.

A significant part of the fall in China's direct energy exports over the five-year period to 2007 was a response to central government initiatives aimed at increasing the domestic availability of energy fuels. The measures appear to have been successful, as China's direct energy exports fell from 9 per cent of total energy use in 2002 to less than 5 per cent in 2007, though the importance of government intervention relative to changes in China's competitive and comparative advantage is not easy to determine. Figure 6.7 makes clear that the majority of the fall in direct energy exports was obtained through reduced coal exports. Comparing Table 6.3 and Table 6.4 supports this conclusion, since direct exports of petroleum and natural gas, coke and electricity all increased marginally over the period.

While China managed to reduce the amount of energy it exported directly as energy-fuels, the amount of energy used to produce Chinese exports rose dramatically over the period so that by 2007 China's non-energy exports embodied a substantial amount more energy than was mitigated by non-energy imports (2,500 PJ, or 4.5 per cent of China's total energy use). Energy embodied in non-energy exports almost doubled, to 9,300 PJ. During the same period energy 'mitigated' through imports rose by less than one fifth, to 6,800 PJ. The result was that China's non-energy trade went from acting as a source of net energy-use mitigation in 2002 (though a small one) to a substantial source of demand for Chinese energy use by 2007.

Figure 6.7: China's coal and oil import and export volume (million tons)



Note: Units are not specified beyond "t". Tons of Standard coal equivalent is the assumed unit.
Source: NDRC, Energy Data 2010 (2010)

Energy use and exports

Energy can be exported either directly as an energy fuel or indirectly, embodied in a non-energy good or service. The values of direct, embodied and total energy exports of each fuel type for 2002 are summarised Table 6.3 and for 2007 in Table 6.4. Direct energy exports in 2002 were considerable at 3,200 PJ, though substantially lower than embodied exports at 5,000 PJ. The discrepancy expanded over the five years to 2007 as direct energy exports shrank to 2,700 PJ and embodied energy exports grew to 9,300 PJ.

Table 6.3: Direct, embodied and total energy export by fuel (2002)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct exports (PJ)	1,826	968	389	35	3,218
(per cent of total fuel consumption)	6.9	14.4	25.9	2.9	8.9
Embodied exports (PJ)	2,222	2,231	281	344	5,078
(per cent of total fuel consumption)	8.3	33.1	18.7	28.3	14.1
Total exports (PJ)	4,048	3,199	670	378	8,296
(per cent of total fuel consumption)	15.2	47.4	44.7	31.2	23.0

Note: total fuel consumption is the estimate of fuel use required to produce total Chinese output
Source: Author's calculations

Table 6.4: Direct, embodied and total energy export by fuel (2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct exports (PJ)	1,126	1,035	465	52	2,678
(per cent of total fuel consumption)	2.6	12.5	22.4	2.6	4.8
Embodied exports (PJ)	3,764	3,953	825	752	9,294
(per cent of total fuel consumption)	8.6	47.7	39.7	37.4	16.6
Total exports (PJ)	4,889	4,988	1,290	804	11,972
(per cent of total fuel consumption)	11.2	60.2	62.2	40.0	21.4

Note: total fuel consumption is the estimate of fuel use required to produce total Chinese output
Source: Author's calculations

The change in exports of energy from China over the five years following WTO membership can be calculated from Tables 6.3 and 6.4. While total energy exports grew at a relatively modest average annual rate of 7.6 per cent, the growth of energy embodied in non-energy exports was much higher, at an average annual rate of 12.9 per cent. The next section decomposes the change in energy embodied in exports using SDA.

Structural decomposition analysis

Exports of energy from China increased by almost 50 per cent over the five years to 2007. This is expressed in equation form below, where $D_{\exp_{tot}}$ is the ratio of total energy exports in 2007:2002, $V_{\exp}^{T}$ is the total energy exported in 2007, and $V_{\exp}^{0}$ is the total energy exported in 2002, measured in PJ.

$$D_{\exp_{tot}} = \frac{V_{\exp}^{2007}}{V_{\exp}^{2002}} = \frac{11,972}{8,296} = 1.44 \tag{6.4}$$

Separating the direct energy consumption from the embodied energy consumption produces the following results:

$$D_{d_{tot}} = \frac{2,678}{3,218} = 0.83 \tag{6.5}$$

$$D_{e_{tot}} = \frac{9,294}{5,078} = 1.83 \tag{6.6}$$

Energy embodied in non-energy exports grew faster than energy embodied in any other final-use category studied in this thesis, embodying almost twice as much energy in 2007 as in 2002. This compares with an increase of around half for energy embodied in government services, around a third for energy embodied in urban household consumption, and almost no change in energy embodied in rural household consumption. Only energy embodied in investment came close to growing as rapidly as that embodied in exports.

The change in exports of embodied energy can be decomposed into changes in energy intensity$\left(D_i\right)$, export patterns $\left(D_s\right)$ per capita export quantity $\left(D_c\right)$, and population$\left(D_p\right)$, such that:

$$D_{tot} = \frac{V^T}{V^0} = D_i D_s D_c D_p \tag{6.7}$$

where the values of D_x are given by the formula established in Equation (6.3). Consistent with previous chapters, interpreting the values of D_x is relatively simple: a value of 1 implies zero impact, a value between 0-1 implies the factor contributed to a decline in embodied fuel consumption (for example: 0.80 implies a 20 per cent decline) and a value greater than 1 implies that that factor contributed to an increase in embodied fuel consumption (for example: 1.10 implies a 10 per cent increase).

The results of the SDA are presented in Table 6.5. The first row presents estimates of the intensity effect: the amount by which energy embodied in non-energy exports would change if only China's production processes had been allowed to alter, but the quantity and composition of exports had been held constant between 2002 and 2007. The results estimate substantial energy savings due to changes in the production process, with the estimated reduction in coal use greatest by a substantial margin.

Table 6.5: SDA - Exports

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.56	0.63	0.87	0.72	**0.62**
Export structure: D_s	1.11	1.04	1.25	1.12	**1.09**
Exports per capita: D_c	2.62	2.60	2.61	2.61	**2.61**
Population: D_p	1.03	1.03	1.03	1.03	**1.03**
Total: D_{tot}	**1.67**	**1.74**	**2.89**	**2.15**	**1.80**
Error:	*-0.02*	*-0.03*	*-0.04*	*-0.04*	*-0.03*

Source: Author's calculations

The second row of Table 6.5 shows changes in the export bundle (the structural effect). The results show that China's export bundle in 2007 contained more energy intensive products than the 2002 bundle, driving an estimated 9 per cent increase in energy embodied in exports. In contrast to the structural shift in domestic consumption that moved toward oil and gas intensive sectors, the change in the export bundle moved furthest toward coke and coal-intensive products, while the observed shift of exports intensive in petroleum and natural gas was relatively modest.

The export pattern resulted in a move toward energy-intensive products. This was largely due to the increase in exports of products from three sectors: rolling of steel (059), manufacture of communication equipment (082) and manufacturing of computers (084). In the five years after WTO membership, exports of rolled steel rose from 0.4 to 3.3 per cent of Chinese exports while exports of communication equipment rose from 1.5 per cent to 5 per cent and exports from the computer manufacturing sector rose from less than 1 per cent to almost 10 per cent of China's exports in 2007. No other sectors expanded their share of Chinese exports as substantially as these three sectors.

The expansion of these sectors' share of China's total exports came primarily at the expense of the share of exports from three sectors: manufacture of other electrical machinery and equipment (081), manufacture of other electronic equipment (087.1) and wholesale and retail trades (108). The details of energy use in these six key sectors are summarised in Table 6.6.

While the SDA results estimate a modest increase in energy embodied in exports due to the structural effect, the estimated impact of the quantity effect is very large, at 2.61. The implication is that the growth of China's exports per capita following WTO membership contributed to an increase in energy embodied in exports of 161 per cent. If the growth in total exports is considered, rather than exports per capita (calculated by multiplying the quantity and population effects) the result is 2.68. This implies that the quantity effect of China's export boom almost tripled the quantity of energy embodied in exports over five years. In relative terms, this is the single largest component of growth in China's energy use. The next largest decomposed source of energy use growth was the quantity of investment, with an estimated quantity effect per capita of 2.03. The effect was somewhat restrained by improvements in the energy intensity of exported sectors exceeding the improvements of non-exported sectors, but this does not undermine the final analysis: the importance of China's export boom to understanding its energy boom cannot easily be overstated.

Table 6.6: Key sectors embodying energy in Chinese exports

	Coal	Petroleum and natural gas	Coke	Electricity	Value of Exports (Billion RMB)
Rolling of steel (059)					
2002					11
Embodied in exports (PJ)	12	8	3	1	
Intensity (GJ / 10,000 RMB)	102	69	26	12	
2007					312
Embodied in exports (PJ)	231	258	87	40	
GJ per 10,000 RMB	74	83	28	13	
Manufacture of other electrical machinery and equipment (081)					
2002					159
Embodied in exports (PJ)	98	87	13	21	
Intensity (GJ / 10,000 RMB)	62	55	8	13	
2007					168
Embodied in exports (PJ)	68	75	14	18	
Intensity (GJ / 10,000 RMB)	40	45	8	10	
Manufacture of communication equipment (082)					
2002					50
Embodied in exports (PJ)	11	13	2	2	
Intensity (GJ / 10,000 RMB)	23	25	3	5	
2007					480
Embodied in exports (PJ)	139	160	31	34	
GJ per 10,000 RMB	29	33	6	7	
Manufacture of computers (084)					
2002					239
Embodied consumption (PJ)	30	34	3	5	
Intensity (GJ / 10,000 RMB)	127	140	13	19	
2007					928
Embodied consumption (PJ)	269	290	56	66	
Intensity (GJ / 10,000 RMB)	29	31	6	7	
Manufacture of other electronic equipment (087.1)					
2002					67
Embodied consumption (PJ)	148	159	15	23	
Intensity (GJ / 10,000 RMB)	134	144	13	20	
2007					11
Embodied consumption (PJ)	4	5	1	1	
Intensity (GJ / 10,000 RMB)	38	44	9	9	
Wholesale and retail trades (108)					
2002					67
Embodied consumption (PJ)	72	66	6	12	
Intensity (GJ / 10,000 RMB)	26	24	2	4	
2007					401
Embodied consumption (PJ)	66	101	7	12	
Intensity (GJ / 10,000 RMB)	16	25	2	3	

Source: Author's calculations

Energy use and imports

As is the case with China's exported energy, China imports energy both directly as an energy fuel and indirectly, embodied in a non-energy good or service. Because of the unique interpretation of energy in imports in the context of single-country IOA it does not make sense to think of direct energy imports and mitigated energy use due to non-energy imports as additive. Direct energy imports measure energy that is actually used in China, despite originating abroad. This is distinct from energy-use mitigated by importing non-energy goods. Therefore, the values of direct and embodied energy in imports of each fuel type for 2002 are summarised in Table 6.7 and for 2007 in Table 6.8 but 'total' energy in imports is not reported.

Direct energy imports were already considerable in 2002 at 4,400 PJ (almost two thirds of the petroleum and natural gas required for China's total output was imported), substantially higher than direct energy exports, and grew rapidly, approaching 10,000 PJ by 2007. These results are in accordance with those in Figure 6.7, which shows China's annual oil and coal imports and exports from 1995 to 2009. Taking just the two data points from the IO tables indicates that direct energy imports grew at an astonishing average annual rate of 17.5 per cent, doubling every 4 years, very close to the average annual growth rate of 16.3 per cent using the NDRC yearly data depicted in Figure 6.7.

The change in energy mitigated through imports over the five years following WTO membership can be calculated from Table 6.7 and Table 6.8. In 2002, energy mitigated through imports of non-energy use was 5,400 PJ, slightly larger than the energy embodied in China's exports. China's imports of non-energy products grew over the five years but at a much slower rate than energy embodied in exports, such that by 2007 mitigated energy use approached 6,800 PJ, considerably less than the 9,300 PJ embodied in exports. The average annual growth rate of mitigated energy use due to non-energy imports was a modest 4.7 per cent. The next section decomposes the change in embodied energy consumption using SDA.

Table 6.7: Direct, embodied and total energy import by fuel (2002)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct imports (PJ)	236	4,184	14	8	4,442
(per cent of total fuel consumption)	0.9	62.1	0.9	0.7	12.3
Mitigated energy due to import (PJ)	2,367	2,282	362	381	5,392
(per cent of total fuel consumption)	11.1	11.7	12.5	13.6	14.9

Note: total fuel consumption is the estimate of fuel use required to produce total Chinese output
Source: Author's calculations

Table 6.8: Direct, embodied and total energy import by fuel (2007)

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	Total Energy
Direct imports (PJ)	1,097	8,787	50	15	9,949
(per cent of total fuel consumption)	2.5	106.1	2.4	0.8	17.8
Mitigated energy due to import (PJ)	2,583	2,905	706	590	6,784
(per cent of total fuel consumption)	5.9	35.1	34.0	29.4	12.1

Note: total fuel consumption is the estimate of fuel use required to produce total Chinese output
Source: Author's calculations

Structural decomposition analysis

As was explained at the beginning of this section on energy use and imports, direct and indirect energy 'imports' are not additive, therefore the growth factor of 'total' energy imports is not reported. Instead, only the growth factor of mitigated energy use due to imports is reported. This can be expressed in equation form below, where $D_{e_{imp}}$ is the ratio of total energy mitigated through imports in 2007:2002, measured in PJ.

$$D_{e_{imp}} = \frac{V_{imp}^{2007}}{V_{imp}^{2002}} = \frac{6,784}{5,392} = 1.26 \tag{6.8}$$

This compares with a growth factor of 1.83 for energy embodied in exports. The change in energy mitigated through imports can be decomposed into changes in energy intensity (D_i), import patterns (D_s) per capita import quantity (D_c), and population (D_p), such that:

$$D_{tot} = \frac{V^T}{V^0} = D_i D_s D_c D_p \tag{6.9}$$

where the values of D_x are given by the formula established in Equation (6.3).

The results of the SDA are presented in Table 6.9. Because of the unique concept of energy mitigated through imports, interpretation of the SDA results for imports is slightly different to SDA results of other final use categories. The first row presents estimates of the intensity effect. The intensity effect is an estimate of the change in energy that would be required for China to produce the imported goods were they to be produced domestically. The total intensity effect was 0.55, implying a 45 per cent reduction in the energy intensity of imported sectors. Importantly, this refers to a change in China's production processes, not a change in the production processes of the producing countries. In this sense, the amount of energy 'mitigated' through imports fell by 45 per cent because Chinese production processes improved their energy-efficiency in the importing sectors by that amount. As has been observed in results from Chapters 4 and 5, the intensity effect had the greatest impact on coal, with China's coal intensity of imported sectors falling by 52 per cent of the five years. The intensity effect of imported sectors had only marginally less impact on petroleum and natural gas, with a 46 per cent reduction in the intensity with which China would have required those fuels to produce its import bundle domestically. The intensity effect had much greater impact on imported sectors than non-imported sectors suggesting at least two explanations.

First, the exposure to international competition experienced by importing sectors has provided a strong incentive to China's producers to reduce costs, including the costs of energy and other intermediate inputs. Since the intensity effect has had the second greatest impact on exporting sectors, this hypothesis could be expanded to include the international competition faced by Chinese exporters. If this hypothesis were correct, it would suggest a policy prescription in direct opposition to that offered by Zhao and Hong (2008), who recommend China restrict the export of energy intensive sectors as a means of reducing the net export of embodied energy. Such a prescription not only ignores alternative policy objectives but takes a short-sighted approach toward the objective of reducing energy consumption: it trades less energy use now for improved energy efficiency permanently. The policy prescription suggested here is that encouraging trade (not only, but especially imports) across a wide range of sectors could be an effective means of reducing the energy intensity of domestic production. This policy recommendation is even stronger in the context of China's climate change commitments since the most GHG intensive fuel types appear to be most responsive to trade exposure.

The second (and most likely much more important) factor relates to China's foreign trade and investment policies, which specifically target technology transfer into China. A common practice for the large multinational companies that account for the largest proportion of global trade is to establish a presence in countries at both ends of a trade flow. Chinese laws regarding foreign companies registering in China are designed to strongly encourage technology transfer to Chinese firms, either by requiring a joint venture with an existing Chinese firm or requiring specific technology transfer strategies for wholly foreign-owned enterprises (WFOE). Since traded sectors attract the majority of joint ventures and WFOEs, this approach almost certainly contributes to the substantial differential in the improvement of energy intensity in traded sectors compared with primarily domestic sectors.

Table 6.9: SDA - Imports

	Coal	Petroleum and Natural Gas	Coke	Electricity and Heat Power	**Total Energy**
Fuel intensity: D_i	0.48	0.54	0.85	0.66	**0.55**
Import structure: D_s	0.98	1.03	0.99	1.03	**1.01**
Imports per capita: D_c	2.21	2.16	2.22	2.20	**2.19**
Population: D_p	1.03	1.03	1.03	1.03	**1.03**
Total: D_{tot}	**1.08**	**1.25**	**1.92**	**1.53**	**1.24**
Error:	*-0.01*	*-0.02*	*-0.03*	*-0.02*	*-0.02*

Source: Author's calculations

The second row of Table 6.9 shows changes in the import bundle (the structural effect). The results show that changes in the import bundle had almost no net effect on the energy mitigated through imports. This is despite some substantial changes in the relative share of imports of particular sectors. Most notably, the manufacture of electronic components (085) increased from just under 10 per cent of imports in 2002 to almost 17 per cent in 2007. The manufacture of computers (084) also increased substantially, from less than half a per cent of imports to almost 5 per cent. The increase in the relative share of imports of these sectors came at the expense of several other sectors, most notably the manufacture of other electrical machinery and equipment (087.1) which fell from almost 6 per cent to just 1 per cent of imports. The energy content of these key sectors is summarised in Table 6.10.

Imports grew substantially in China in the last decade (Figure 6.5) and the impact of import growth on energy use was also substantial. Table 6.9 shows the estimated quantity effect (imports per capita) on energy use in imports was 2.19. The implication of this result is that were China to have foregone imports and produced the import bundle domestically, the energy required to produce that bundle would have more than doubled over the five years due to the quantity effect alone. Another way to think of this is that the energy use mitigated by China increased by 119 per cent over five years because of the increase of imports per capita. Taken as total imports (estimated by multiplying the quantity effect and the population effect) the impact was 2.26, an increase of 126 per cent.

Taken together, the rapid increase in imports and the rapid improvement in China's energy intensity in import sectors, resulted in a more modest growth factor of 1.24. The implication is that China would have required 24 per cent more energy to produce the 2007 import bundle than would have been required to produce the 2002 import bundle. Importing goods instead of producing everything domestically therefore saved China 24 per cent more energy in 2007 than it did in 2002,

Table 6.10: Key sectors mitigating energy through imports

	Coal	Petroleum and natural gas	Coke	Electricity	Value of Exports (Billion RMB)
Rolling of steel (059)					
2002					11
Embodied in exports (PJ)	12	8	3	1	
Intensity (GJ / 10,000 RMB)	102	69	26	12	
2007					312
Embodied in exports (PJ)	231	258	87	40	
GJ per 10,000 RMB	74	83	28	13	
Manufacture of other electrical machinery and equipment (081)					
2002					159
Embodied in exports (PJ)	98	87	13	21	
Intensity (GJ / 10,000 RMB)	62	55	8	13	
2007					168
Embodied in exports (PJ)	68	75	14	18	
Intensity (GJ / 10,000 RMB)	40	45	8	10	
Manufacture of communication equipment (082)					
2002					50
Embodied in exports (PJ)	11	13	2	2	
Intensity (GJ / 10,000 RMB)	23	25	3	5	
2007					480
Embodied in exports (PJ)	139	160	31	34	
GJ per 10,000 RMB	29	33	6	7	
Manufacture of computers (084)					
2002					239
Embodied consumption (PJ)	30	34	3	5	
Intensity (GJ / 10,000 RMB)	127	140	13	19	
2007					928
Embodied consumption (PJ)	269	290	56	66	
Intensity (GJ / 10,000 RMB)	29	31	6	7	
Manufacture of other electronic equipment (087.1)					
2002					67
Embodied consumption (PJ)	148	159	15	23	
Intensity (GJ / 10,000 RMB)	134	144	13	20	
2007					11
Embodied consumption (PJ)	4	5	1	1	
Intensity (GJ / 10,000 RMB)	38	44	9	9	
Wholesale and retail trades (108)					
2002					67
Embodied consumption (PJ)	72	66	6	12	
Intensity (GJ / 10,000 RMB)	26	24	2	4	
2007					401
Embodied consumption (PJ)	66	101	7	12	
Intensity (GJ / 10,000 RMB)	16	25	2	3	

Source: Author's calculations

Conclusion

The results of the SDA on imports and exports show that China's trade transformation has substantially altered the relationship between energy use and economic growth in China. As a component of aggregate demand, the export market has not only grown in size phenomenally, but has also shifted toward a more energy-intensive bundle of goods. Conversely, a large and growing amount of energy that would otherwise have been used by China to meet aggregate demand has been mitigated through imports. The energy embodied in the production of China's exports has grown far faster since 2002 than has the energy 'embodied' in imports. This provides evidence that China has also come to occupy a more energy intensive part of the international production process. The shift has not been without cost: by domestically using energy for exported products, China has assumed a higher burden of environmental degradation and resource consumption on behalf of other countries (Liu, Xi, Guo, & Li, 2010).

It is fairly clear that trade has been one of the drivers of China's growing energy use, and the explosion of trade following China's entry to the WTO is a main contributor to the 2002 energy boom. This was not only because of the additional energy embodied in China's net exports, but also because of the investment stimulated by the sudden increase in expected demand and the sudden increase in openness toward foreign investors.

What are the implications for China's energy future and its impacts on global energy-use? One consequence of the increased demand for energy has been China's determined search for sources of energy imports, particularly petroleum imports, combined with a restriction on direct energy exports. As a result, China went from being a modest net importer of energy in 2002 to a major net importer of energy in 2007.

As long as China continues to produce the energy intensive component of international supply chains, trade will constitute a major component of the aggregate demand for energy in China. However, this is a locational effect. At the global level exports are not a component of aggregate demand. China will not always fulfil the role of the world's energy user. When China's wages rise, domestic demand will increase, China's low-wage production advantages will decrease, and China's real exchange rate will rise. The combination of these effects is likely to lead to China importing much of what it currently exports, including many energy intensive products. The result will be the loss of one of the three main components of embodied energy demand in China, but the locational change of energy intensive production will have no direct impact on energy embodied in global aggregate demand. It is clear from the estimated structural effects of energy embodied in exports and imports that China is not at this important turning point yet, but it will come. The collapse of external demand in 2008 has hastened that moment.

These results also have important implications for issues related to climate change. A large and growing part of China's GHG emission intensive energy is used in the production of goods consumed outside of China. This has obvious implications for international climate change negotiations, but also has implications for unilateral climate change policies such as those legislated in Australia. The argument is often made in Australia that China's emissions are so much greater and faster-growing than Australia's that any mitigation achieved in Australia cannot have any serious impact on a global scale. The observation that a substantial portion of China's emissions are embodied in exported goods suggests that changes in consumer behaviour in China's export markets will have a substantial impact on emissions related to production in China.

Therefore, market based policies in rich countries that import goods from China which embody GHG emissions can have a greater impact on emissions made in the production country than is often assumed, provided they change consumption patterns in a way that also affects imported products. Additionally, arguments that focus on China's culpability for GHG emissions are undermined by results that demonstrate that the emissions, while produced in China, are embodied in goods consumed by people in countries such as Australia.

Perhaps the most interesting finding of this chapter is that the scale of improvement in the energy intensity of traded sectors was so much higher than non-traded sectors. This suggests a potentially important implication for Chinese policy makers: expanding the number of sectors exposed to trade may considerably improve the energy intensity of China's economy, particularly if China continues to make technology transfer a condition of investment. Foreign companies will, no doubt, resent such a condition and China will eventually find a more subtle approach beneficial, but the evidence here appears to vindicate China's approach so far.

The thesis has now analysed the recent change in the relationship between economic growth and energy use by focusing on both the supply side and each component of the demand side (household consumption, government services, investment and trade) in turn. The final chapter ties the previous analysis together in order to give a sense of the relative importance of the findings of the thesis and to provide a comprehensive view of the implications of the recent stages of economic transformation in China for future energy use in China.

Chapter 7. Conclusion

The economic and social transformation occurring in China is unprecedented. In a speech to AsiaLink, Australian Prime Minister Julia Gillard contrasted the British industrialisation covering a period of 70 years, from 1830 to 1900, and a population of millions in which the British GDP quadrupled, with the Chinese industrialisation covering a period of 30 years and a population of 1.3 billion in which the Chinese GDP grew by a factor of twenty (Gillard 2011). An important part of China's unprecedented transformation is the growth in its use of energy, particularly since 2002 when energy use entered a growth period above the already high growth trajectory. It has been the objective of this thesis to understand the drivers of China's energy growth during the period since 2002. The thesis has addressed four key questions: why has China been consuming so much energy since 2002? Is China's economy peculiar in its huge and rapidly growing consumption of energy or does it conform with the experience of other countries? Do the bewilderingly rapid changes to China's economy alter the relationship between the economy and its use of energy and if so, how? What can we say about China's energy future?

Despite the importance of the energy issue, we still lack a full and sufficient understanding of how energy relates to economic growth. Stern (2011) presents six 'stylised facts' relating energy consumption to economic growth but the six facts are deliberately broad, as they are intended to describe the broad patterns that are observable in all modern economies[1]. The largest part of the literature that focuses on the relationship between economic growth and energy consumption focuses on direct energy consumption. It is relatively easy to measure direct energy use and it is an important indicator for many issues including those relating to climate change commitments, national energy security concerns, local energy supply decisions, and geopolitical questions. The direct-use approach leads to the observation of the Kuznets' curve for energy intensity. Chapter 1 observed that the Kuznets' curve for energy intensity broadly exists in China, just as it exists in many other countries, and that China has been on the declining part of the curve since 1978. But the

[1] The six stylised facts identified by Stern (2011) are: 1: energy use per capita increases over time, 2: energy use per capita increases with GDP per capita, 3: energy intensity is not correlated with GDP per capita, 4. energy/capital is not correlated with GDP per capita, 5. energy intensity declines over time, 6. the energy cost share declines over time.

direct-use approach struggles to explain why this should be so. Measures of direct energy consumption do not reveal much about the relationship between energy use and broader economic changes.

Estimating indirect, or embodied, energy consumption makes it possible to determine how much energy is required to satisfy the demand of a particular group (such as urban households) or for a particular process (such as the construction of buildings). This is important when analysing the long-term demand issues that are at the centre of the thesis. In a country such as China that is undergoing sustained economic transformation, understanding how energy use relates to the demand side of the economy is crucial.

Understanding how energy relates to an economy undergoing transition such as China begins with analysing how energy is used in the production process. Chapter 3 analysed the relationship between energy and production in the Chinese economy, particularly between the years 1997 and 2007. The results of this analysis quantified the importance of expanding output as a driver for energy use in China as well as the importance of changes to the production mix and the role that changes to the technology, or production processes, played in constraining the growth of energy use. These results established empirically the relationship between aggregate energy use and output, but showed that the relationship is not constant over time. This result acts as a foundation for the rest of the analysis in the thesis.

The key to understanding how energy relates to economic growth is to analyse separately the relationships between energy use and the core components of the demand-side: consumption, investment, and trade. These relationships combine to make up the aggregate relationship between energy use and economic growth. Each of the Chapters 4, 5 and 6, considers one of these demand-side components of the overall energy use – economic growth relationship.

Chapter 4 analysed the relationship between energy use and final consumption (including rural household and urban household final consumption as well as government service provision). The very rapid growth of urban household consumption is a prominent feature of this part of the story. As urban households have become richer their consumption preferences have moved toward manufactured products, with food and agricultural products occupying a smaller share of their consumption bundle. On a per capita basis, however, the growth of government service provision generated an even greater relative increase in energy use than the growth of either rural or urban household consumption. A substantial change in the fuel mix was also detected. Though the fuel mix required for the production of both rural and urban household consumption bundles was heavily dominated by coal, the change in consumption patterns since 2002 favoured products intensive in petroleum and natural gas: gone are days when a visitor to Beijing would be shocked by the sea of bicycles, these are the days of being shocked by gridlock on 10 lane freeways and the consequent air pollution.

Chapter 5 analysed the relationship between energy use and investment in fixed assets. The growth of energy use for investment in China has been astounding: the energy embodied in investment increased by 75 per cent over the five years since 2002. Only a substantial reduction in the coal intensity of key sectors prevented that growth factor from being even higher. Chapter 5 identified the surge in investment as a very likely cause of the 2002 energy boom in China. It also revealed 29 manufacturing sectors as those most responsible for the growth in energy embodied in newly-created fixed assets. The construction sector was identified as a substantial driver of the growth of China's energy use and though energy embodied in construction grew less quickly than energy embodied in those 29 manufacturing sectors, construction provided a steadier, more constant source of growth for China's energy use. Construction is therefore a better explanatory factor of China's high growth trend over the whole decade, rather than of the 2002-2005 hyper-boom in energy use.

Energy for investment, as with consumption, is dominated by coal, but, as with consumption the substantial progress in coal efficiency relative to progress in oil and gas efficiency, means the growth of petroleum and natural gas as an energy fuel for fixed asset investment has far outpaced the growth of coal. The importance of investment for China's use of coke, specifically, is even greater than its impact on energy use generally: investment was responsible for three quarters of the coke used in China and the construction sector was responsible for half the coke used in investment.

Chapter 6 analysed the relationship between energy use and trade. The export boom, intensified by China's accession to the WTO, resulted in a dramatic growth in the quantity of energy embodied in goods produced for export. While the other side of China's trade boom, an increase in imports, acted to mitigate a large amount of the energy use that would have otherwise occurred in China, the overall effect was for China to occupy a more energy-intensive part of the global production chain.

Throughout the thesis, results from each chapter have been presented separately from each other, as growth rates. Table 7.1 summarises the results presented throughout the thesis, providing a useful comparison of the relative importance of each of the components (consumption, investment and trade) of the energy use – economic growth relationship. It shows the estimated level of change measured in petajoules (PJ) caused by changes in fuel intensity, structure of consumption/investment/trade, level of consumption/investment/trade per capita and changes in the population for rural households, urban households, government services, investment, exports and imports, and presents the total effects for China as a whole.

Table 7.1: Summary of SDA results: total energy

(PJ)	RHH	UHH	Gov	Inv	Exp	Imp	Total
2002 Embodied energy consumption	1,519	4,123	2,132	7,421	5,078	5,392	**20,272**
Fuel intensity: D_i	-426	-1,449	-486	-1,515	-3,385	-3,668	**-7,261**
Structural effect: D_s	170	482	215	-153	617	49	**1,331**
Per capita consumption: D_c	405	1,852	1,174	7,078	6,695	4,763	**17,204**
Population: D_p	-107	796	70	279	181	158	**1,219**
Total change	**42**	**1,680**	**974**	**5,688**	**4,109**	**1,303**	**12,493**
Error	-2	-117	-6	-2	-107	-89	**-234**
2007 Embodied energy consumption	1,563	5,920	3,112	13,111	9,294	6,784	**32,999**

Note: RHH = rural households; UHH = urban households; Gov = government services; Inv = Investment in fixed assets; Exp = exports; Imp = imports
Total does not include imports. It is the sum of RHH, UHH, Gov, Inv and Exp
Source: Author's calculations

These results are equivalent to the additive form of the log-mean Divisia index (LMDI). The ready conversion between the multiplicative and additive forms of the

LMDI was put forward in Chapter 2 as one of the justifications for selecting the LMDI approach.

Table 7.1 shows a number of interesting results. First, the scale of the growth of China's economy is clearly the biggest driver of overall energy use. Changes in the per capita level of household consumption, government service provision and investment in fixed assets would have, *ceteris paribus*, led to an increase in China's energy use of more than 17,000 PJ over five years from a starting point of only slightly more than 20,000 PJ: almost doubling China's total energy use in five years. But Table 7.1 also indicates what type of per capita consumption growth drove the majority of the 17,000 PJ increase. Chapter 4 showed that the growth of per capita consumption drove up energy embodied in rural household consumption by 30 per cent, while Table 7.1 shows that that the change is relatively minor in relation to other demand-side changes, at just 405 PJ. Conversely, the 45 per cent growth of energy embodied in urban household consumption generated by changes in the per capita consumption level equated to almost 2,000 PJ – almost 50 per cent more than the growth in energy embodied in government services owing to an expansion of the per capita quantity of service provision. Even combining rural and urban households, the impact of growth in total household consumption on energy use was dwarfed by the per capita increase in both investment and exports. The per capita increase in investment required an additional 7,078 PJ, greater even than the 6,695 PJ of additional energy required by China's export boom.

Second, the structural effects were less significant but not negligible, resulting in 1,331 PJ of additional energy demand. The largest share of the additional energy demand that can be attributed to changes in demand patterns are due to changes in the export structure, which resulted in an additional 617 PJ (almost half the growth in energy use resulting from the structural effect). Urban household consumption patterns were also very important, accounting for 482 PJ (more than one third). Structural change resulted in an increase in energy use despite being one of the government's main strategies to reduce energy use. This is a timely reminder that economies are not easy to guide – even when they are as dynamic as China's.

Third, as discussed in Chapter 6, the intensity effect was much greater in the traded sectors than non-traded sectors. Although exports embodied less energy in 2002 than combined rural and urban household consumption, the reduction in energy use due to changes in the production processes of exported sectors was almost twice the reduction due to changes in the production processes of products consumed by Chinese households. The improvement in energy efficiency of importing sectors was even greater than that of exporting sectors.

Finally, with respect to the total impact on embodied energy of each component of aggregate demand, Table 7.1 shows that investment in fixed assets was the greatest growth-driver of China's energy use over the period, accounting for almost half the total growth (5,688 of 12,493 PJ). The next greatest impact was due to net exports. Although changes to trade flows can essentially be considered as a matter of economic geography (the physical location of supply and demand) rather than changes to aggregate global demand, changes in trade patterns resulted in an additional 2,806 PJ of energy being used in China in 2007 compared with 2002. The impact of trade flows exceeded the impact of growing household consumption and government service provision combined: 1,722 PJ.

Tables 7.2 to 7.5 break down the additive LMDI results presented in Table 7.1 according to the impacts on each of the four main fuel types: coal, petroleum and natural gas, coke and non-thermal electricity. Here, the most important results are the differences between the impacts of the intensity and structural effects on coal compared with petroleum and natural gas. The intensity effect on coal embodied in final demand was a very substantial restraint, at -4,127 while the impact on petroleum and natural gas was much less, at -2,497. Although China has large quantities of domestic coal reserves, technological changes in recent years have been most heavily biased against coal use.

Table 7.2: Summary of SDA results: coal

	RHH	UHH	Gov	Inv	Exp	Imp	Total
2002 Actual	734	1,711	626	3,872	2,222	2,367	**9,166**
Intensity	-297	-848	-199	-1,082	-1,702	-1,798	**-4,127**
Structural	40	43	35	-216	313	-46	**215**
Per capita	176	670	326	3,517	2,815	1,964	**7,505**
Population	-47	288	20	139	76	65	**476**
Total change	**-127**	**153**	**182**	**2,357**	**1,502**	**185**	**4,068**
Error	4	-57	-1	0	-39	-31	**-94**
2007 Actual	604	1,922	809	6,229	3,764	2,583	**13,328**

Source: Author's calculations

Table 7.3: Summary of SDA results: petroleum and natural gas

	RHH	UHH	Gov	Inv	Exp	Imp	Total
2002 Actual	633	2,041	1,360	2,586	2,231	2,282	**8,851**
Intensity	-101	-505	-279	-204	-1,408	-1,567	**-2,497**
Structural	119	425	171	-6	131	87	**840**
Per capita	186	1,008	760	2,610	2,872	1,989	**7,437**
Population	-49	433	46	103	78	66	**610**
Total change	**154**	**1,362**	**697**	**2,503**	**1,673**	**576**	**6,389**
Error	-6	-49	-4	-1	-50	-46	**-109**
2007 Actual	792	3,452	2,061	5,090	3,953	2,905	**15,349**

Source: Author's calculations

Table 7.4: Summary of SDA results: coke

	RHH	UHH	Gov	Inv	Exp	Imp	Total
2002 Actual	59	146	55	551	281	362	**1,092**
Intensity	-5	-16	4	-118	-71	-81	**-206**
Structural	10	8	4	37	111	-5	**170**
Per capita	14	69	34	542	484	410	**1,144**
Population	-4	30	2	21	13	14	**63**
Total change	**15**	**91**	**45**	**483**	**536**	**337**	**1,170**
Error	3	-5	0	0	-7	-7	**-10**
2007 Actual	71	243	100	1,034	825	706	**2,272**

Source: Author's calculations

Table 7.5: Summary of SDA results: non-thermal electricity

	RHH	UHH	Gov	Inv	Exp	Imp	Total
2002 Actual	92	225	91	412	344	381	**1,164**
Intensity	-21	-72	-11	-97	-174	-199	**-375**
Structural	6	5	5	27	58	12	**101**
Per capita	25	98	53	399	500	378	**1,075**
Population	-7	42	3	16	14	13	**68**
Total change	**3**	**74**	**50**	**345**	**398**	**204**	**869**
Error	0	-6	0	-1	-10	-5	**-18**
2007 Actual	96	304	141	757	752	590	**2,051**

Source: Author's calculations

Conversely, the structure of demand has shifted more toward petroleum and natural gas than it has shifted toward coal, although the shift was positive in both cases. The result of these two changes is that while in 2002 the largest single source of energy embodied in final demand was coal (contributing 9,166 PJ compared with 8,851 PJ from petroleum and natural gas), by 2007 this was no longer the case. By that time 15,349 PJ of petroleum and natural gas were embodied in final demand compared with 13,328 PJ of coal. Although this still represents a substantial increase in coal embodied in final demand, the relative shift is important. Sadly, from an environmental point of view, non-thermal electricity still contributed just 2,051 PJ.

One reason for the difference in the impact on coal compared with oil and gas was the role of urban households. In 2007 the amount of coal embodied in urban household consumption was just 153 PJ more than in 2002 but the amount of additional embodied oil and gas was 1,362 PJ. This has important implications for China's future fuel mix since urban household consumption is likely to be a key driver of future energy growth due to urbanisation.

Chapter 1 posed four central questions. The second question asked, is China's economy is peculiar in its huge and rapidly-growing consumption of energy, or does it conform with the experiences of other countries when they were at similar stages of economic development? The analysis of the thesis has shown that China's consumption of energy is not necessarily peculiar, but rather can be seen as broadly conforming with the experiences of other countries when they were at similar stages of economic development. China's economy broadly conforms to expectations based on theoretical literature and literature discussing observations from other countries at similar stages of development with regard to the relationship between economic growth and energy consumption. It is only the scale of China's economy, and to an extent, the pace of change, that is substantially different from other countries' experiences. The sheer size of China combined with the gap between the global frontier and China's economy at the beginning of the reform period means that China's industrialisation is bigger and faster than that of earlier industrialising countries, but it can still be explained in similar ways.

The third question asked, how do the bewilderingly rapid changes to China's economy alter the relationship between the economy and its use of energy? Evidence of this impact has been presented throughout the thesis and again in this chapter. The relative importance of different components of aggregate demand with respect to derived demand for energy, the changing structure of household consumption, investment in fixed assets and trade flows all result in changes in the relationship with energy use: not just in the aggregate quantity of energy used but also in the fuel mix. In addition, the different rates of technological progress in different sectors have changed the relationship between economic growth and energy use in profoundly important ways, especially by improving the energy efficiency of traded sectors much more than non-traded sectors.

Perhaps the main contribution of the thesis, however, relates to the first question, which asked, why has China's consumption of energy grown so rapidly since 2002? The simplest way to answer this question is to identify three short-term factors that reversed the progress of energy efficiency between 2002 and 2005, and three long-term factors that will continue to drive energy use for much longer.

The short-term, or acute factors are all related to China's WTO membership. China experienced an export boom in manufactured goods and a large quantity of additional energy was required to produce those goods. The export boom was essentially a positive demand side shock: China's producers had to respond by increasing capacity and the sudden increase in investment in fixed assets in the manufacturing sectors also embodied large quantities of energy. In addition, China's policy makers embraced market ideology with, perhaps, a little too much vigour in 2001, relaxing many non-market measures designed to reduce energy use.

These three acute factors are revealed most strongly in the results presented in Table 3.4 that show the importance of the quantity effect of production on China's energy use beginning in 2001, as well as the lack of improvement in the energy intensity of China's production between 2001 and 2003. Additionally, Tables 7.1 to 7.5 show the importance of the expansion of China's exports and investments as the two greatest drivers of energy use in China since 2002. Chapter 5 demonstrated that the majority of investment growth since 2002 was in the manufacturing sector, supporting the conclusion that much of the investment that drove China's energy use was itself a response to the increased demand for exports following China's WTO membership.

The long-term, or chronic, drivers of China's energy use identified in the thesis are urbanisation, household consumption and a resumption of policy- and market-driven technological progress. Identifying and weighing the relative significance of these factors is one of the main contributions of the thesis. Trade would also count as a long-term driver of China's energy use, and has certainly been identified as a key driver of energy use since 2001, except for the fact that the outlook for trade following the global financial crisis and European debt crisis is not bright due to the state of demand outside of China.

Implications for China's energy future

The final question this thesis set out to answer is, what are the implications for China's energy future? The drivers of the growth of China's energy use have a lot of momentum. Despite the collapse of external demand that occurred outside the period covered by the SDA in this thesis, China has a very robust set of domestic assets that have the potential to drive continued growth for years[2] to come – notably the large population that is yet to urbanise and the still low wage conditions that are only now beginning to change in the coastal parts of China. While these are often described as challenges for China, they also provide the greatest potential for future growth. The 12th Five-Year Plan offers a new direction for China's economy and the relationship between economic growth and energy use.

So far, consumption has been a relatively small part of China's GDP, relative to investment and trade. This is consistent with other 'rapid-catch-up' economies. The implication is that consumption is not currently the main driver of energy use. Urbanization, however, is one of the key driving forces of the Chinese economy. Urban per capita incomes have grown faster than rural per capita incomes even while urban populations have exploded and rural populations shrunk. The continued urbanization will see greater emphasis on consumption of products embodying petroleum and lesser emphasis on direct consumption of cheap, dirty

[2] How many years is a debated point, but it is the author's opinion that the factors discussed provided good foundations for strong economic growth to last another two decades, barring any major crises.

coal. Chapter 4 showed that urban household per capita consumption embodied more than three times the amount of energy than rural household per capita consumption. The higher energy needs of urban households relative to rural households combined with the long process of urbanization still ahead of China mean household consumption is one factor that will continue to drive substantial energy use well into the future.

Linking the 2002-2005 hyper-boom in energy use to the sudden increase in fixed asset investment and exports of 29 manufacturing sectors implies a repeat boom is unlikely. The growth of trade not only embodied much higher quantities of energy in products for export but was also one of the key drivers of the investment boom, at least in the 29 manufacturing sectors. The sudden increase in trade that stimulated the expansion of output was largely due to China joining the WTO – something that is, obviously, a one-time event.

While the 2002-2005 level of energy-use growth may not be repeated, as long as China continues to produce relatively energy-intensive components of international supply chains, trade will be a major driver of energy use in China. Chapter 6 explained that this is a locational effect: at the global level exports are not a component of aggregate demand and China will not always fulfill the role of the world's energy user. If China's current efforts to increase the wage share of GDP are successful, domestic demand will increase. But China's existing comparative advantage will also change since it is based on low wages, and the real exchange rate will rise. The current locational effect of trade could be reversed if China began to import much of what it currently exports, thus reducing the role of (or even ending) one of the three main components of embodied energy demand in China. But, as discussed in Chapter 6, such a reversal of the locational effect of trade will have no direct impact on energy embodied in global aggregate demand. This transition has not yet occurred, but it will.

The prospects for trade as a driver of growth in China seem bleak at present, since the US economy is yet to recover from the financial crisis of 2008 and the European economies seem to be in a process that may take some years to resolve. A comparison of Tables 7.2 and 7.3 reveals that, contrary to the general trend, trade resulted in greater growth of coal consumption compared with oil and gas consumption. It is possible that this was a repercussion of stricter pollution controls in China's export markets than in China itself. Whatever the reason, the implication is that a decline in the rate of export growth will impact on coal demand in China disproportionately to oil and gas demand.

The other major finding related to trade was the high rate of technological progress in the traded goods sectors. If China's trade growth slows substantially, will this result in a decline in the rate of technological transfer? Such an outcome is certainly possible, but it may not necessarily be a bad outcome for China. China is currently attempting to reduce the role of imitation or adaptation and increase the role of innovation in its technological development. This is being driven across a broad spectrum of Chinese society from people who asked, in response to his passing, "where was the 'Chinese Steve Jobs'?" to the architects of the 12th Five-Year Plan who instigated one of the greatest R&D investments in history. A decline in technological transfer driven by slower trade growth may provide space for a greater role for China's domestic innovation.

Excluding trade, the other two major drivers of China's recent energy-use growth have been investment in fixed assets and urban household consumption.

On investment, Chapter 5 showed that more than half of the energy growth came from investment in construction. Given the very large number of rural Chinese who would still like to migrate to cities, and the consequent need to build many more cities, this driver of energy use is likely to persist well into the future, possibly for another 15-20 years. As China reaches developed country urbanization rates, replacement of existing structures is likely to dominate construction of new structures and the growth of energy embodied in construction should slow considerably.

The other portion of investment in fixed assets that resulted in substantial energy-use growth recently was investment in China's manufacturing capacity. Prospects for continued investment in manufacturing are more complex. Labour in China's coastal provinces is already becoming too expensive for the type of very low-margin manufacturing that has driven growth there over recent years. And China is producing some 5.3 million university graduates each year (NBSC 2011, 20-2) who aspire to employment that utilizes their skills and knowledge rather than their labour. It is likely that the coastal provinces will see an increase in the importance of their service sectors relative to both agricultural and industrial sectors. Although much of the manufacturing base is likely to migrate inland in search of cheaper labour the overall growth of investment in manufacturing could be substantially lower in the decade ahead compared with the decade past (Cai and Wang 2010).

On household consumption, much depends upon the rate of wage growth. Outsiders have been encouraging China to 'shift to a consumption driven growth model' for some time. A point often ignored is that this is only possible if households have disposable income with which to consume. The government is pursuing many reforms designed to reduce the household propensity to save, such as public income and health insurance, affordable housing and other forms of welfare. These may increase per capita household consumption with commensurate impacts on embodied energy use (that will likely be disproportionately weighted toward petroleum). But increasing per capita disposable income will be the most important change associated with increasing household consumption. Household consumption has been only a modest driver of energy use since 2002 but when income levels do finally grow, experience from Asia's other catch-up economies suggests they are likely to grow quite suddenly. Garnaut contends that "most observers will be surprised by how quickly China catches up now that it has entered the turning period" (Garnaut 2010). The impact on final demand and the energy required to supply it (especially oil) may be equally sudden and given the population of China, it will have enormous consequences.

China's energy future carries very important strategic implications. Hundreds of millions of Chinese people are now aspiring to higher standards of living. Meeting those aspirations will inevitably require ever more supplies of energy. This will provide tremendous opportunity for profit on the part of supplying nations such as Australia. But even if the associated geopolitical issues are managed well, the environmental impacts are likely to be as challenging. Even though China's fuel mix has shifted substantially toward oil rather than coal, this has been the result of more rapid growth in oil consumption than coal consumption, not the result of declining coal consumption. Coal consumption will almost certainly continue to grow in China, driven especially by investment in construction and manufacturing capacity (particularly if China's manufacturing base is re-located inland over the next decade) and the production of manufactured goods. Figure 6.7 shows that China became a net importer of coal in 2008, despite producing more than half of the world's coal output in 2010 (IEA 2011, 14). Similarly, as China continues to urbanize, additional oil use (largely for private and public transport) will continue to cause damage to China's urban air quality.

Understanding the drivers of China's energy-use growth is crucial if it is to be managed so as to ameliorate the problems associated with energy use while still ensuring the Chinese people can realize their aspirations toward an easier, healthier, more comfortable and more fulfilling life.

Future research

As always, the more we learn the more we realise we don't know. This thesis raises many more questions than it answers. A few of the most important are discussed here.

Regional divergence

Understanding regional differences in energy consumption, especially in respect to household consumption, is a very important part of this story. Chapter 3 showed how China's provinces are hugely diverse. Analysing the impact of the different consumption patterns of households in different provinces at different stages of development would have some important advantages. In particular, observations of the trajectory of energy embodied in the urban households in China's richest provinces could guide expectations for energy embodied in the future consumption bundle of household in provinces that are yet to become as rich. If the embodied energy trajectory of household consumption in China's richest provinces was in the opposing direction to the poorer provinces then that would certainly have significant implications for China's energy future. Similarly, patterns of investment can be better understood and predicted if regional divergence is fully taken into account. Trade patterns also depend on underlying economic conditions such as factor endowments that are regionally diverse. A greater focus on regional divergence could improve the analysis of energy use in all dimensions of the economy, including production, consumption, investment and trade.

Import component of exports

The story of the energy content of trade told in Chapter 6 is incomplete. The treatment of imports needs improvement to reflect the actual energy content of imports rather than the counterfactual concept of ‘mitigated energy use’. The approach adopted in the thesis has been chosen because it provides the maximum exploitation of the data available. It does not account for the fact that a large portion of China’s exports include imported components as well as would be preferred. Improving the analysis of energy in trade flows is an important part of understanding China’s place in the world. It has significant implications for international negotiations on a range of issues, not least of which is climate change. It also provides an important part of the context in which countries determine their policies toward China. Making further improvements in this direction should be a high priority.

Electrification

The approach taken in the thesis focuses on primary fuel use. One of the big changes in China’s energy story relates to electricity, or power generation. Changes in the electricity generation sector have important implications for the fuel mix that could not be addressed in the thesis but nonetheless should be covered in future research.

GHG emissions

The approach adopted in the thesis can relatively easily be extended to consider implications for GHG emissions. This has not been done here because the focus of the thesis is elsewhere but it would be a relatively simple extension to further the relevance of the research to broader implications at low marginal cost.

Future availability of energy resources

The scale of energy resources that will be required, even in the near future, brings into question the availability of such resources. If the global energy system continues to rely on fossil fuels such as coal and oil or even uranium, the continued economical supply of those resources cannot be taken for granted. Whether there exists a substantial risk that supply constraints pose a serious limit to China’s and the world’s continued economic growth is a question that needs addressing.

The future role of renewable energy

This thesis has shown that the key drivers of China’s overall energy demand are likely to continue driving energy use in China for many years. This thesis has not specifically considered the drivers of renewable energy. In the context of limited supplies of fossil fuels and the stress placed on the climate system by GHG emissions, the role of renewable energy sources such as solar, wind, geothermal and others becomes increasingly important and needs more attention. In China, the importance of de-carbonising the energy supply cannot be over-stated.

The role of technological progress

The thesis identified technological progress as the main constraint on the expansion of energy use in China's economy. More work is required to identify ways the government and the private sector can increase the rate of technological improvement so as to hasten the reduction in energy intensity of the Chinese economy.

The role of the energy pricing system

IOA makes assumptions that exclude the role of prices in the economy. Clearly price plays a very important role in economic decision-making. China's factor markets, and the energy sector in particular, are renowned for having complicated pricing systems with heavy government influence. Additional research is needed on the role that price reform can play in moving China toward a more energy efficient future.

Lifestyle analysis

The household consumption analysis presented in Chapter 4 can be taken further with proper lifestyle analysis. According to Baiocchi et al. (2010), "'Lifestyle analysis' provides a systemic view of the entire socio-technological system that links consumption and induced production activities together in one analytical framework." Applying such analysis to Chinese households could provide valuable insights into the energy implications of China's changing household wealth and consumption trends.

Much more needs to be done if the inexorable relationship between economic growth and energy use is not to hinder the aspirations of the future Chinese people or to render those aspirations unsustainable in the long term. If there is one lesson to learn above all from this study, it is that the relationship between energy and the economy is complex and dynamic, and even more so in a country such as China that is undergoing a period of major economic transformation. Understanding that relationship requires a nuanced approached that accommodates the variations and transformations. Getting China's energy story wrong could have repercussions that eventually come to be much lamented.

Appendix A: Mapping of sectors between China Energy Statistical Yearbook 2008 and China Input-Output Tables: 2002 and 2007

China Energy Statistical Yearbook 2008	China Input-Output Table 2002		China Input-Output Table 2007	
Farming, Forestry, Animal Husbandry, Fishery & Water Conservancy	Farming	01001	Farming	001
	Forestry	02002	Forestry	002
	Timber and bamboo harvesting and transport	02003		
	Animal husbandry	03004	Animal husbandry	003
	Fishery	04005	Fishery	004
	Services in support of agriculture	05006	Services in support of agriculture	005
Mining and Washing of Coal	Mining and Washing of Coal	06007	Mining and washing of coal	006
Extraction of Petroleum and Natural Gas	Extraction of Petroleum and Natural Gas	07008	Extraction of petroleum and natural gas	007
Mining and Processing of Ferrous Metal Ores	Mining of ferrous metal ores	08009	Mining of ferrous metal ores	008
Mining and Processing of Non-Ferrous Metal Ores	Mining of non-ferrous metal ores	09010	Mining of non-ferrous metal ores	009
Mining and Processing of Non-metal Ores	Mining of salt	10011	Mining and processing of non-metal ores and other ores	010
Mining of Other Ores	Mining of other ores	10012		
Processing of Food from Agricultural Products	Processing of grains and cereals	13013	Grinding of grains	011
	Processing of animal feed	13014	Processing of forage	012
	Processing of vegetable oils	13015	Refining of vegetable oil	013
	Processing of sugar	13016	Manufacture of sugar	014
	Slaughter and processing of meat	13017	Slaughtering and processing of meat	015
	Other food processing and manufacturing	03019	Processing of Aquatic products	016
			Processing of other foods	017
Manufacture of Foods	Other food processing and manufacturing	03019	Manufacture of convenience food	018
			Manufacture of flavouring and ferment products	020
			Manufacture I of other foods	021
Manufacture of	Production of alcoholic beverages	15020	Manufacture of alcohol and wine	022

Beverages	Manufacture of beverages	13018	Processing of soft drinks and purified tea	023
	Production of other beverages	15021	Manufacture of liquid milk and dairy products	019
Manufacture of Tobacco	Manufacture of tobacco	16022	Manufacture of tobacco	024
Manufacture of Textiles	Cotton and synthetic spinning, dying and finishing	17023	Spinning and weaving, printing and dyeing of cotton and chemical fibre	025
	Wool spinning, dying and finishing	17024	Spinning and weaving, dyeing and finishing of wool	026
	Hemp and silk spinning and finishing	17025	Spinning and weaving of hemp and tiffany	027
	Producing of spinning equipment	17026	Manufacture of textile products	028
	Manufacture of knitwear and baskets	17027	Manufacture of knitted fabric and its products	029
Manufacture of Textile Wearing Apparel, Footwear, and Caps	Manufacture of clothes, shoes and hats	18028	Manufacture of textile wearing apparel, footwear and caps	030
Manufacture of Leather, Fur, Feather and Related Products	Manufacture of leather, fur and feather products	19029	Manufacture of leather, fur, feather (down) and its products	031
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and straw products	Processing of wood, bamboo, rattan, palm and straw products	20030	Processing of timbers, manufacture of wood, bamboo, rattan, palm and straw products	032
Manufacture of Furniture	Manufacture of furniture	21031	Manufacture of furniture	033
Manufacture of Paper and Paper Products	Manufacture of paper and paper products	22032	Manufacture of paper and paper products	034
Printing, Reproduction of Recording Media	Printing, reproduction and recording	23033	Printing, reproduction of recording media	035
Manufacture of Articles For Culture, Education and Sport Activity	Stationary and cultural products	24034	Manufacture of articles for culture, education and sports activities	036
	Manufacture of toys, sports and entertainment products	24035		
Processing of Petroleum, Coking, Processing of Nuclear Fuel	Processing of petroleum and nuclear fuel	25036	Processing of petroleum and nuclear fuel	037
	Coking	25037	Coking	038
Manufacture of Raw Chemical Materials and Chemical Products	Manufacture of raw chemicals and chemical products	26038	Manufacture of basic chemical raw materials	039
	Fertilizer products	26039	Manufacture of fertilizers	040
	Agricultural and farm chemical products	26040	Manufacture of pesticides	041
	Paint, pigments, printing ink, and similar	26041	Manufacture of paints, printing inks, pigments and	042

	products		similar products	
	Synthetic products	26042	Manufacture of synthetic materials	043
	Manufacture of specialised chemical products	26043	Manufacture of special chemical products	044
	Manufacture of daily use chemical products	26044	Manufacture of chemical products for daily use	045
Manufacture of Medicines	Manufacture of medicines	27045	Manufacture of medicines	046
Manufacture of Chemical Fibres	Manufacture of synthetic chemical fibres	28046	Manufacture of chemical fibre	047
Manufacture of Rubber	Manufacture of rubber	29047	Manufacture of rubber	048
Manufacture of Plastics	Manufacture of plastics	30048	Manufacture of plastic	049
Manufacture of Non-metallic Mineral Products	Manufacture of cement, lime and gypsum	31049	Manufacture of cement, lime and plaster	050
			Manufacture of products of cement and plaster	051
			Manufacture of brick, stone and other building materials	052
	Manufacture of glass and glass products	31050	Manufacture of glass and its products	053
	Manufacture of ceramic products	31051	Manufacture of pottery and porcelain	054
	Manufacture of fireproof products	31052	Manufacture of fire-resistant materials	055
	Manufacture of non-metal mineral products	31053	Manufacture of graphite and other non-metallic mineral products	056
Smelting and Pressing of Ferrous Metals	Iron smelting	32054	Iron smelting	057
	Steel production	32055	Steel making	058
	Steel pressing	32056	Rolling of steel	059
	Production of ferrous alloys	32057	Smelting of ferro-alloy	060
Smelting and Pressing of Non-ferrous Metals	Smelting of non-ferrous metals	33058	Smelting of non-ferrous metals and manufacture of alloys	061
	Pressing of non-ferrous metals	33059	Rolling of non-ferrous metals	062
Manufacture of Metal Products	Manufacture of metal products	34060	Manufacture of metal products	063
Manufacture of General Purpose Machinery	Manufacture of boilers and engines	35061	Manufacture of boiler and prime mover	064
	Manufacture of metalworking machinery	35062	Manufacture of metalworking machinery	065
	Manufacture of other general purpose machinery	35063	Manufacture of lifters	066
			Manufacture of pump, valve and similar machinery	067
			Manufacture of other general purpose machinery	068
Manufacture of Special Purpose Machinery	Manufacture of agricultural specialised machinery	36064	Manufacture of special purpose machinery for agriculture, forestry, animal husbandry and fishery	071

	Manufacture of other specialised machinery	36065	Manufacture of special purpose machinery for mining, metallurgy and construction	069
			Manufacture of special purpose machinery for chemical industry, processing of timber and non-metals	070
			Manufacture of other special purpose machinery	072
Manufacture of Transport Equipment	Manufacture of transport equipment	37066	Manufacture of railroad transport equipment	073
	Manufacture of cars	37067	Manufacture of automobiles	074
	Manufacture of car components	37068		
	Manufacture of ships	37069	Manufacture of boats and ships and floating devices	075
	Other transportation manufacturing	37071	Manufacture of other transport equipment	076
Manufacture of Electrical Machinery and Equipment	Manufacture of electrical machinery	39072	Manufacture of generators	077
			Manufacture of equipments for power transmission and distribution and control	078
			Manufacture of wire, cable, optical cable and electrical appliances	079
	Manufacture of household appliances	39073	Manufacture of household electric and non-electric appliances	080
	Manufacture of other electrical appliances	39074	Manufacture of other electrical machinery and equipment	081
Manufacture of Communication Equipment, Computers and Other Electronic Equipment	Manufacture of communication equipment	40075	Manufacture of communication equipment	082
			Manufacture of radar and broadcasting equipment	083
	Manufacture of computers	40076	Manufacture of computer	084
	Manufacture of electrical components	40078	Manufacture of electronic component	085
	Manufacture of home audio visual equipment	40079	Manufacture of household audiovisual apparatus	086
	Manufacture of other electrical equipment	40077	Manufacture of other electronic equipment	087
	Manufacture of other communication equipment	40080		
Manufacture of Measuring Instruments and Machinery for Cultural Activity and office work	Manufacture of measuring instruments	41081	Manufacture of measuring instruments	088
	Manufacture of cultural and office equipment	41082	Manufacture of machinery for cultural activity & office work	089
Manufacture of Artwork	Manufacturing of art and craft works	42083	Manufacture of artwork, other manufacture	090

and Other Manufacturing	Other manufacturing	42084		
Recycling and Disposal of Waste	Disposal of waste	43085	Scrap and waste	091
Production and Distribution of Electric Power and Heat Power	Production and supply of electrical and heating power	44086	Production and supply of electric power and heat power	092
Production and Distribution of Gas	Production and supply of heating gas	45087	Production and distribution of gas	093
Production and Distribution of Water	Production and supply of water	46088	Production and distribution of water	094
Construction	Construction	47089	Construction	095
Transport, Storage, Postal & Telecommunications Services	Rail passenger transport	51090	Transport via railway	096
	Rail freight transport	51091		
	Road transport	52092	Transport via road	097
	Urban public transport	53093	Urban public traffic	098
	Water-based transport	54094	Water transport	099
	Air passenger transport	55095	Air transport	100
	Air freight transport	55096		
	Pipeline transport	56097	Transport via pipeline	101
			Loading, unloading, portage and other transport services	**102**
	Storage	58098	Storage	103
	Postal services	59099	Post	104
Other	Information transmission services	60100	Telecom & other information transmission services	105
	Computer services and software	61101	Computer services	106
			Software industry	107
Wholesale, Retail Trade and Catering Service	Retail and wholesale trade	63102	Wholesale and retail trades	108
	Hotel accommodation	66103	Hotels	109
	Restaurants, bars, cafes etc	67104	Catering services	110
Other	Financial services	68105	Banking, security, other financial activities	111
	Insurance	70106	Insurance	112
	Real estate	72107	Real estate	113
	Rental accommodation	73108	Leasing	114
	Business services	74109	Business services	115
	Tourism	74110	Tourism	116

	Scientific research	75111	Research and experimental development	117
	Specialised and other technical services	76112	Professional technical services	118
			Services of science and technology exchanges and promotion	119
	Geological surveys	78113	Geological prospecting	120
	Water conservation and management	79114	Management of water conservancy	121
	Management of environmental resources and public facilities	80115	Environment management	122
			Management of public facilities	123
	Residential and other services	82116	Services to households	124
			Other services	125
	Teaching and education	84117	Education	126
	Hygiene and health	85118	Health	127
	Public safety and welfare	86119	Social security	128
			Social welfare	129
	Art and culture and film and television broadcasting	88120	Journalism and publishing activities	130
			Broadcasting, movies, televisions and audiovisual activities	131
			Cultural and art activities	132
	Sports	91121	Sports activities	133
	Entertainment	92122	Entertainment	134
	Public management and social organisation	93123	Public management and social organization	135

Appendix B: Notes on matrix algebra

Some important notes on matrix algebra relevant to the equations presented in this thesis are presented here:

1. Post multiplication of a matrix by $\mathbf{i}$ creates a column vector whose elements are the row sums of the matrix (Miller and Blair 2009, 12)
2. Pre-multiplication of a matrix by $\mathbf{i}'$ creates a row vector whose elements are the column sums of the matrix (Miller and Blair 2009, 12)
3. A 'hat' over a vector denotes a diagonal matrix with the elements of the vector along the main diagonal, eg: $\hat{\mathbf{x}} = \begin{bmatrix} x_1 & \cdots & 0 \\ \vdots & x_2 & \vdots \\ 0 & \cdots & x_3 \end{bmatrix}$ (Miller and Blair 2009, 20)
4. Post multiplication of a matrix, $\mathbf{M}$ by a diagonal matrix, $\hat{\mathbf{d}}$, creates a matrix in which each element in column j of $\mathbf{M}$ is multiplied by d_j in $\hat{\mathbf{d}}$. (Miller and Blair 2009, 20)
5. Post multiplication of a matrix, $\mathbf{M}$ by a diagonal matrix, $\hat{\mathbf{d}}^{-1}$, creates a matrix in which each element in column j of $\mathbf{M}$ is divided by d_j in $\hat{\mathbf{d}}$.

Appendix C: Data sources for industrial value added

	Agriculture	Industry	Construction	Services
1995	China Rural Statistical Yearbook 2007 (NBSC 2008, 6-1)	CSY1996 (NBSC 1997, 12-11)	CSY2010 (NBSC 2011, 2-1)	CSY2010 (NBSC 2011, 2-6)
1996		CSY1997 (NBSC 1998, 12-11)		
1997		CSY1998 (NBSC 1999, 13-11)		
1998		CSY1999 (NBSC 2000, 13-8)		
1999		CSY2000 (NBSC 2001, M06)		
2000		CSY2001 (NBSC 2002, 13-5)		
2001		CSY2002 (NBSC 2003, 13-5)		
2002		CSY2003 (NBSC 2004, 13-5)		
2003		CSY2004 (NBSC 2005, 14-3)		
2004		No data available		
2005	CSY2010 (NBSC 2011, 2-11)	CSY2006 (NBSC 2007, 14-4)		
2006		CSY2007 (NBSC 2008, 14-2)		
2007		CSY2008 (NBSC 2009, 13-2)		

Note: CSY = China Statistical Yearbook

Appendix D: Value added by sector (1995-2007)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2005	2006	2007
GDP	**60,793.70**	**71,176.60**	**78,973.00**	**84,402.30**	**89,677.10**	**99,214.60**	**109,655.20**	**120,332.70**	**135,822.80**	**184,937.40**	**216,314.40**	**265,810.30**
Primary Industry	**12,135.80**	**14,015.40**	**14,441.90**	**14,817.60**	**14,770.00**	**14,944.70**	**15,781.30**	**16,537.00**	**17,381.70**	**22,420.00**	**24,040.00**	**28,627.00**
Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	12,135.80	14,015.40	14,441.90	14,817.60	14,770.00	14,944.70	15,781.30	16,537.00	17,381.70	22,420.00	24,040.00	28,627.00
Secondary Industry	**28,679.50**	**33,835.00**	**37,543.00**	**39,004.20**	**41,033.60**	**45,555.90**	**49,512.30**	**53,896.80**	**62,436.30**	**87,598.10**	**103,719.50**	**125,831.40**
Industry	24,950.60	29,447.60	32,921.40	34,018.40	35,861.50	40,033.60	43,580.60	47,431.30	54,945.50	77,230.80	91,310.90	110,534.90
Mining and Quarrying	2,982.48	3,327.41	3,744.65	3,809.68	3,936.95	5,010.41	4,787.87	4,731.45	5,272.51	9,457.15	11,248.50	12,814.65
Mining and Washing of Coal	976.74	1,126.90	1,190.08	1,067.63	939.61	919.21	1,074.77	1,321.19	1,507.48	3,090.06	3,596.53	4,434.99
Extraction of Petroleum and Natural Gas	1,532.62	1,633.51	1,931.72	2,105.64	2,392.10	3,482.41	3,105.61	2,784.59	3,125.06	5,150.32	6,002.12	6,091.86
Mining and Processing of Ferrous Metal Ores	66.99	92.73	98.22	96.21	88.20	98.23	111.19	123.99	191.29	456.30	589.62	877.10
Mining and Processing of Non-Ferrous Metal Ores	185.27	199.10	222.46	197.48	209.62	220.34	218.11	216.78	232.46	457.48	679.32	919.16
Mining and Processing of Non-metal Ores	218.51	271.02	298.93	196.54	196.83	193.29	192.94	204.82	213.13	300.11	379.10	488.46
Mining of Other Ores	2.33	4.15	3.24	146.17	110.59	96.94	85.24	80.09	3.09	2.89	1.81	3.09
Manufacturing	19,833.90	23,787.62	26,250.61	26,635.72	28,025.26	31,064.35	34,324.74	37,826.85	44,606.09	61,230.36	72,623.93	88,747.52
Processing of Food from Agricultural Products	810.51	1,171.78	1,305.21	1,209.60	1,266.95	1,316.79	1,453.28	1,599.54	1,918.85	2,937.83	3,501.11	4,384.11
Manufacture of Foods	344.47	477.26	589.19	576.72	572.98	655.50	695.14	795.84	872.91	1,249.95	1,471.04	1,757.97
Manufacture of Beverages	576.94	752.60	931.01	964.80	974.13	975.66	988.48	1,020.14	1,041.55	1,246.11	1,442.80	1,778.84
Manufacture of Tobacco	999.54	1,246.23	1,375.72	1,572.76	1,483.45	1,475.24	1,681.53	1,954.52	2,058.95	2,203.93	2,385.88	2,756.40
Manufacture of Textile	1,465.94	1,711.07	1,866.21	1,805.51	1,857.74	2,006.57	2,134.50	2,255.65	2,494.97	3,466.59	3,973.22	4,640.47
Manufacture of Textile Wearing Apparel, Footwear, and Caps	566.65	735.57	775.10	855.33	841.41	933.29	1,058.57	1,072.52	1,199.32	1,519.07	1,838.44	2,139.06
Manufacture of Leather, Fur, Feather and Related Products	328.72	458.15	485.96	484.96	471.63	510.17	602.67	658.34	773.80	1,010.37	1,175.89	1,398.01
Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	155.14	235.83	284.06	199.79	220.99	248.34	296.76	307.52	347.70	546.55	687.34	972.96
Manufacture of Furniture	92.07	130.94	148.69	136.06	129.65	149.54	180.88	200.31	239.41	411.76	502.38	610.77
Manufacture of Paper and Paper Products	379.11	541.66	566.36	566.02	591.29	650.47	730.52	820.66	891.66	1,226.50	1,390.02	1,646.05
Printing, Reproduction of Recording Media	200.97	279.99	313.47	324.27	329.17	317.48	375.33	388.90	437.65	495.41	559.20	653.44
Manufacture of Articles For Culture, Education and Sport Activity	148.77	199.42	218.53	250.50	233.15	244.82	276.70	294.01	327.04	406.24	466.14	523.71

Processing of Petroleum, Coking, Processing of Nuclear Fuel	915.88	920.52	1,006.86	938.13	981.50	1,242.23	1,358.83	1,443.18	1,684.67	2,120.10	2,320.21	2,924.64
Manufacture of Raw Chemical Materials and Chemical Products	1,538.17	1,955.69	1,988.51	1,958.39	2,023.63	2,231.95	2,463.32	2,677.62	3,225.37	4,698.79	5,412.73	6,931.95
Manufacture of Medicines	431.84	587.27	687.73	768.33	856.20	999.28	1,111.35	1,199.84	1,340.90	1,636.69	1,812.76	2,159.36
Manufacture of Chemical Fibres	331.20	320.79	350.16	327.66	419.98	466.28	341.67	356.54	386.34	519.22	605.73	764.39
Manufacture of Rubber	225.77	310.08	350.41	360.46	336.93	345.21	381.96	420.55	484.09	636.96	716.81	905.63
Manufacture of Plastics	367.22	533.72	598.47	628.78	644.90	732.15	838.43	929.86	998.67	1,360.93	1,673.19	2,018.21
Manufacture of Non-metallic Mineral Products	1,468.32	1,736.17	1,849.66	1,613.54	1,670.62	1,776.22	1,864.30	1,962.47	2,288.72	3,004.11	3,665.64	4,579.35
Smelting and Pressing of Ferrous Metals	1,718.50	1,643.30	1,713.69	1,744.03	1,797.92	2,048.26	2,353.91	2,586.84	3,695.30	6,180.54	7,022.54	8,505.92
Smelting and Pressing of Non-ferrous Metals	492.88	504.35	520.17	589.82	673.57	808.23	909.44	900.10	1,180.46	2,064.48	3,206.26	4,228.44
Manufacture of Metal Products	626.45	807.63	863.54	895.02	899.20	960.78	1,097.28	1,209.30	1,270.58	1,811.70	2,231.69	2,842.89
Manufacture of General Purpose Machinery	1,092.82	1,195.65	1,328.29	1,236.93	1,236.60	1,325.40	1,494.71	1,657.53	2,081.07	3,174.27	3,809.07	4,823.32
Manufacture of Special Purpose Machinery	733.24	856.02	911.40	861.49	857.64	915.87	979.75	1,123.80	1,319.25	1,799.05	2,302.28	2,896.67
Manufacture of Transport Equipment	1,313.66	1,528.21	1,681.12	1,917.28	1,984.16	2,086.60	2,513.19	3,129.77	3,790.77	4,098.17	4,946.15	6,586.37
Manufacture of Electrical Machinery and Equipment	985.21	1,219.17	1,369.77	1,561.06	1,667.24	1,941.40	2,120.53	2,278.11	2,647.78	3,823.86	4,629.88	5,716.90
Manufacture of Communication Equipment, Computers and Other Electronic Equipment	1,036.09	1,091.37	1,508.07	1,989.48	2,241.60	2,875.93	3,130.60	3,623.93	4,556.96	6,121.92	7,102.59	7,483.59
Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	199.96	237.42	248.36	299.00	300.10	337.93	365.97	386.04	582.34	784.42	970.44	1,098.52
Manufacture of Artwork and Other Manufacturing	287.85	399.77	414.90	0.00	460.93	486.74	525.13	573.44	455.03	610.71	707.54	866.56
Recycling and Disposal of Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.96	64.12	94.96	153.03
Electric Power, Gas and Water Production and Supply	2,134.22	2,332.57	2,926.13	3,573.00	3,899.30	3,958.84	4,468.00	4,873.00	5,066.90	6,543.28	7,438.47	8,972.73
Production and Distribution of Electric Power and Heat Power	1,992.37	2,167.38	2,719.25	3,328.09	3,595.04	3,670.95	4,147.86	4,550.88	4,718.73	6,119.44	6,930.31	8,337.59
Production and Distribution of Gas	5.09	0.00	17.80	25.08	60.93	50.04	70.98	76.33	98.58	143.92	192.21	289.60
Production and Distribution of Water	136.76	165.19	189.08	219.83	243.33	237.85	249.15	245.79	249.59	279.92	315.95	345.54
Construction	3,728.80	4,387.40	4,621.60	4,985.80	5,172.10	5,522.30	5,931.70	6,465.50	7,490.80	10,367.30	12,408.60	15,296.50
Tertiary Industry	**19,978.50**	**23,326.20**	**26,988.10**	**30,580.50**	**33,873.40**	**38,714.00**	**44,361.60**	**49,898.90**	**56,004.70**	**74,919.30**	**88,554.90**	**111,351.90**
Transport, Storage and Post	3,244.30	3,782.20	4,148.60	4,660.90	5,175.20	6,161.00	6,870.30	7,492.90	7,913.20	10,666.20	12,183.00	14,601.00
Wholesale and Retail Trade	4,778.60	5,599.70	6,327.40	6,913.20	7,491.10	8,158.60	9,119.40	9,995.40	11,169.50	13,966.20	16,530.70	20,937.80
Hotels and Catering Services	1,200.10	1,336.80	1,561.30	1,786.90	1,941.20	2,146.30	2,400.10	2,724.80	3,126.10	4,195.70	4,792.60	5,548.10

Financial Intermediation	2,798.50	3,211.70	3,606.80	3,697.70	3,816.50	4,086.70	4,353.50	4,612.80	4,989.40	6,086.80	8,099.10	12,337.50
Real Estate	2,354.00	2,617.60	2,921.10	3,434.50	3,681.80	4,149.10	4,715.10	5,346.40	6,172.70	8,516.40	10,370.50	13,809.70
Others	5,602.90	6,778.30	8,423.00	10,087.30	11,767.70	14,012.40	16,903.30	19,726.70	22,633.90	31,488.00	36,579.10	44,117.70

Source: see Appendix C.

Appendix E: 29 key manufacturing sectors

Manufacture of furniture	033	Manufacture of generators	077
Manufacture of metal products	063	Manufacture of equipment for power transmission and distribution and control	078
Manufacture of boiler and prime mover	064	Manufacture of wire, cable, optical cable and electrical appliances	079
Manufacture of metalworking machinery	065	Manufacture of household electric and non-electric appliances	080
Manufacture of lifters	066	Manufacture of other electrical machinery and equipment	081
Manufacture of pump, valve and similar machinery	067	Manufacture of communication equipment	082
Manufacture of other general purpose machinery	068	Manufacture of radar and broadcasting equipment	083
Manufacture of special purpose machinery for agriculture, forestry, animal husbandry and fishery	071	Manufacture of computer	084
Manufacture of special purpose machinery for mining, metallurgy and construction	069	Manufacture of electronic component	085
Manufacture of special purpose machinery for chemical industry, processing of timber and non-metals	070	Manufacture of household audio-visual apparatus	086
Manufacture of other special purpose machinery	072	Manufacture of other communication equipment	087.2
Manufacture of railroad transport equipment	073	Manufacture of measuring instruments	088
Manufacture of automobiles	074.1	Manufacture of machinery for cultural activity & office work	089
Manufacture of boats and ships and floating devices	075	Manufacture of artwork and crafts	090.1
Manufacture of other transport equipment	076		

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