Chapter 6 Conclusions and discussions

The main objectives of this dissertation are

*analysis of the determinants of China’s energy efficiency at provincial level and at selected firm level and, based on the analysis, the development of policy handles to further improve China’s energy efficiency.*

From the overall objective 4 sub-objectives were derived. This chapter presents the main conclusions per sub-objective, policy recommendations and directions for future research.

This chapter is organized as follows. Section 6.1 presents the main empirical findings, section 6.2 offers policy recommendations, and section 6.3 discusses directions for future research.

6.1 Main empirical findings

(1) *The drivers of energy intensity in China*

The first sub-objective was analysis of the drivers of energy intensity, particularly the analysis of the relationship between income per capita and energy intensity (Energy Intensity Kuznets curve). The sub-objective was analyzed in the main theme of Chapter 2. I first analyzed energy intensity of the 29 Chinese provinces, both temporally and spatially. I found a clear downward trend, though with an interruption in 2002 due to a spurt of economic growth (Andrews-Speed, 2009). After 2003, the trend continued to decline. Next, the spatial distribution of average energy intensity from 2003 to 2011 was analyzed. I found that the northwestern provinces have high energy intensity, the eastern provinces low energy intensity with an intermediate corridor in between.

Secondly, I examined whether there was an inverted U-shaped relationship between energy intensity and per capita gross provincial product by means of a fixed
effects spatial Durbin error model, taking into account key exogenous variables and their spatial lags. I indeed found an inverted U-shaped curve. Moreover, I found that ten developed eastern coastal provinces had already passed the turning point of 29,673 RMB. The number of years for the other 19 provinces that had not yet passed the turning point ranged from 8.3 (Jilin province) to 21.8 (Yunnan province).

Finally, I analyzed the main determinants of the above developments and found that the share of the secondary sector in the own province and in neighboring provinces drives energy intensity up while the capital labor ratio has a negative impact. Foreign direct investment also turned out to have a significant negative spatial spillover effect on energy intensity. The spatial autocorrelation coefficient of the residuals was significant.

(2) Energy efficiency in the Chinese provinces

The second sub-objective was the analysis of energy efficiency of the Chinese provinces and its determinants. In the first-stage analysis, I calculated single factor energy efficiency derived from multi-factor efficiency estimated by means of a fixed effects stochastic frontier model and a translog production function based on a panel data set for 29 provinces over the period 2003 to 2011. The yearly energy efficiency scores of the 29 Chinese provinces for the period 2003-2011 were thus obtained. I found that the yearly energy efficiency scores of 18 provinces had increased continuously. The scores of the other provinces had fluctuated with a clear upward trend, though. In total, the yearly average energy efficiency scores over the period 2003-2011 showed a clear upward trend, from 0.475 in 2003 to 0.703 in 2011. Regarding spatial distribution, I found that the average score of the eastern provinces was 0.6406, followed by the central provinces, 0.6108, and the western provinces, 0.5106.

In the second-stage analysis, I applied a fixed effects spatial Durbin error model to estimate the impacts of some key control variables and their spatial lags on energy efficiency estimated in the first-stage analysis. I found that per capita income in the
own province has a positive impact on energy efficiency. Foreign direct investment in the own province and in neighboring provinces has positive impacts while the share of state-owned enterprise in gross provincial product in the own province and in neighboring provinces have negative impacts.

(3) Convergence of cross-province energy intensity in China

The third sub-objective was the analysis of convergence of cross-province energy intensity in China based on a panel data set of 29 Chinese provinces for the period 2003-2012 by way of $\sigma$ convergence, kernel density, unconditional and conditional $\beta$ convergence.

For $\sigma$ convergence I found an overall downward trend throughout the entire sample period 2003-2012. In addition, among 10th, 25th, 50th, 75th, and 90th percentiles, the 90th percentile exhibited the strongest decline, implying that high energy intensive provinces had reduced energy intensity more than low energy intensive provinces.

Similar results were obtained by means of kernel density analysis. I found that annual average energy intensity had gradually declined over time and that its distribution had grown more compact and steeper, also implying convergence. Besides, the upper tail of the distributions had decreased over time indicating that provinces with high energy intensity had gradually improved.

I analyzed unconditional and conditional $\beta$ convergence by means of a fixed effects spatial Durbin error model. First, I found evidence of unconditional $\beta$ convergence. Regarding conditional $\beta$ convergence, I applied two types of models: one controlling for the fixed effects only, and the other also for six exogenous variables, viz. per capita gross provincial product, the share of the secondary sector, investment, the ratio of capital to labor, foreign direct investment, and energy reserves. Moreover, I considered the spatial lags of these variables. The estimates showed that the convergence parameter of the latter model was larger than that of the former indicating that controlling for the 6 key exogenous variables and their spatial lags tends to remove downward bias of the estimator of the convergence parameter.
Besides, I found that per capita gross provincial product and the ratio of capital to labor in the own province and in neighboring provinces had negative impacts on the growth of energy intensity. On the other hand, the share of the secondary sector and investment in real estate and infrastructure in the own province and in neighboring provinces had positive impacts. Foreign direct investment had a significant negative spatial spillover effect on the growth of energy intensity.

4) Interaction between output and environmental efficiency

The fourth sub-objective was to get insight into the interaction between output efficiency and environmental efficiency. In the first-stage analysis, I derived energy efficiency (EEF), waste water efficiency (WWEF), waste gas efficiency (WGEF), soot efficiency (STEF), and output efficiency (OutEF) for 137 textile firms in Jiangsu province by means of generalized DEA (GDEA) which considers both desirable and undesirable output simultaneously. I found that generalized efficiency had the lowest mean among all efficiency measures. The explanation is that it is a multi-factor efficiency measure. The means of the environmental efficiency measures EEF, WWEF, WGEF and STEF ranged from 0.2896 to 0.3874 and were much lower than that of OutEF (0.8189). Besides, the means of the environmental efficiency indicators EEF, WGEF and STEF were very close due to the fact that they are all related to coal combustion.

In the second-stage analysis, I applied a structural equation model with latent variables (SEM) to analyze the interaction between the endogenous latent variable environmental efficiency - measured by the four observed environmental indicators EEF, WWEF, WGEF and STEF- and output efficiency. I furthermore took into account the endogenous variable profit. In addition, I considered 6 exogenous firm characteristics that were hypothesized to impact the endogenous variables, i.e. the ratio of capital to labor, age, taxes, size, liabilities and sales. The main findings were the following. First, environmental efficiency had a negative impact on profit while profit had a positive impact on environmental efficiency. A similar relationship held for output efficiency and profit: output efficiency reduced profit while profit induced
output efficiency. Finally, environmental efficiency positively impacted on output efficiency while there was no significant effect of output efficiency on environmental efficiency. Besides, age turned out to be highly insignificant and was deleted from the SEM. The analysis also showed that the ratio of capital to labor negatively and significantly impacted on environmental efficiency. A possible explanation is that the textile industry traditionally is a labor-intensive industry rather than a capital-intensive industry. Capital investment therefore tends to raise energy intensity. Taxes negatively impacted on output efficiency indicating that a heavy tax burden impaired a firm’s output efficiency. Size had a positive impact on output efficiency implying that large firms tend to exploit economies of scale which benefits output efficiency. The impact of liabilities on profit was significant and negative. Sales on the other hand positively impacted on profit indicating that firms with high turnover tend to have high profits.

### 6.2 Policy recommendations

Energy shortage and environmental degradation have been worsening in China for decades. The Chinese central government has been fully aware of both problems and has taken series of measures, particularly reduction of energy intensity. For instance, the 11th Five-Year Plan contained a reduction target of 20%. Further reduction targets in future Five-Year Plans are expected to be 16% relative to the 2010 benchmark (Wang et al., 2013).

From the analyses presented in this thesis the following policy handles for further improvement of energy efficiency can be derived: (1) optimization of industrial structure, (2) balanced investment in fixed assets, notably infrastructure and real estate, (3) attraction of FDI, (4) development of indigenous innovation, (5) increasing the share of clean energy in the energy mix, (6) stimulating environmental efficiency as a long-run national strategy.

(1) China’s remarkable economic growth is attributed to its rapid industrialization.
However, from the analyses in this thesis it follows that the excessive development of the secondary industry is one of the main causes for the unprecedented amount of energy consumption. For instance, in 2012 the secondary industry only accounted for 45% in GDP but consumed 67% of total primary energy of China (NBS, 2014). Hence, in order to build up a resource-conserving society, an optimized industrial structure with decreased share of the secondary industry and increased share of the tertiary industry in China’s economy is urgently needed (Liu, 2009). Unsurprisingly, the share of the tertiary industry in GDP has been increasing since the economic reforms, from 23.9% in 1978 to 46.1% in 2013. Nevertheless, the secondary sector still plays a major role in the Chinese economy. Since the development of the secondary sector is affected by Five-Year Plan policies, there is a need for a long-term national overall industrial development road map.

(2) China has been an investment-led economy. Over the last decade total fixed investment has risen fivefold, from 5349 billion Yuan in 2003, accounting for nearly 40% of GDP in 2003, to 26908 billion Yuan, accounting for nearly 50% in 2013 (NBS, 2014). This investment in fixed assets has triggered a shift towards heavy and energy intensive industries, such as cement, iron, steel, and aluminum. For example, in 2007 China accounted for 35% of global steel production, 28% of global aluminum production and 48% of global cement production (Rosen and Houser, 2007). Due to low levels of technology, Chinese steel and cement industries use 20% and 45% more energy than the developed countries averages, respectively (Elliott et al., 2013). Consequently, China has experienced a relatively slow rate of energy efficiency improvement over the last decade. Furthermore, there exists overcapacity in energy intensive sectors, including steel, cement and aluminum (Zhang et al., 2014). Hence, a series of economic policy handles and reforms are urgently needed to reduce the investment in fixed assets, including cutting preferential policies towards fixed investment and reforming the GDP-oriented political performance assessment. Administrative policies are also
urgently needed to ban new energy intensive projects. Besides, China’s government should enforce higher energy and environmental standards for the energy intensive enterprises, which will not only help to reduce overcapacity, but also contribute to environmental quality improvement.

(3) In this thesis foreign direct investment (FDI) has been identified as an effective way of energy efficiency improvement (see also Elliott et al., 2013). Since its economic reform in 1978, China has taken a number of preferential policies in order to attract FDI. As a result, FDI inflows into China have substantially increased over the past two decades, from less than 2 billion US dollars in 1985 to 118 billion US dollars in 2013. However, it is worth noting that the majority of the aggregate FDI flows into the eastern coastal provinces due to geography and preferential policies. Although the western provinces have also taken great efforts to attract FDI inflows, they lag far behind the eastern provinces. For instance, in 2011 they only accounted for 14% of the aggregate FDI inflow. This is because current FDI inflows into such energy intensive sectors as mining, steel, aluminum, construction, and transportation - some of which are main economic pillars for the western energy-rich provinces - are still highly restricted by the central government. Hence, more preferential policies are urgently needed to stimulate more FDI inflows into the western region. For this purpose, the central Chinese government should further deepen economic reforms and open up wider to the international community so that multinational firms have incentives to invest new energy-saving capital and diffuse new technology to China, notably to the western region.

(4) One plausible way of reducing energy consumption, mitigating pollution and improving environmental quality is to develop domestic technological innovation and strengthen domestic innovative capacity. The Chinese government has already developed a series of national strategies to build up an innovation-oriented country, 

\( ^{24} \) FDI may also have negative effects such as the “pollution heaven” effect. However, China has strictly forbidden those multinational firms engaged in highly polluting production activities with weak environmental standards to enter China.
including the release of a national medium and long-term program for science and technology development (2006-2020)\textsuperscript{25}. As a result, China’s expenditures for research and development activities (R&D) have substantially increased, from 300 billion RMB in 1990 to 1030 billion RMB in 2012 (NBS, 2014) indicating that China has become fully aware of the need to develop indigenous R&D. However, in spite of the rapid increase in R&D investment, its share in China’s GDP still lags behind that of developed economies. Specifically, in 2012 its share of 1.98% was far lower than the 3.39% of Japan, the 2.98% of Denmark, the 2.92% of Germany, the 2.79% of the U.S., the 2.26% of France, and even lower than the 2.13% of the world average\textsuperscript{26}. Therefore, China should continue expanding investment in indigenous innovation in fields like energy exploration and energy saving, and environmental protection (Zhang et al., 2013). Furthermore, energy-intensive industrial sectors, e.g. metal and cement, need to be encouraged to adopt advanced domestic energy-saving technologies (Zhang et al., 2015).

(5) Another way of protecting the environment is optimization of the energy consumption structure. Particularly, China should reduce its overdependence on coal and increase the share of clean(er) energy sources including non-fossil fuels, in the energy mix. Large scale development of non-fossil fuels is also an effective strategy to cope with energy shortage. China has already taken steps into this direction. In the 11\textsuperscript{th} Five-Year Plan (2006-2010), the Chinese central government launched a target of increasing the share of clean(er) energy sources in primary energy supply. As a result, the share of coal as primary energy source declined from 71% in 2006 to 66% in 2013, the share of natural gas increased from 2.9% in 2006 to 5.8 in 2013, and the share of hydro-power, nuclear power and wind power combined increased from 6.7% in 2006 to 9.8% in 2013 (NBS, 2014). The 11\textsuperscript{th} Five-Year Plan was strengthened by the Medium and Long-Term Plan for
renewable Energy Development (2010-2020) released in 2008.\(^{27}\) This was the first national plan for renewable energy development in China. It set an overall target for renewable energy shares and specific targets for hydropower, biomass, wind, solar, geothermal and ocean energy. According to the plan, the share of renewable energy in the energy mix is to reach 15% by 2020. As of today, China already has the world’s largest installed capacities of hydropower, wind energy and solar water heating (Hong et al., 2013). Following Chow (2008), I note that increasing its share in the energy consumption structure, clean energy should not be priced higher than the price of power generated by coal (Chow, 2008). Otherwise, the secondary industry, the largest energy consumer, has no incentive to use clean energy. For this purpose, specific policy handles are urgently needed, particularly taxes on coal.

(6) This thesis shows that environmental efficiency promotes output efficiency which has significant implications for environmental policy. Although environmental policy aimed at improving environmental efficiency, particularly energy efficiency, depresses profit in the short run, it stimulates output efficiency in the longer run. This is an indication for China’s policymakers that continuing the development and implementation of environmental policy aimed at improving environmental and energy efficiency should be adopted in a long run. Most importantly, since the serious environmental degradation has been posing a huge threat to people’s health, both short-run and long-run environmental improvement policies as the top priority of China’s national strategies can never be over-emphasized.

The Chinese government has been aware of environmental protection and enacted a number of environmental protection laws since 1980’s, including the “Water Pollution Prevention and Control Law” of 1984, the “Air Pollution Prevention and Control Law” of 1987, the “Water and Soil Conservation Law” of 1991, the “Solid Waste Law” of 1995, the Energy Conservation Law” of 1997 (Chow, 2008). Moreover, China joined several important international environmental treaties, 

including the Kyoto Protocol and Montreal Protocol\textsuperscript{28} (Zhao and Ortolano, 2003; Pao, 2012). However, environmental protection laws have not been effectively enforced by local officials, especially when local producers violate laws to reduce production costs (He et al., 2012). Local officials tend to allow polluting activities to take place for the benefit of local economic growth since economic performance contributes to their political prestige and promotion. To resolve this problem, an environmental evaluation indicator combined with economic growth indicators should be applied as integrated assessment handle of local government performance. Besides, a series of strict actions are urgently needed to ensure enforcement of various environmental protection laws, to sharply raise taxes on various emissions, and to severely punish environmental protection laws violators (Chow, 2008). Awareness of the beneficial impacts of environmental efficiency on output efficiency is likely to enhance adoption of these kinds of environmental policy.

6.3 Suggestions for future research

This dissertation may be further developed in various ways. First, in Chapter 2 I considered the variable energy resources reserves as driver of energy intensity. Generally speaking, energy-rich provinces tend to attract and develop relatively large shares of energy intensive industries, which reduces their energy efficiency. However, the variable turned out to be insignificant. A possible explanation is that the variable used in this research was not a good indicator due to little variation over time. Further analysis of the impacts of energy resources reserves on energy intensity and efficiency is important, especially since economic development in the western Chinese provinces which have been lagging far behind the eastern provinces, has high priority in China’s national socio-economic policy. This achievement of this policy goal should not jeopardize the national goal of improving energy efficiency.

\textsuperscript{28} Kyoto Protocol is an international treaty that commits parties to reduce man-made CO\textsubscript{2} emissions in order to respond to global climate change. The Montreal Protocol is also an international treaty that is designed to protect the ozone layer.
Secondly, in Chapter 3 I estimated energy efficiency by way of a fixed effects stochastic frontier model taking into account three inputs, viz. capital, labor and energy and one output, viz. provincial gross product. As argued in chapter 5, production leads to both desirable and undesirable outputs. The development of a stochastic frontier model that accounts for both desirable and undesirable output would enrich economic efficiency analysis.

Thirdly, Chapter 4 analyzed convergence of cross-province energy intensity in China inter alia by way of non-parametric kernel density analysis. Since there are large differences in population, level of economic development across provinces in China, a weighted kernel density taking into account population size and level of economic development would enrich convergence analysis.

Fourthly, the analysis in Chapter 5 relates to a small industrial sector in a specific province, Jiangsu, for one year only. It would be desirable to extend the analysis to other sectors, provinces, even entire China, and for longer time spans to get further insight into the interdependence between environmental efficiency and output efficiency.

Finally, this thesis relates to energy efficiency in China. However, environmental degradation, energy shortage and energy efficiency are also major issues in other developing countries like India, Pakistan, Bangladesh, Indonesia and several African and Latin American countries. The analyses presented in this thesis could be readily applied in other developing countries. In addition cross-country energy efficiency analyses for China and other developing countries on the other hand and OECD countries would be instrumental for the further development of policy handles aimed at improving energy efficiency in China and elsewhere.
References


