Environmental Policies in China

Shunsuke Managi [1] * and Shinji Kaneko [2]

[1] Faculty of Business Administration, Yokohama National University, Japan

[2] Graduate School for International Development and Cooperation,
Hiroshima University, Japan

** Very Preliminary Version **

Abstract

China is an economic powerhouse with annual economic growth averaging close to 9% over the last 25 years. However, as a result of this extremely rapid economic growth, the scale and seriousness of its environmental problems are clearly evident. Consequently, a number of environmental problems, including growing energy consumption, heavy reliance on coal, and increasing air pollution, are threatening China's sustainable future. This paper measures and analyses the determinants of various components of total factor productivity within a joint-production model of market and environmental outputs in China from 1992 to 2003. The results indicate that although China began implementing new environmental policies, and although the stringency of these regulations is increasing, there is no short-term positive benefit associated with their implementation. However, some environmental productivity measures, such as wastewater treatment, have exhibited an increase in managerial efficiency. Detecting the determinants of these factors, this paper finds the foreign direct investment (FDI) instead of domestic invention is the major factor to increase the market productivity growth while FDI has negative effects on environmental productivities. We also examined whether traditional command and control regulations and/or market mechanism such as pollution taxation are effective on encouraging efficient management of pollution control.

Keywords: Productivity, Empirical Policy Analysis, Technological change, Environmental Regulations, China.

JEL Classification: D24; O40; Q10.

1. Introduction

Market transition reforms in China have been shaped by the interaction of a number of factors, including economic conditions, political constraints and official ideology. During this process, transitional institutions took some unconventional forms. However, although these transitions were second-best arrangements, the incentives of economic agents were generally improved. The consequences of this reform process were generally comprehensive, consistent and deep, and this helps to explain why the reform process was more successful in China, as against Eastern Europe, in the period up to 1990[1,2]. The relations between the institutional changes, economic performance, and economic conditions are clearly interconnected as the cycle continues and reform moves forward.

China is clearly an economic powerhouse with average economic growth of close to 9% per annum over the last 25 years (World Bank, 2001). However, as a result of China's extremely rapid economic growth, the scale and seriousness of its environmental problems are clearly evident. Consequently, a number of environmental problems, including growing energy consumption, heavy reliance on coal, and increasing air pollution, are threatening China's sustainable future[3]. For example, the World Bank estimated that economic damage caused by

---

[1] See Qian (1999) for an analysis of the institutional foundations of China's market transition.

[2] There is a growing literature studying the transition of economies from socialist to market systems. One aspect of this literature examines why the experience in China differs from that in other transitional economies, including Russia, Vietnam and those in Eastern Europe. One major difference is that China's economy is much larger and more diversified than most other transitional economies, with the exception of Russia. As a result, countries with a small and homogeneous economy can adjust their legal and financial systems much easier than large countries (e.g., Shleifer and Treisman 2000). This is probably because it is easier for other countries to adopt drastic reform measures in the short run. China also differs because of the influence of Confucian philosophy. In this regard, people in China believe that fundamental changes in society should be gradual and only fully implemented after they are proved correct (Qian, 2003). This view, however, does not prevent regional experiments being conducted at a smaller scale. Accordingly, China adopted a gradual, 'dual-track' path in its economic reform, in that the continued enforcement of the existing planning system went alongside the fast-paced development of financial markets, as compared to the 'big bang' approach taken by some other countries (e.g., Qian 1999; Lau et al. 2000).

[3] For more information, see World Bank (2001).

pollution in China cost around $54 billion annually, amounting to close to 8% of domestic GDP (World Bank, 1997). Similarly, Economy (2004) reported that in 2000, China had 16 of the 20 most polluted cities in the world, and Bolt et al. (2001) conclude that China's air pollution problem is the world's worst. By the end of the 20th century, the explosion in economic growth also made China the world's second largest carbon dioxide (CO_2) emitter and energy consumer after the United States.

In response, from the late 1970s, China began implementation of a number of environmental policies in relation to air and water pollution and solid waste disposal, and the number of these regulations has been steadily increasing (Sinkule and Ortolano, 1995). The State Environmental Protection Administration (SEPA) in China has also declared control of industrial pollution to be a top priority for Chinese regulators. Responding to this severe environmental pollution, the National Environmental Protection Agency (NEPA) and the State Planning Commission (SPC) jointly proposed China's Environmental Action Plan for 1991–2000. The plan highlights the environmental issues that officials at the national level consider particularly significant. The top three (of seven) problems listed deal with water pollution, air pollution, and hazardous waste. The next three involve conservation of natural resources in the form of water, land, forests and grasslands. The final problem centers on the balance and integrity of China's ecosystems (Ma and Ortolano, 2000). However, weak enforcement of environmental regulations has been recognized as a major problem in China.

Growth of productivity plays an important role in GDP growth in China (Wang and Yao 2003). In addition, the costs (and availability) of alternative production and pollution

---

[5] State-owned enterprise (SOE) reform by the government in this period increased enterprise autonomy and heightened profit incentives. Most economists agree that, despite the great effort in improving SOE performance, the most significant achievement was made by the fast entry and expansion of urban and rural nonstate enterprises. These firms were under tighter budget constraints and had better internal incentive structures. Indirectly, they also benefited from the various reforms aimed at the state sector, including fiscal decentralization, financial reform, the dual-price system, and expanding the SOE autonomy.

abatement technologies, which are important determinants of the environmental compliance cost, are also influenced by productivity (e.g., Jaffe, Newell, and Stavins 2003). Thus, it is important to understand the interaction between productivity change and environmental policies, which influence the compliance costs. In the long run, the most important single criterion on which to judge environmental policies might be the extent to which they spur new technology toward the efficient conservation of environmental quality (Kneese and Schultze, 1978; Robinson, 1995). There is a blossoming growth of literature, mainly theoretical, on the effects of environmental policies on technological innovation (see Jaffe, Newell, and Stavins (2003) for review). In general, the incentive to innovate is stronger under market-based systems (e.g., emission fees or permits) than under command and control regulations (e.g., Downing and White, 1986).

The relationship between environmental policies and technological change are complex, however, and there is no unambiguous case for preferring any of the policy instruments from emissions taxes, auctioned emissions permits and free permits. In practice, there are even more factors that make the evaluation difficult (Fischer, Parry, and Pizer, 2003). Thus, how the actual environmental policies effects technological change positively is an empirical question.

Thorough analyses of technological change are essential for identifying appropriate policy actions to encourage economic growth and mitigate negative effects of environmental problems. The principal focus of this paper is to measure technological change both for market and non-market (i.e., environmental) outputs and to find the determinants of these changes.

2. Background in Chinese Economic Growth

2.1. Economic Growth in China

By 1978, China was one of the most closed economies in the world. The Chinese economy had been closed to Western countries since 1949, and it had been closed to the Eastern block since the early 1960s following conflict with the Soviet bloc. The fiscal system as a whole before reform was quite centralized. This is because the Planning Commission in the central government had the authority to determine local revenue and expenditure plans on an annual basis, although some fiscal decentralization was implemented. This was known as the principle of “unified revenue and unified expenditure”. This meant that all government revenue and expenditures had to be directed through the central government.

In December 1978, the Third Plenum of the Eleventh Chinese Communist Party Congress was held. This event is widely regarded as the beginning of the reform era. The main achievement of the meeting was the decision to shift the Communist Party’s focus from “class struggle” to “economic development.” An intensive ideological debate between Mao’s orthodox version of Marxism–Leninism and pragmatism preceded this meeting in mid-1978.

In 1979, the government in China decided to welcome foreign investment and expand foreign trade. This allowed a change in ideology from within the Communist Party and paved the way for the initialization of reform. The accepted ideology during the first phase of reform was the idea of “planning as a principal part and market as a supplementary part.” This was a significant change from Mao’s ideology of abolishing markets.

As a result of these reforms, a significant improvement in people’s living standards came about. The state sector was no longer the dominant part of the economy, and most of the old revolutionaries disappeared from the political scene. In 1980, a major fiscal reform concerning central and provincial relationships began. This reform, known as the “fiscal contracting system”, was colloquially referred to as “eating from separate kitchens”. Under this system, budgetary revenue was first divided into “central fixed revenue,” which was remitted to the center, and “local revenue,” which was shared. The contractual sharing rates varied from province to province.

2.2. Origin of Growth

Before the reform, China was poor, overpopulated, short of human capital and natural resources, and centrally planned. After more than two decades of market transition, China progressed into a lower middle-income, emerging market economy. During this period, China’s per capita gross domestic product (GDP) more than quadrupled, and total GDP grew at an average annual rate of more than 9%. In the early 1980s, few economists would have expected the outcomes seen in China today. This growth is also likely to continue for the foreseeable future. Figure 1 presents the GDP growth of several major regions, including China, the European Monetary Union, Japan and the United States. Clearly, the speed of growth in China is much higher than these other regions. For example, the growth rate in China is around three times higher than that in the USA over the past five years. Even when considered as a developing economy, its more than US$1.3 trillion economy in 2003 is bigger than all other transition economies combined. In 2004, however, GDP in China is still only 13%, 22%, and 28% of GDP in the USA, the European Monetary Union and Japan, respectively (see Figure 2). However, in GDP dollars expressed in purchasing power parity (PPP) terms (shown in Figure 3), putting aside the limitations of GDP conversion at market exchange rates, China surpassed Japan in 1995 and is close to the European Monetary Union. China also has a population almost three times the combined size of the eight highest-performing East Asian economies (Japan, South Korea, Taiwan, Hong Kong, Singapore, Malaysia, Thailand, and Indonesia).

Conventional economics suggests a basic recipe for transition from planned economy to market economy. This entails stabilization, liberalization, and privatization following political democratization. To guarantee sound reforms, this recipe may not be sufficient, but theoretically these essential ingredients are necessary for reform to succeed. Although many of its policies, such as being open to trade and foreign investment, and attention to macroeconomic stability, have been adopted by the government in China, violations of these standard prescriptions are clear. For the most part, China's reforms in the last two decades succeeded without complete liberalization, privatization and democratization. Therefore, the Chinese path of reform and its associated rapid growth is puzzling because it appears to defy conventional wisdom. Blanchard and Fischer (1993), for example, have questioned why China has grown so fast when the conditions thought to be necessary for growth are absent.

Several plausible explanations are provided in the literature. One aspect concerns alternative financing and governance mechanisms. One of the most important of these mechanisms is reputation and relationships (see Allen et al., 2005). This literature indicates that traders' organizations in the 11th Century were able to overcome problems of asymmetric information and the lack of legal and contract enforcement mechanisms (Greif, 1989; 1993). This is so because they developed institutions based on reputation, implicit contractual relations and coalitions. China's private sector closely resembles certain aspects of these traders' organizations, especially in terms of how firms raise funds and contract with investors and business partners. Greif (1994) and Stulz and Williamson (2003) have also pointed out the importance of cultural and religious beliefs to the development of institutions, legal origins and investor protections.

The second most important mechanism is competition in product and input markets (see Allen et al., 2005). This mechanism has been shown to work well in both developed and developing countries (e.g., McMillan 1995, 1997; Allen and Gale 2000; Allen et al., 2005)[5]. For example, Allen et al. (2005) showed how firms in the private sector raise funds, their various growth paths, and the alternative mechanisms employed by owners that can substitute for formal corporate governance mechanisms. Their survey included private sector firms in Wenzhou, a city in the Zhejiang province. The survey suggested that it was only those firms that had the strongest comparative advantage in an industry (in the area) that survived and thrived. See also Djankov et al. (2002), which examines entry barriers in 85 countries, including China.

The third mechanism is local government's fiscal incentives (Qian, 2003). China has been viewed as supporting local development and helping local businesses. Specifically, the Chinese planning system has been decentralized along regional lines, and local governments have played an important role in economic decision making and resource allocation[6]. Chinese decentralization led to the rise of many small-scale state-owned enterprises financed from local government revenues[7]. In addition, they induced collective enterprises, such as Commune and Brigade Enterprises in rural areas, predecessors of Township-Village Enterprises, to emerge outside the state plan before the advent of reform.

Jin et al. (2001) have used panel data on 28 provinces between 1982 and 1992 for local governments' revenues and expenditures to evaluate the marginal fiscal incentives of provincial governments. They conclude that the new fiscal system did indeed substantially enhance the fiscal incentives for local governments. These results are in contrast to the Russian experience, where increases in a city's own revenue were almost entirely offset by a decrease in shared revenue from the region to the city (Zhuravskaya, 2000).

The incentive theory argues that local government does not have an incentive to support productive local businesses if the central government subtracts all of the locally generated

---

[6] Central planning was usually aggregated, crude, and not comprehensive, and plan fulfillment often was not a binding constraint. These features represented a significant departure from the textbook model of the Soviet system.

[7] We take an example in the banking industry. Before the reform, there was only one bank, the People's Bank of China (PBOC), which served as both the central bank and a commercial bank. In 1983, the State Council granted the PBOC the authority of a central bank and subsequently transferred commercial operations to four specialized banks. After 1984, local governments at provincial, municipal, and county levels gained great influence over credit decisions through the regional branches of the central bank and state specialized banks.

revenue, because it cannot benefit from their support. Conversely, if local governments' expenditures are closely linked to the revenue they generate, the local governments will more likely support productive local businesses as they benefit directly from their support. The empirical evidence found by Jin et al. (2001) reveals that such incentive effects do exist and are significant. An increase in the marginal fiscal revenue retention rate in a province by 10 percentage points is associated with an increase of one percentage point in the growth rate of employment by nonstate enterprises in that province.

2.3. Productivity Growth

The empirical literature on economic growth in China suggests that total factor productivity (TFP) growth has played an import role in increasing GDP during the reform period (e.g., World Bank, 1997; Madisson, 1998). However, there is little consensus on the results in more recent years, i.e., Chinese economic growth during the 1990s has followed a different pattern from that in the 1980s. For example, Liu (2000) believes that most of the productivity gains in the past two decades stemmed from the rectification of resource misallocations that were the legacy of the central planning era, and from narrowing the technology gap between China and the developed economies. Over time, as China moves closer to a market economy, such gains will inevitably diminish.

In addition, several economists have raised questions regarding the origin of economic growth in China. For instance, Krugman (1994), citing work by Young (1994, 1995), has argued that rapid growth in the East Asian NICs has been driven mainly by the massive injection of factor inputs, rather than innovation. As China's growth is likened to the East Asian NICs, the same argument is made about the Chinese economy. If this argument is true for China, growth is not sustainable. Sachs and Woo (1997) also pointed out that China's broad growth performance is in line with the performance of other East Asian economies and is attributable mainly to factor accumulation. Characteristics similar to those of other East Asian economies include low initial capital endowment, access to international sea lanes, an export orientation strategy, and a high proportion of the labor force in agriculture. They also find that economic reform has not improved state-owned enterprise (SOE) performance, as based on declining profitability, and SOEs have actually become a destabilizer for the economy as a whole (Sachs and Woo, 1997) [8].

Input-driven growth, such as capital-oriented growth, is also not sustainable in the long term because of diminishing returns to capital. This leaves productivity as the only viable engine of long-term economic growth (Liu, 2000). Young (2000) questions the performance of China's growth by linking his findings on the convergence of the provincial industrial structure to the fragmentation of the domestic market and the distortion of regional production away from patterns of comparative advantage. Young (2003) also shows that one can reduce the growth rate during the reform period to levels previously experienced by other rapidly growing economies, so that total factor productivity growth in the nonagricultural economy is found to be about 1.4% per year—a respectable performance, but by no means extraordinary.

In the literature on China's productivity, several studies apply a growth accounting approach to examine the role of productivity in China's economic growth. For example, by employing Solow's residual growth accounting method, Borensztein and Ostry (1996) and Hu and Khan (1997) found a significant contribution of total factor productivity to growth in China during the reform period. However, the growth accounting method should be treated with caution since it suffers from some major drawbacks. The method requires the assumption of constant returns-to-scale, revenue maximization, and the assumption that all decision-making units are

---

[8] A number of empirical studies have attempted to measure total factor productivity (TFP) growth for the Chinese state-owned sector. Although some find that economic reform made little or no contribution to TFP growth in the state sector, most find that TFP growth has improved since 1978. However, it still lags behind TFP growth in township and village enterprises (Jefferson et al., 1996). We also need to be cautious about the interpretation of SOE TFP because productivity is not necessarily a good indicator of enterprise performance in transition economies, given the nonprofit objectives of SOEs.

efficient, and requires information on cost and/or input and output price data that is often unavailable. The second assumption especially is questionable when producers' objectives differ, or are unknown or unachieved. The third assumption is crucial if there are situations in which prices are distorted or nonexistent. Finally, and most importantly, the growth-accounting method cannot distinguish between technological progress and changes in technical efficiency.

In this study, we use an alternative technique to overcome these problems. We apply a mathematical programming technique called nonparametric frontier analysis or Data Envelopment Analysis (DEA) (see, for example, Färe et al., 1994) to compute the change in productivity over time. This study decomposes total factor productivity (TFP) change to provide a better understanding of the relative importance of various components over the study period. The TFP includes all categories of productivity change, which can be decomposed into two components including technological change and efficiency change (Färe et al., 1994).

Technological change (TC) and efficiency change (EC) have additive or multiple relationships in the composition of TFP. It is then important to analyze these two conceptually different measurements considering the effects of economic reform. TC measures shifts in the production frontier or measures productivity growth by stimulating innovation. EC measures changes in the position of a production unit relative to the frontier—so-called "catching up". If existing resources are not fully utilized in production before reform, we are able to expect a significant increase in EC. Understanding these two components of productivity changes is important since it provides valuable insights into understanding the source of a country's spectacular growth. Additionally, distinction between these two effects provides insights for future growth such that the effect of technological change can be large and sustainable while the effects of efficiency change can be drawn out over time (Lucas, 1988).

The most recent study analyzing productivity in China is provided by Wu (2003), who found that total factor productivity (TFP) has on average contributed to 13.5% of economic growth during the period 1981–1997 using economy-wide province-level data, including the agricultural sector. Wu (2003) also found that this contribution is mainly due to technological progress, which tends to accelerate over time. Efficiency change has also been very volatile, reflecting the uncertainties associated with economic reforms and transition in China (see Figure 4). TFP growth was found to be 1.41% on average, results similar to Young (2003), which have been used to question Chinese growth performance. Significant improvements in productivity are found to appear in the early 1980s; that is, in the years after initiation of the reforms. This is consistent with reforms that began in the agricultural sector in the late 1970s and the success of rural reforms (Lin, 1992).

On the other hand, poor performance is suggested in the second half of the 1980s. Efficiency declined every year except 1988 during the period 1986–1991. The decline in efficiency may well have occurred in many economic sectors during this period. The poorest performances are in the agricultural, industrial and nonstate sectors, including township, village and private enterprises (TVPs), and these have been well analyzed in the literature (see Kalirajan et al., 1996; Jefferson et al., 1992; Fong and Tong, 1998, respectively). Finally, all three indicators have shown an upward tendency during the early 1990s. This may be the result of reforms initiated in the mid-1980s and more comprehensive reforms implemented in the early 1990s. In particular, price deregulation, which removed price distortions in the early 1990s, created a better business environment for both domestic and foreign investors.

On this basis, Wu (2003) suggests that China’s growth will be sustainable in the near future and concludes, unlike Krugman (1994), that productivity increases contributed to economic growth. However, it should be noted that the contribution of productivity increases to economic growth is relatively small compared to developed countries or even some developing countries.

Economic development in China still clearly depends on the massive injection of factor inputs. For example, Dougherty and Jorgenson (1996) estimate that productivity accounted for 26.2%, 49.8% and 57.6% of output growth during the period 1960–1989 in the United States, Japan and Germany, respectively. These figures are much higher than the Chinese equivalent of 13.5%. Chang and Luh (2000) analyze data from 10 Asian economies, including China, Japan, the NIEs and the ASEAN-4, using distance-function-based Malmquist productivity indices following Färe et al. (1994). Compared with the other countries, they find that China exhibited productivity regress in both the 1970s and the 1980s. It is thus clear that there is ample scope for improvement in productivity performance in China. Our study evaluates more recent growth, focusing on the industrial sector and using a more sophisticated technique.

3. Institutional Development of Environmental Policy in China

3.1. Decision-Making System of Environmental Policy

As a result of China's rapid economic growth, degradation of the environment has become increasingly severe over the last two decades. For example, the World Bank estimated that economic damage caused by pollution in China cost around $54 billion annually, amounting to close to 8% of domestic GDP (World Bank, 1997). During the 1990s and early 2000s, some mega cities, including Beijing, Shenyang, Xian, Shanghai, and Guangzhou, have always been included among the 10 most polluted cities in the world. Urban pollution in China has also caused significant public health and economic damage. To protect public health and environmental quality, the Chinese government has undertaken a series of actions. Several laws, regulations, and standards have been promulgated (Sinkule and Ortolano, 1995; Edmonds, 2004).

The decision-making system of environmental policy in China consists chiefly of three organizations. First, the National People's Congress (NPC) has a committee responsible for environmental policy, called the Environment and Resources Protection Committee (ERPC). The NPC makes policy decisions for environmental protection, passes legislation, and supervises its enforcement. Second, the State Environmental Protection Commission (SEPC) of the State Council drafts policies, regulations, and laws for environmental protection. Third, the State Environmental Protection Agency (SEPA) of the State Council administers and supervises the environmental protection laws throughout the country[9]. The local Environmental Protection Bureaus (EPBs) and Environmental Protection Offices (EPOs) at the province, municipality, and city levels are directly under the SEPA. EPBs and EPOs are raised to first-tier status under local governments because of the upgrade of the SEPA. The chief responsibility of the EPBs and EPOs is to enforce laws, implement policies, and assist in drafting local regulations to supplement central organization. Therefore, EPBs and EPOs work directly with local factories, other polluters, and industrial bureaus local government actors. The industrial bureaus local government actors include planning commissions, economic commissions, the People's Congress and mayors.

Radical reform of government administration was conducted by the Ninth National People's Congress in 1998 when the environmental protection agency was upgraded to ministerial status and renamed as the SEPA. During this reform period, the number of government ministry-level organizations was reduced from 40 to 29. Around 50% of government employees were slated for elimination from the government payroll (Eckholm, 1998). The emergence of environmental protection administration was an exception during this massive effort to cut central government administration. Whether the administrative reforms of the 1998 Ninth National People's Congress actually changed the performance of environmental management in China is an

---

[9] The National Environmental Protection Bureau, which was established in 1984, was then upgraded to the vice-ministry level as the National Environmental Protection Agency (NEPA). Finally, in 1998, NEPA was further upgraded to ministerial status and renamed SEPA.

empirical question.

Before the 1998 administrative reforms, industrial ministries, such as the Ministry of Chemical Industry, were responsible for industry-specific environmental management. They developed their own monitoring stations for specific types of pollution as well as sector-specific environmental regulations to supplement national regulations. After the 1998 reforms, many ministries were abolished, and several were recreated as bureaus under the State Economic and Trade Commission (SETC).

Actual implementation of regulation, at least in part, has depended on the effectiveness of the monitoring system and incentives to use environmental technologies better. Pollution monitoring systems have been established and system management has been improved over time[10]. Additionally, research and development (R&D) programs for pollution control have been implemented over the past two decades. The Chinese government initiated a series of R&D programs involving studies analyzing atmospheric and water pollutants, solid waste, environmental planning, development of advanced technologies, and demonstration studies of pollution control. Also, many international organizations and foundations, such as the United Nations Development Programme (UNDP), the World Bank, Japan, the United States and others, have provided financial and technological support[11].

3.2. History of Environmental Policy

As the starting point of formal environmental management and administration, the Chinese government held the first National Congress of Environmental Protection in 1973. Pollution

---

[10] Urban air pollution monitoring in China started as early as the mid-1970s. For example, more than 350 cities conduct routine urban air quality monitoring of the pollutants SO_2, TSP, and NO_x. In addition, Beijing, Shenyang, Shanghai, Guangzhou, and Xian joined the Global Environmental Monitoring System.

[11] These are provided to help improve the capacity of Chinese experts and researchers to solve pollution challenges for themselves. The investment in environmental infrastructure, including pollution control devices, cleaner production technology, and natural gas pipelines, has also increased over time.

control during the 1970s, however, only concerned three forms of industrial waste—wastewater, waste gas, and solid waste—and no effort was made towards pollution prevention and abatement (Sinkule and Ortolano, 1995). At this stage, the actual authority of the local environmental agency was extremely limited. For example, industry bureaus and local factories resisted efforts by the local environmental agency to implement policy, by delaying or refusing to take action. Local government frequently intervened to help firms. Consequently, Environmental Protection Laws were issued in 1979 and again in 1989[12].

During 1982 and 1983, the most critical setbacks of these environmental agencies came with the structural reforms of the bureaucracy. As a practical result, the status of the environmental agency decreased, and this weakened their managerial power. As a response to the damaged environment, changes in policy occurred in 1984, when the State Council established the National Committee for Environmental Protection, responsible for the coordination of environmental activities among the relevant ministries. Several changes in the policy occurred after 1984. For example, on September 15 1987, NPC approved the *Law on Air Pollution Prevention and Control of the People's Republic of China* (LAPPC). According to the law, all plants that discharge pollutants into the air need to comply with the rules for pollution control. Consequently, a series of policies and regulations was published by the government and a set of national standards related to air quality was established. In 1988, the status of the environmental agency was raised, and it took a more independent position from the other ministries.

But environmental protection has only really started to exert its full presence on the political agenda in China since the 1990s (Sinkule and Ortolano, 1995). Six environmental laws and

---

[12] During this stage, a pollution charge or levy system was set up with Article 18 of China's Environmental Protection Law of 1979 specifying that "in cases where the discharge of pollutants exceeds the limit set by the state, a compensation fee shall be charged according to the quantities and concentration of the pollutants released." Effective levy rates are the levies actually collected per unit of above-standard wastewater discharge.

regulations were revised and/or issued in the 1990s. One of the most significant changes in policy was the 1997 revision of the Panel Code of the People’s Republic of China, which added new articles on a charge of damage to protect natural resources and the environment, and a charge of misconduct in environmental management. In March 1998, the Ninth National People’s Congress swept in a radical reform of government administration. By 2001, 430 sets of environmental standards were in place at the central government level and 1,020 sets of laws, regulations, ordinances and rules at the local level.

A formal process for environmental impact assessment (EIA) has been used in China for more than 20 years. In October 2002, the new EIA law, “The Law of the People’s Republic of China on Environmental Impact Assessment”, was approved by the government of China and came into force on September 1, 2003. This allowed government agencies and other public and private sector bodies affected by the legislation time to prepare for the new requirements. Essentially, the new law superimposed a form of strategic environmental assessment (SEA) for government plans and programs, but apparently not for policies, on the existing provisions for project-level EIA. In general, the new law does not attempt to modify the existing EIA system in any radical way, suggesting that the government considers current practices satisfactory (Wang et al., 2003).

3.3. Evaluation of Environmental Management

Although the administrable status of environmental agencies has been enhanced in China, the actual implementation of environmental regulation has not improved dramatically. Insufficient authority and a lack of coordination between institutional actors appear to be the main reasons. In detail, these are: (1) the low environmental consciousness of managers; (2) incomplete monitoring and compliance measures; (3) environmental facilities being easily damaged by lowering maintenance costs; (4) lack of environmental engineers leading to insufficient management; (5) insurance not supporting maintenance and control expenses; (6) the low quality of the facilities (sometimes already broken when purchased); and (7) the fact that it is often cheaper to pay charges than to pay pollution abatement costs (see, for example, Kai, 1996). As a result, environmental facilities often face difficulty in operation. Based on a report to the Fourth National Congress of Environmental Protection in 1996, for example, one-third of environmental facilities in large and medium-sized firms worked properly, another third did not work properly, and the remainder did not work at all. Ma and Ortolano (2000) also find evidence for problems in environmental protection management at the local level, where the administrative rank of the environmental protection bureaus is sometimes lower than that of the enterprises it is intended to oversee (Ma and Ortolano, 2000; Economy, 2004).

Local government, instead of a higher-level environmental protection agency such as SEPA, provides the annual budget, approves institutional advancements in rank, determines changes in personnel, and allocates resources such as office buildings to the local environmental protection administrations such as the EPBs and EPOs. The local environmental protection administrations are then obliged to take local government into account when they regulate industries, since they depend, in part, on the local government.

There are large differences in size, funding, staffing, and work methods between environmental protection agencies at the province level. Wealthier coastal provinces tend to be better funded, with more staff better technically trained than provinces in the poorer interior provinces. However, it is not necessarily the case that wealthier regions are more inclined to protect the environment. This is so because individual commitment to environmental protection by local officials or leaders plays an important role in policy implementation.

The implementation of environmental policies in China is also sensitive to differences in economic development and environmental quality (Dasgupta et al., 1997; Wang and Wheeler, 2000). In addition, policy enforcement by local authorities diverges from the legal system established by the central government. In particular, the level of completeness in policy varies across polluting firms: some firms comply perfectly, while others do not (Wang and Wheeler, 1996). Chinese officials are often aware of the problem but have largely responded inadequately, with the demand for continuing economic growth superseding environmental considerations (Economy, 2004).

Wang et al. (2003), for example, concluded that the bargaining power of Chinese factories in enforcing pollutant discharge depended on the type of ownership, profitability, and public pressure. Wang and Wheeler (2003) analyzed the determinants of differences in enforcement of China’s pollution levy system across urban areas. They found that effective levy rates are sensitive to regional ambient quality, local incidence of pollution-related complaints, factory profitability, ownership, production, sales and the sector. Evidence of administrative discretion can also be found in the studies by Wang et al. (2002). They measured townships’ environmental performance according to the number of township leaders’ visits/inspections, and whether townships provided environmental services. They found that environmental performance is dependent upon upper-level government environmental performance, GDP, the percentage of adult population employed in industries, worker wages, public pressure, and environmental quality (Wang and Di 2002; Wang and Jin 2002).

For example, firms facing adverse financial conditions have more bargaining power and are more likely to pay lower pollution charges, i.e., less enforcement (Wang et al., 2002). However, little is known about how environmental management changes over time. By considering the divergence between policy intention and actual implementation in each province, this study measures the efficiency of environmental management in China using two techniques explained in the following section.

4. Literature Review

4.1. Environmental Policies and Technological Change

Numerous works in literature have examined theoretically the role of environmental policy in encouraging (or discouraging) productivity growth[13]. On the one hand, abatement pressures may stimulate innovative responses that reduce the actual cost of environmental compliance below the original estimates (Downing and White, 1986). Firms might be reluctant to innovate, on the other hand, if they believe regulators will respond by ratcheting up standards even tighter (e.g., McCain 1978).

Regarding the environmental technologies, recent empirical studies have found a systematic relationship between environmental regulation and environmental technological progress. Empirical analyses of environmental technologies in the literature focus on the use of patent data, an indirect measurement of innovation. Lanjouw and Mody (1996) found a positive relationship between environmental compliance cost and patenting of new environmental technologies using the dataset of the US, Japan and Germany. Jaffe and Palmer (1997) used US data and found no significant relationship between environmental compliance cost and patents[14]. However, they found a significant relationship between compliance costs and research & development (R&D) expenditure. Brunnermeier and Cohen (2003) analyzed the environmental patent to the US manufacturing industry as a proxy for environmental innovation and found environmental innovation responded to increases in pollution abatement expenditures. However, problems of using patent data need to be noted. This is so because not all inventions that see commercial application are patented, some are subdivided into multiple patents and patent

---

[13] Kemp (1997), Jaffe, Newell and Stavins (2003) and Parry (2003) provide thorough surveys of the literature relating policy, technological change, and the environment.

[14] Note, however, the patent data include both of market and environmental technologies.

policy change over time[15].

Regarding the conventional market technologies, in general, the impact of the regulations on market productivity is expected to be negative since the regulations are likely to induce firms to invest in environmental compliance (or non-productive inputs) and therefore reduce the investment for market output. Recently, however, researchers have challenged this conventional view with an alternative hypothesis that environmental regulations can encourage productivity growth and ultimately higher profits. This is the well-known Porter hypothesis (Porter, 1991; Porter and van der Linde, 1995). In addition, if the social benefits of regulation were fully taken into account as an additional output, theoretical prediction would be further complicated.

Jaffe *et al*. (1995) and more recently Gray and Shadbegian (2003) reviewed empirical studies on the subject of environmental regulations on market productivity and showed that the regulations reduced market productivity. For example, Gray and Shadbegian (2002) found that more regulated firms have significantly lower market productivity growth than less regulated firms in the US steel, oil, and paper industries. In contrast, the recent study of the US oil refiners by Berman and Bui (2001) suggests that environmental regulation is productivity enhancing. These studies, however, did not consider the full range of impacts of environmental regulations, including the possible positive external impacts of reducing the pollutions (e.g., Barbera and McConnell, 1990; Repetto, 1996). Thus, the effects of the regulations into productivity need to be tested to both of the market and pollution control technologies[16].

---

[15] For example, see Managi et al (2004a) for the review of patent and innovation studies. In addition, even though invention, which is a new idea such as patent, might respond quickly to incentives (Popp, 2002), commercial application of new technologies, which is the actual use of new technologies, might be a more complex issue.

[16] Mohr (2002), for example, develop the theoretical model assuming the new technology enables firms to produce the same amount of output, but for less pollutant, and his results support Porter

4.2. Foreign Direct Investment and Productivity

Multinational enterprises possess superior production technology and management techniques and the entry of affiliate leads to more severe competition in the host economy (Blomstrom and Kokko, 1998). Thus, Foreign Direct Investment (FDI) might generate productivity spillovers for the host economy. Empirical literature, however, provides little support for this view (Hanson, 2001). For example, Haddad and Harrison (1993) found a weak negative correlation between total factor productivity growth and the presence of foreign firms in the Moroccan manufacturing sector. Aitken and Harrison (1999) found mixed results between total factor productivity growth and the presence of foreign firms in the Venezuelan manufacturing sector. These empirical research studies suggest that FDI is sensitive to both host-country tax polices and economic conditions, including the education level of the labor force, overall market size and the size of the local industrial base. Abramovitz (1986) also note that the adoption of foreign knowledge is a complicated affair since a country must have a factor supplies, production processes and industrial production structure reasonably similar to those of the nation where the technology was created. Thus, whether FDI promotes the productivity growth in a particular region is an empirical question.

The phenomenal economic growth per capita of China has been accompanied by a rapid increase in the inflows of FDI (Lin and Song 2002). The application of FDI in China is important since China has become the largest host country for FDI in the developing world (UNCTAD 2001). In our knowledge, we are not aware of any studies that test the relationship between FDI and productivity “growth” in China. One recent study in China shows that FDI is positively related to TFP (Liu and Wang 2003).

---

hypothesis. If market production and pollution control technologies are non-separable, however, this result may not hold (Nagase, 2004).

5. Model

5.1. Productivity Measurement

Production frontier analysis provides the Malmquist indexes (e.g., Malmquist, 1953; Caves *et al*, 1982), which can be used to quantify productivity change and can be decomposed into various constituents, as described below[18]. Malmquist Total Factor Productivity is a specific output-based measure of TFP. It measures the TFP change between two data points by calculating the ratio of two associated distance functions (e.g., Caves *et al*. 1982). A key advantage of the distance function approach is that it provides a convenient way to describe a multi-input, multi-output production technology without the need to specify functional forms or behavioral objectives, such as cost-minimization or profit-maximization.

The Luenberger productivity index is the dual to the profit function and does not require the choice of an input–output orientation (Chambers, Färe and Grosskopf, 1996). Since the Luenberger productivity index can be applied with an output- or input-oriented perspective,

---

[18] In the productivity analysis literature, the Stochastic Frontier Analysis (SFA) is preferred to Data Envelopment Analysis (DEA) when either random error needs to be considered or production is subject to uncontrollable factors including uncertainties in the prices of input and output, and other market situations. Recent development of the DEA, however, incorporates stochastic characteristics of the production frontier in the DEA framework (or distance function estimation) and we utilize this advantage following Fuentes *et al*. (2001).

[24] Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Sichuan and Chongqing, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. Note; Tibet is excluded because some relevant data are not available. Hainan, a new province from 1988, is also excluded. Data for Chongqing, which was separated from Sichuan in 1997, is merged with data for Sichuan.

it is a generalization of, and superior to, the Malmquist productivity index (Luenberger, 1992a,b, 1995; Chambers et al., 1998; Boussemart et al., 2003). Luenberger (1992a,b) generalizes the previous notion of distance functions as a shortage function and provides a flexible tool to take account of both input contractions and output improvements when measuring efficiency. This shortage function, also called a directional distance function, is the dual to the profit function (Luenberger, 1992b, 1995; Chambers, Chung and Färe, 1998).

The directional distance function involving a simultaneous input and output variation in the direction of a preassigned vector $g_t = \left(g_t^i, g_t^o\right) \in R_+^{M+N}$ is defined as follows.

$$D^t\left(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}; g_t\right) = \max \ \left\{\delta : (\mathrm{x}_\mathrm{t} - \delta g_t^i, \mathrm{y}_\mathrm{t} + \delta g_t^o) \in P_t\right\}$$

Considering the special case of a general directional vector *g*: $g_t^i = \mathrm{x}_\mathrm{t}$ and $g_t^o = \mathrm{y}_\mathrm{t}$, we are able to define the proportional distance function, which is a special case of the shortage function. The proportional distance function is defined at *t* as:

$$D^t\left(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}\right) = \max\left\{\delta : ((1-\delta)\mathrm{x}_\mathrm{t}, (1+\delta)\mathrm{y}_\mathrm{t}) \in P_t\right\}$$

where δ is the maximal proportional amount that output, y^t, can be expanded and input, x^t, can be reduced given the technology, P^t. As in the Malmquist index, the DEA formulation calculates the Luenberger productivity index under variable returns-to-scale by solving the following optimization problem (Chambers et al., 1996):

$$\begin{aligned} D^t(\mathrm{x}_\mathrm{t}, \mathrm{y}_\mathrm{t}) &= \max_{\delta,\lambda} \delta \\ s.t. \quad & Y_t\lambda \geq (1+\delta)\, y_t^i \\ & X_t\lambda \leq (1-\delta)\, x_t^i \\ & N1'\lambda = 0 \\ & \lambda \geq 0 \end{aligned}$$

where N1 is an identity matrix, λ is a N×1 vector of weights, Y^t, and X^t are the vectors of output, y^t, and inputs, x^t.

As in Malmquist indices, several different proportional distance functions are necessary to estimate the change in productivity over time. For the mixed period distance function, we have two years, *t* and *t+1*. The t-period and t+1-period Luenberger index due to Caves et al. (1982) are defined as follows.

$$L^t\left(\mathrm{x}_t, \mathrm{y}_t, \mathrm{x}_{t+1}, \mathrm{y}_{t+1}\right) = D^t\left(\mathrm{x}_t, \mathrm{y}_t\right) - D^t\left(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}\right)$$

$$L^{t+1}\left(\mathrm{x}_t, \mathrm{y}_t, \mathrm{x}_{t+1}, \mathrm{y}_{t+1}\right) = D^{t+1}\left(\mathrm{x}_t, \mathrm{y}_t\right) - D^{t+1}\left(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}\right)$$

The Luenberger productivity index, TFP(L), defined by Chambers, Färe and Grosskopf (1996) and Chambers (2002), is as follows.

$$\mathrm{TFP(L)} = \frac{1}{2}\left[\left(\mathrm{D^t}(\mathrm{x}_t, \mathrm{y}_t) - \mathrm{D^t}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1})\right) + \left(\mathrm{D^{t+1}}(\mathrm{x}_t, \mathrm{y}_t) - \mathrm{D^{t+1}}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1})\right)\right].$$

This is an arithmetic mean of period *t* (the first difference) and period *t+1* (the second difference) Luenberger indices, as an attempt once again to avoid any arbitrary selection of base years (e.g., Balk, 1998). The above index can be decomposed into two components:

$$\begin{aligned} TFP(L) &= \left[\mathrm{D^t}(\mathrm{x}_t,\mathrm{y}_t) - \mathrm{D^{t+1}}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1})\right] \\ &\quad + \frac{1}{2}\left[\left(\mathrm{D^{t+1}}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1}) - \mathrm{D^t}(\mathrm{x}_{t+1}, \mathrm{y}_{t+1})\right) + \left(\mathrm{D^{t+1}}(\mathrm{x}_t,\mathrm{y}_t) - \mathrm{D^t}(\mathrm{x}_t,\mathrm{y}_t)\right)\right]. \end{aligned}$$

where the first difference represents efficiency changes, and the arithmetic mean of the two last differences represents technological change.

We estimate productivity improvement associated with the efficient use of environmental abatement efforts or the efficient reduction of pollution. $TFP_{Environment}$ is estimated from two Total Factor Productivity (TFP) estimates; (i): productivity of market output (i.e., gross regional product), TFP_{Market}, and (ii): productivity of joint-outputs of market output and non-market output (i.e., reduction in environmental pollutants), TFP_{Joint}, following Managi *et al.* (2004b). TFP_{Market} includes usual production input and output, and TFP_{Joint} includes environmental degradation and abatements effort in addition to production input/output. Given input level, increase in market output raises usual productivity, TFP_{Market}. Holding input and environmental output constant, increase in market output raises TFP_{Joint}. Also, holding input and market output constant, decrease in environmental output raises TFP_{Joint}. Thus, the residual effects of two factors explain the productivity due to changes in technology for the non-market goods (environmental degradation) given by,

$$TFP_{Environment} = TFP_{Joint} - TFP_{Market}.$$

where an increase in $TFP_{Environment}$ implies a productivity improvement in abatements, which might be either a reduction of environmental degradation given the same level of abatement effort or the reduction of abatement efforts given the same level of environmental degradation level, or both. Note that both of the $TFP_{Environment}$ and TFP_{Market} are estimated for each year for each province. Environmental technological change and efficiency change are calculated in the same manner.

3.2. Econometric Model

Our second objective is to study the determinants of several productivity indices. In modeling this relationship, we follow the economic growth and industrial organization literature on productivity and add new variables to incorporate the effect of environmental policies on productivity. To analyze the historical development of productivity in China, we use economy-wide province level data from 1992 to 2003. We consider changes in productivity (and its components of technological and efficiency change) in both market output and non-market output. Several variables, such as patent number as a proxy for new invention, in a particular year will affect productivity change several years down the road when the productivity improvement process has been completed. The process of productivity or technological change, however, is quite complex and still poorly understood. Contemporaneous impact analysis of productivity is needed to find the immediate cost of patent, environmental policies, and FDI. But time lags are needed to consider the longer-term gains associated with technological change and consequent change in productivity. In particular, we estimate the following equation:

$$\ln A^{i,t} = \sum_z \sum_j \varpi_z^j \ln r_z^{i,t-j}$$

where $A^{i,t}$ is the annual productivity where we use overall productivity in this preliminary version, technological or efficiency change for province i, at time t, A is one of the measurement of joint, market and environmental outputs. $r_z^{i,\,t\text{-}j}$ is the z^{th} independent variable of lag year j, and ϖ_z is the coefficient associated with r_z. In our analysis, we consider a number of independent variables.

In modeling the market and joint output case, we expect the number of patent applications (*Patent*), as a proxy for invention within a province, to have a positive long-term impact on technological change (Griliches 1984). There are two variables capturing environmental regulations: the number of command and control regulations (*CAC*), and the actual collected pollution levy rate (*Levy*). *FDI* is included to test the hypothesis that FDI generates productivity growth or “international spillover” for the host economy. Annual changes in the above invention, environmental, and FDI variables are used to capture the effects to productivity measurements. The share of secondary industry, which includes such industries as the heavy and chemical industry, to GRP (*Poll-Inten*) is included since the growth of secondary industry becomes the main engine of rapid development for China's economy and the secondary industry tends to be pollution-intensive. Before proceeding to the model estimation, a discussion of some econometric issues seems in order. In recent productivity analyses, the two-step approach has been used to identify the determinants of productivity. Having completed the first step of computing the Malmquist productivity index, set of explanatory variables is used in a static regression model (e.g., Umetsu et al., 2003). However, a serial correlation problem arises. This is because the productivity change index is a cross-period index and, consequently, the previous period productivity change affects the current change, and this yields intertemporal cross-individual serial correlation. A dynamic model that uses the lagged productivity change is estimated to eliminate the serial correlation. In this way, one does not have to use the alternative, computationally demanding, bootstrapping technique suggested by Simar and Wilson (2006). Since serial correlation is a concern, second-order autocorrelation of the random error was not tested for (Arellano and Bond, 1991). If both of the environmental outcome and independent variables are I(1), the static regressions should be interpreted as co-integrating relationships between the environmental outcome and independent variables. Under this interpretation, the residuals should be I(0) if the model is a correct representation of the data generating process. A test for stationarity of the residuals is thus an important model specification test, and we make use of the panel data unit root test of Im *et al.* (2003).

4. Data

In this study, we use panel data on Chinese secondary industries, including mining, manufacturing, electricity, gas and water. This study focuses on industrial pollution, since Chinese industry is a primary source of the pollution and the industry accounting for about 40%

of national water pollution and about 80% of air pollution from SEPA estimates in 2000.

The dataset consists of annual data for the period 1992–2003 for 29 of the 31 provinces, including three municipalities, in the People's Republic of China[24].. Nominal data are converted into real data using the CPI, hence the national total is consistent with the sum of regional data in the dataset. *Labor* is quality-adjusted labor in secondary industry. The wages for labor are used to control for quality[25]. Pollution abatement cost and expenditure (*PACE*) are funds actually used to remedy industrial environmental pollution in the form of wastewater, waste gas and solid waste. PACE is considered as an environmental input. Increase in PACE given other input/output will reduce pollution. In addition to PACE and market inputs such as capital and labor, we estimate efficiency with inputs including coal consumption, oil consumption, and fresh water use. An increase in coal and oil consumption is associated with an increase in both air pollution and gross regional product (GRP).

Crude oil consumption has increased at an average rate of 6% per year in the past few decades. China's growing energy consumption, reliance on coal, and air pollution are rapidly emerging as major environmental issues in China. Coal consumption, the primary energy source accounting for more than 70% of total energy consumption, is the main source of anthropogenic air pollution emissions in China. These include TSP pollution, SO_2 pollution, and acid rain. Use of fresh water in production process is also necessary to produce goods. The models in this study are able to estimate efficiency improvements in the use of coal and oil consumption to save fuel and fresh water.

---

[25] Note that the labor and capital related to pollution abatement are excluded from these variables. Thus, market inputs and the data on labor, capital and environmental input are independent of each other.

5. Application

This study uses different models to measure and decompose productivity change in terms of market outputs, environmental (pollution) outputs, and joint production (so-called “green” productivity). The vectors of outputs and inputs for each model are listed in Table 2. The output variables in our model are gross regional product, waste gas, solid waste, wastewater, SO_2, dust, soot, COD, lead and chromium six (see Table 2). Our input variables include labor, capital, oil consumption, coal consumption, fresh water, PACE, PACE for waste gas, PACE for solid waste, and PACE for wastewater.

Separate frontiers are estimated for each year, and shifts in the frontiers over time are used to measure technological change. The mean values are presented in each figure. Values larger than one are regarded as increases in productivity using ratio-based indices, respectively. We estimate the productivity indices in both constant returns-to-scale (CRS) and variable returns-to-scale (VRS). Table 3 presents the summary of the results, as detailed analyses are provided below. The table shows the results for VRS (Ray and Desli, 1997).

Several types of environmental pollution are considered in this section. First, a joint model of all pollutants is provided. Model 5 includes the environmental outputs such as waste gas, solid waste, and wastewater. Additionally, Model 6 includes SO_2, dust, soot, COD, lead, and chromium six in environmental outputs. Figure 6 provides the cumulative TFP of both Model 5 and Model 6. Environmental productivity increases as a cumulative value once the model results of joint output (Model 5 and Model 6) are larger than the base model (Model 3).

Environmental productivity increases by about 1.35%, or a mean rate of 0.2% decrease per year, with the Luenberger indices. In 1998 and 2003, environmental productivity of Model 5 increased, i.e., environmental technologies were efficiently utilized and environmental managements were well organized. Model 6 has similar results and tends to show larger changes in environmental productivity than Model 5 in many years. Radical reform of government administration was conducted by the Ninth National People's Congress in 1998, and the environmental protection agency was upgraded to ministerial status and renamed as SEPA. However, our study shows that environmental productivity decreased over the period 1999–2002. This suggests that the reforms were not effective in increasing implementation of environmental management in the long run or, at least, the reforms required several years to increase efficiency. These results, however, do not show which sector (wastewater, waste gas or solid waste) influenced the result. Therefore, we are not able to judge fully the effects of management and policy implementation.

We show the results with more detailed pollutants in the remainder of this section. We especially focus on the management of SO_2 pollution. We are interested in SO_2 since more detailed analysis is available of its policy options than for other pollutants. SO_2 is an important precursor of acid rain and secondary particles, and it severely impairs public health. More than 85% of SO_2 comes from coal combustion in China[26]. Since SO_2 emission and coal combustion are closely correlated, the key to reducing the SO_2 emissions is to control the SO_2 emitted from coal combustion (He et al., 2002). A series of laws, regulations, and standards to control SO_2 and acid rain were established in the 1990s. In 1995, articles on acid rain control were first listed in the law on air pollution prevention and control. National standards were successively published to limit SO_2 emissions from power plants, coke ovens, cement plants, and boilers. In 1999, SEPA distributed the Control Objectives in Acid Rain Zones and SO_2 Pollution Control Zones in 1999. This required comprehensive protection plans for the control of SO_2 in every area in the Two Control Zones[27]. All cities within the Two Control Zones are expected to meet

---

[26] Industry is a large SO_2 emission source, estimated to account for about one-half of total emissions.

[27] The Two Control Zones include 175 cities and districts in 27 provinces, autonomous regions, and municipalities accounting for 60% of the national SO_2 emissions. The zones are characterized by

the standards by 2010. The following methods are considered: limiting the production and use of high-sulfur coal, promoting coal washing, controlling SO_2 discharge sources, adjusting the spatial layout of SO_2 emission sources, controlling total regional emissions of key pollutants, implementing a discharge license system for regional SO_2 pollution sources, implementing an SO_2 emission trading system, revising SO_2 emission standards, extending the scope of SO_2 emission charges and raising the level of charges, and establishing a national acid rain monitoring network (Tian et al., 2001).

Figure 7 shows the results for waste gas. Model 11 includes SO_2, dust, and soot in environmental outputs while Model 12 also includes the total quantity of waste gas in the model. TFP for environmental outputs decreases by 0.02%, or a mean rate of 0.003% decrease per year, for Luenberger indices. As in Figure 6, environmental productivity increased until 1998. The main difference between waste gas and the all-pollutants case is that the increase in environmental productivity before 1998 is larger with waste gas. Again after 1999, environmental productivity decreased until 2002, which also implies ineffectiveness in environmental policy implementation.

We provide a careful review so as to understand fully the relation between air pollution policy focusing on SO_2 and actual outcomes as environmental productivity. Starting in the 1990s, several policies to control SO_2 were implemented in China. Experimental imposition of levies on SO_2 started in 1992 and was further expanded in 1995. The SEPA published a notice in April 1998 to Extend Areas for Trial Charges for SO_2 in the Acid Rain Control Zones and SO_2 Pollution Control Zones (SEPA, 1998, No. 6). This notice required the standard charge for SO_2 emissions to be 0.20 RMB/kg. The total revenue from the pollution levies on SO_2 in the power sector increased from 116 million RMB in 1997 to 347 million RMB in 1998. Some power

---

dense populations, developed industries and large flourishing cities important to the national economy.

plants installed desulfurization equipment and automatic monitoring systems to control SO_2 emissions as a response to the levy system. The result of Model 11, showing a significant increase in environmental productivity in 1998, may reflect this. In 1999, however, environmental productivity significantly dropped and remained stable until the end of our study period. We suspect that the existing SO_2 emission levy system in China is not an efficient way to control SO_2 pollution, and therefore the environmental productivity does not show continuing growth over the long run.

Several critiques are provided in the literature (e.g., Yang et al., 2000). First, the abatement cost of SO_2 is much higher than the amount charged. Thus, it is unreasonable to expect the levy system to motivate compliance and control of SO_2 emissions by power enterprises. For example, the amount charged for SO_2 emissions within the Two Control Zones is only 200 RMB/ton, whereas the average abatement cost is around 1100 RMB/ton (Yang et al., 2000). The levy system is different from common taxation in that the plants are able to obtain refunds for 90% of the SO_2 levy fees to be used for pollution mitigation. However, the actual amount refunded is much lower than 90%. For example, the average refund was only about 12% in 1998. In addition, some of the charges not refunded were not actually used for SO_2 pollution control (Wang, 2000).

Solid waste is analyzed in Model 13, and the results are shown in Figure 8. Solid waste has not been considered as an important environmental problem in China. In 1996, however, the Law on the Prevention and Control of Pollution of the Environment by Solid Waste was promulgated. With the exception of a slight increase in 1998 and 2001, environmental productivity kept decreasing over our study period. Overall, TFP for environmental outputs decreases by about 2.07%, or a mean rate of 0.3% decrease per year, for Luenberger indices. The results of wastewater are analyzed in Model 15 and Model 17. The results are shown in Figure 9. Model 15 includes a quantity of total wastewater, while Model 17 includes more specific water pollutants such as COD, lead, and chromium six. Both of these show that environmental productivity decreased in 1999 and 2000 but increased significantly in 2001 and 2002. Overall, environmental productivity increased in our study period. Since both Model 15 and Model 17 show similar results, using wastewater quantity may not be a poor approximation for several different wastewater substances. In Model 17, environmental productivity increased by 0.63%, or a mean rate of 0.09%, over our study period.

With rapid industrialization and a continuous increase in water use, improving the efficiency of water use is an increasingly crucial issue, especially in the northern region. Because of decreased precipitation and increased air temperature over the last 50 years, water resource endowment in the Yellow River has deteriorated: the Yellow River first dried up before reaching the river mouth in 1972. This phenomenon continued chronically until its most serious occurrence in 1997. Water use efficiency has improved over time. As shown in Figure 10, the result in 2003 shows the largest increase of TFP in water use. During our study period, environmental productivity increased by about 4.42%, or a mean rate of 0.6% decrease per year, according to the Luenberger indices. This increase in efficiency may reflect the scarcity of water resources in the past in China. The problem of scarcity has been dramatically reduced by the enforcement of two new water management policies in 1998. One of the new policies is to allocate water drawn from the Yellow River to each province administratively in order to balance water distribution between upper and lower reaches.

Figure 10 summarizes the results of the environmental productivities as cumulative values. Water use efficiency improved the most. Second, the case of all pollutants and the case of wastewater also showed an increase in environmental productivity. The worst score appears for solid waste treatment management. All of the scores in the figure show an increase in environmental productivity in 1998. The reforms of 1998 appear to affect the environmental productivities negatively in the short term. In 2000, none of the values is more than zero. The results show all of the indices in the graph decreasing from 1998 to 2000. Excepting the results for water use, all of the scores were worse in 2000. All the indices increased from 2000 to 2003, excepting the decrease of solid waste TFP in 2003. This study is not able to distinguish whether these increases in environmental productivities are the long-term effects of environmental productivities. Further analysis of factors determining changes in environmental productivity is required to evaluate the policies.

Overall, environmental managements in China have not effectively regulated wastewater, air and solid waste pollutants emissions over our study periods. We expect that limited enforcement of environmental laws and policies and firms' insufficient environmental management capacity lead to this environmental inefficiency. These seem to dominate the opposing forces that many factories have to shutdown of facilities since they are not able to satisfy environmental standards and newly started factories tend to have better environmental technologies[28]. We intend to provide some answer why there is no progress in environmental productivity in addition to the determinants of market and joint productivity growth.

We estimate the determinants of the productivity measurements using differential equation and two-way fixed effects model using our cross-section and time-series data. The linear fixed effects model is given by $y^{i,t} = \alpha^i + \gamma^t + X^{i,t}\beta + \varepsilon^{i,t}$, where $y^{i,t}$ is the log of the dependent variable, $X^{i,t}$ is the vector of the log of explanatory variables, α^i is the province-specific terms, γ^t is the time effects, and $\varepsilon^{i,t}$ is a random disturbance term.

The results of the three model estimates, which are TFP, TC and EC for market output,

---

[28] Especially smaller firms such as township and village enterprises are forced to shutdown their facilities from the middle of 1990s. See Arayama and Taketoshi (1998) for more description about the facility shutdown.

are presented in Table 4 (where only overall productivity indices are used in this preliminary version). This table provides the determinants of the level of production technology from information on technology related variables, level of environmental policies, and industry characteristic variable[29]. The *Patent*, as a proxy for the invention within the province or "domestic invention", is not significant for all of TFP, TC and EC[30]. In contrast, several time lag of FDI, "international spillover" for the host economy, are significant with positive sign. Contemporaneous and first lagged terms are significant for TFP and TC while all of three lags are significant for EC[31].

Overall, our result shows that "international spillover, *FDI*" instead of "domestic invention, *Patent*" is the major factor to increase the productivity growth[32]. This result suggests that, although GDP in China is the fourth largest in the world and its growth records are higher than the other developed countries, China is still a developing country and the adoption of new technologies from developed countries, or imitation, is the main source of growth in market productivity. This is consistent with the observations that the number of original innovations in China is limited and China is far behind the world technology frontier (Hu and Jefferson, 2004). Adopting existing technologies from world best practices through FDI might be the best strategy for each province to expand their knowledge stock than adopting through surrounded provinces. This might be a reason why the *Spillover* variable does not have statistically significant results.

---

[29] We examine the stationarity of the residuals using the unit root tests of Im *et al* (2003) as discussed in former section. In all specifications we are able to reject the null hypothesis of a unit root in the residuals.

[30] Choice of time lag does not alter our results and including several more time lags caused the collinearity problem.

[31] Adding more time lags does not show significant results.

[32] As described in the section 2.1, we need to be cautious about the use of patent data.

Finally, the results of the three models of TFP, TC and EC for environmental outputs are presented in Table 5. All of the three time lag of CAC is highly significant with positive sign for TFP while the first two time lags are significant for TC and none of the CAC variables are significant for EC. Magnitudes of the coefficients are larger in the second lag than the others for all of the three models. These results show clearly a strong impact of increase in pollution abatement expenditures (PACE) on environmental productivity and technological progress for consecutive years[34]. None of the levy variables, however, have positive sign with statistical significance. These results might be because the levy is set too low to effectively encourage significant pollution abatement[35].

It is interesting that *Levy* shows a negative effect on TC and EC, where one of the *Levy* variables has significant results for TC and EC, respectively. This observation might be related to the structural set up of the levy system. The levy is a penalty on emissions or discharges in excess of some standard applying to a particular process or plant. The national government decides the basic guidance and legal authority to impose the pollution levy while the local government works on the assessment, collection and use of funds. Thus, the actual rate of levy imposed may differ each province and each year. The levy system provides recycling revenues as a subsidy for abatement projects from collected levy payments to local enterprises. Though the targeted rate is 80%, the actual percentage is more nearly between 30–50%[36]. In addition, this levy system applies only to large and medium-sized sources and smaller enterprises,

---

[34] The other time lag effects do not show significant results.

[35] The levy rate is less than the average cost of pollution abatement (Sinkule and Ortolano, 1995). In addition, the rate of expenditure for actually collected *Levy* to *PACE* was decreased from 17.1 % in 1992 to 8.0 % in 2000 (China Environmental Statistical Data and Materials, 2002).

[36] For example, the rate was 44.5 % in 1992 and decreased to 33.2 % in 2000 (China Environmental Statistical Data and Materials, various years).

particularly town and village enterprises, are not included in their levy system[37]. Since the amount of the penalty is small, even though the rate increased, it would not give an incentive for firms to comply with the regulations. Furthermore, it might actually give a sort of permission for firms to pollute. Thus, the levy system does not function well in the point of encouragement of environmental technological innovation.

In contrast to the cases of market and joint-outputs cases, FDI, "international spillover" for the host economy, are not significant statistically to all of the environmental productivities. Thus, from our empirical research, FDI promotes market and joint-output productivity but not environmental productivity and provides little support for the idea that promoting FDI is warranted on environmental management grounds. The variable *Spillover*, "interregional spillover" effects of accumulated knowledge, does not have statistical significance for any of the cases. Thus, technological diffusion from adjoined regions is not utilized for environmental productivities.

6. Discussion and Conclusion

Successful economic and environmental policies can contribute to technological or efficiency improvements by encouraging, rather than inhibiting, technological innovation. Although a large number of studies have been made on the constituents of technological change (Griliches 1994), little is known about the empirical evaluation of policies that encourage (or discourage) productivity progress and/or regress in China. This paper contributes to the literature on productivity change in several ways. First, we apply a nonparametric and parametric distance function approach to a province-level data set tracked from 1992 to 2003 in China to measure various components of total factor productivity (TFP) within a

---

[37] Although enterprises pay levy, priority of recycling revenues might be larger firms (Arayama and Takeuchi, 1998).

joint-production model of market and environmental outputs. This contributes to our understanding of the various components of total factor productivity change in China. In addition, this study contributes to better economic and environmental policy design for sustainable development in China by empirically estimating the role of economic and environmental management on market and non-market (i.e., environmental) productivity.

Our result for market output is consistent with the literature that there has been considerable TFP growth in China (e.g., Jefferson *et al*., 2000), while environmental managements in China have not effectively regulated wastewater, air and solid waste pollutants emissions over our study periods. Detecting the determinants of these factors, we found the "international spillover, *FDI*" instead of "domestic invention, *Patent*" is the major factor to increase the market productivity growth. While FDI helps economic development by encouraging market productivity improvements, it does not lead to a positive consequence for environmental technologies where FDI does have negative coefficients though they are not significant. Thus, we might be able to say that FDI may lead to more environmental damage since firms in advanced countries might avoid stiff environmental regulations.

We find the negative consequence of levy to environmental productivities. Therefore, it seems reasonable to conclude that the levy system needs to be re-considered and we point out several problems of the current system in the following areas: 1). Enforcement of environmental laws is limited and policies and firms' environmental managements are insufficient. For example, the levy rate is less than the average cost of pollution abatement partially because the levy fees are not indexed for inflation, and, for state-owned enterprises, they can be included under costs and later compensated through price increase or tax deductions (Sinkule and Ortolano, 1995). 2). Smaller enterprises tend not to pay levy though they share significant rate of total industrial outputs. 3). The cost of installing pollution abatement facilities is usually not subject to financial assistance from the commercial banks.

References

Allen, F., Gale, D., 2000. Corporate governance and competition. In: Vives, X. (Ed.), Corporate Governance: Theoretical and Empirical Perspectives. Cambridge University Press, London, pp. 23–94.

Allen, Franklin; Qian, Jun; Qian, Meijun. 2005. Law, finance, and economic growthin China, Journal of Financial Economics 77, 57–116.

Balk, B.M. (1998) Industrial Price, Quantity, and Productivity Indices: The Micro-Economic Theory and an Application, Kluwer, Boston.

Bjurek, H. (1996) The Malmquist Total Factor Productivity Index, Scandinavian Journal of Economics, 98(2), 303-313.

Blanchard, Olivier; and Stanley Fischer. Editorial, NBER Macroeconomics Annual 1993, National Bureau for Economic Research, 1993.

Bolt, K., Dasgupta, S., Pandey, K., Wheeler, D., 2001. Cleaning the air in developing countries. Forum for Applied Research and Public Policy, Washington DC.

Borensztein, E. and J. D. Ostry (1996) Accounting for China’s Growth Performance, American Economic Review 86, 225–8.

Boussemart, J.P., Briec, W., Kerstens, K. and J.C. Poutineau (2003) Luenberger and Malmquist Productivity Indices: Theoretical Comparisons and Empirical Illustration. *Bulletin of Economic Research* 55 (4): 391-405.

Briec, W. and Kerstens, K. (2004) A Luenberger-Hicks-Moorsteen productivity indicator: its relation to the Hicks-Moorsteen productivity index and the Luenberger productivity indicator, Economic Theory, 23, 925-939.

Caves, D.W, Christensen, L.R., and W.E. Diewert (1982) The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity. Econometrica 50(6): 1393-1414.

Chambers, R.G., Chung, Y. and R. Färe (1998) Profit, Directional Distance Functions, and Nerlovian Efficiency. *Journal of Optimization Theory and Applications* 98: 351–364.

Chambers, R.G., Färe, R., and S. Grosskopf (1996) Productivity Growth in APEC Countries. *Pacific Economic Review* 1: 181–190.

Chang, CC and YH Luh (2000) "Efficiency Change and Growth in Productivity: The Asian Growth Experience," Journal of Asian Economics, 10(4), 551-570

Chen F, Chai F.H. 1997. Control strategy of acid deposition in China. Research on

Environmental Science 10(1):27–31

Chen, Baizhu and Yi Feng (2000), Determinants of Economic Growth in China: Private Enterprise, Education, and Openness, China Economic Review 11(1), pp. 1-15.

Cheung, Yin-Wong, Chinn, Menzie D., Fujii, Eiji. 2003. The Chinese Economies in Global Context: The Integration Process and Its Determinants. NBER Working Paper No. 10047.

Dasgupta, S., Huq, M. and D. Wheeler (1997) Bending the rules: discretionary pollution control in China. Policy Research Working Paper 1761, Development Research Group, The World Bank, Washington, D.C.

Debreu, G. (1951) The coefficient of resource utilization, *Econometrica* 19: 273–292.

Djankov, S., La Porta, R., Lopez-de-Silanes, F., Shleifer, A., 2002. The regulation of entry. Quarterly Journal of Economics 117, 1–37.

Dougherty, C. and D. W. Jorgenson (1996) International Comparisons of the Sources of Economic Growth, American Economic Review 86, 25–29.

Eckholm, Erik (1998) New China Leader Promises reforms for Every Sector, New York Times, 20 March, A1.

Economy, E.C. (2004) The River Runs Black: The Environmental Challenge to China's Future, Ithaca: Cornell University Press.

Edmonds, Richard Louis (2004) Managing the Chinese Environment, Studies on Contemporary China, Oxford University Press.

Farrell, M.J. (1957) The measurement of productive efficiency, Journal of the Royal Statistical Society, 120, 253-281.

Färe, R., Grosskopf, S. and C.A.K. Lovell. (1985) *The Measurement of Efficiency of Production*. Boston: Kluwer-Nijhoff.

Färe, R., Grosskopf, S. Norris, M. and Z. Zhang. (1994) Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries. *American Economic Review* 84(1): 66–83.

Fong, R. W. L. and C. S. P. Tong (1998) Technological Change of China’s Township and Village Enterprises (TVPs) and its Corresponding Spatial Disparity: a Combined DEA-Poolong Approach, Working Paper, Hong Kong Baptist University.

Greif, A., 1989. Reputation and coalitions in medieval trade: evidence on the Maghribi traders. Journal of Economic History 49, 857–882.

Greif, A., 1993. Contract enforceability and economic institutions in early trade: the Maghribi traders’coalition. American Economic Review 83, 525–548.

Greif, A., 1994. Cultural beliefs and the organization of society: a historical and theoretical reflection on collectivist and individualist societies. Journal of Political Economy 102, 912–950.

He, Kebin, Huo, Hong and Zhang, Qiang (2002). Urban air pollution in China: current status, characteristics, and progress. Annual Review of Energy and Environment. 27: 397 – 431.

Hu, Z. F. and M. S. Khan (1997) Why is China Growing So Fast?, IMF Staff Papers 44, 103–31.

IEA, 1999. Coal in the energy supply of China. Report of the Coal Industry Advisory Board, OECD/IEA, Paris.

Jaffe, A.B., Newell, R.G. and Stavins, R.N. (2003) Technological Change and the Environment. In: Karl-Göran Mäler and Jeffrey Vincent, (eds) *Handbook of Environmental Economics*. North-Holland. Elsevier Science, Amsterdam, pp 462-516.

Jefferson, G. H., T. G. Rawski and Y. Zheng (1992) Growth, Efficiency and Convergence in China's State and Collective Industry, Economic Development and Cultural Change 40, 239–266.

Jefferson, Gary H., Rawski, Thomas G., Zheng, Yuxin, (1996). Chinese industrial productivity: Trends, measurement issues, and recent developments. Journal of Comparative Economics 23 (2), 146–180.

Jin, Hehui; Yingyi Qian; and Barry R. Weingast. (2005). Regional Decentralization and Fiscal Incentives: Federalism, Chinese Style. mimeo, University of California, Berkeley.

Kai, S. (1996) Maintenance and Response of Wastewater Plants, Environmental Protection, 222: 8-9.

Kalirajan, K. P., M. B. Obwona and S. Zhao (1996) A Decomposition of Total Factor Productivity Growth: the case of Chinese Agricultural Growth before and after Reforms, American Journal of Agricultural Economics 78, 331–338.

Krugman, P. (1994) The Myth of Asia's Miracle, Foreign Affairs 73, 62–78.

Larson, E.D., Z. Wu, P. DeLaquil, W. Chen, and P. Gao, (2003) Future Implications of China's Energy-Technology Choices," Energy Policy, 31(12): 1149-1204.

Lau, L., Qian, Y., Roland, G., (2000). Reform without losers: an interpretation of China's dual-track approach to transition. Journal of Political Economy 108, 120–143.

Lin, J. Y. (1992) Rural Reforms and Agricultural Growth in China, American Economic Review 82, 34–51.

Lovell, C.A.K. (2003) The Decomposition of Malmquist Productivity Indexes, Journal of Productivity Analysis, 20, 437-458.

Lucas, R. E. (1988) On the Mechanics of Economic Development, Journal of Monetary Economics 22, 3–42.

Luenberger, D. G. (1992a) Benefit Functions and Duality, *Journal of Mathematical Economics* 21: 461–481.

Luenberger, D. G. (1992b) New Optimality Principles for Economic Efficiency and Equilibrium. *Journal of Optimization Theory and Applications* 75: 221–264.

Luenberger, D. G. (1995) Microeconomic Theory, McGraw-Hill, New York.

Maddison, A. (1998) Chinese Economic Performance in the Long Run, Paris: OECD Development Centre Studies.

Malmquist, S. (1953) Index Numbers and Indifference Curves. Trabajos de Estatistica, 4 (1): 209-42.

Managi, S. (2004) Competitiveness and Environmental Policies for Agriculture: Testing the Porter Hypothesis, *International Journal of Agricultural Resources, Governance and Ecology* 3 (3/4): 310-324.

Managi, S. Opaluch, J.J. Jin, D. and Grigalunas, T.A. (2004) Technological Change and Depletion in Offshore Oil and Gas, *Journal of Environmental Economics and Management* 47 (2): 388–409.

Managi, S. Opaluch, J.J. Jin, D. and Grigalunas, T.A. (2005) Environmental Regulations and Technological Change in the Offshore Oil and Gas Industry, *Land Economics* 81 (2): 303-319.

Ma, X. and Ortolano L. (2000) Environmental Regulation in China, Lanham, Rowman and Littlefield Publisher

McCain, R.A. (1978) Endogenous Bias in Technical Progress and Environmental Policy. *American Economic Review* 68: 538–546.

McMillan, J., 1995. China’s nonconformist reform. In: Edward, P. (Ed.), Economic Transition in Eastern Europe and Russia: Realities of Reform. Hoover Institution Press, Stanford, pp. 419–433.

Qian, Yingyi, 1999. “The Institutional Foundations of China’s Market Transition,” working paper, Stanford University.

Qian, Yingyi. 2003. How Reform Worked in China,” in Dani Rodrik, editor, In Search of Prosperity: Analytic Narratives on Economic Growth, Princeton University Press, 2003, pp. 297-333.

Ray, Subhash C. and Evangelia Desli. (1997) “Productivity Growth, Technical Progress,. and Efficiency Change in Industrialized Countries:

Comment“ American Economic Review. 87 (5), 1033-39.

Shephard, R.W. (1970) *Theory of Cost and Production Functions*. Princeton, NJ: Princeton University Press.

Shleifer, A., Treisman, D., 2000. Without a Map: Political Tactics and Economic Reform in Russia. MIT Press, Cambridge, MA.

Sinkule, B.J. and Ortolano, L. (1995) Implementing Environmental Policy in China, Westport, CT: Praeger.

Stulz, R., Williamson, R., 2003. Culture, openness, and finance. Journal of Financial Economics 70, 261–300.

Tian HZ, Lu YQ, Hao JM. 2001. The future programming of acid rain and SO2 control in China. Electricity 12(2):35–37.

Wang, H. and W. Di (2002). The Determinants of Government Environmental Performance: An Empirical Analysis of Chinese Townships. Policy Research Working Paper. Washington, D.C., The World Bank.

Wang, H. and Y. Jin (2002). Industrial Ownership and Environmental Performance: Evidence from China. Policy Research Working Paper. Washington, D.C., The World Bank.

Wang, H., Mamingi, N., Laplante, B. and Dasgupta, S. (2002) Incomplete Enforcement of Pollution Regulation: Bargaining Power of Chinese Factories" Policy Research Working Paper No. 2756, Development Research Group, The World Bank, Washington, D.C.

Wang, Y., Morgan, R. and Cashmore, M. (2003) Environmental impact assessment of projects in the People’s Republic of China: New law, old problems. Environmental Impact Assessment Review, Vol. 23 (5), pp 543-579.

Wang, H., Wheeler, D. (1996) Pricing industrial pollution in China: An econometric analysis of the levy system. Policy Research Working Paper No. 1644, Development Research Group, The World Bank, Washington, D.C.

Wang, H., Wheeler, D. (2000) Endogenous Enforcement and Effectiveness of China's Pollution Levy System, Policy Research Working Paper No. 2336, Development Research Group, The World Bank, Washington, D.C.

Wang, H. and D. Wheeler (2003). "Equilibrium Pollution and Economic Development in China." Environment and Development Economics 2003(8): 451-466.

Wang, Y., Yao, Y. (2003) Sources of China’s Economic Growth 1952–1999: Incorporating Human Capital Accumulation. *China Economic Review* 14: 32–52.

Wang, Z.X. 2000. Present situation of charges on pollution discharge of thermal power plants. Electricity Power 33(1):77–81.

World Bank (1997) China 2020: Development Challenges in the New Century, Washington, DC.: World Bank.

World Bank (1997) Clear Water, Blue Skies: China: Environment in the New Century, Washington, DC.

World Bank (2001) China Air, Land and Water: Environmental Priorities for a New Millennium, Washington, DC.

Wu, Yanrui. 2003. "Has Productivity Contributed to China's Growth?," Pacific Economic Review, vol. 8(1), pages 15-30.

Xu, X. (2004) China’s Gross Domestic Product Estimation. *China Economic Review* 15: 302– 322.

Yang J.T, Cao D., Wang J.N, Tian W.Y. 2000. SO2 emission charge in China. SO2 Emission Trading Program: US Experience and China’s Perspective. Beijing: China Environ. Science.

Young, A. (1994) Lessons from the East Asian NICs: a Contrarian View, European Economic Review 110, 641–80.

Young, A. (1995) The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience, Quarterly Journal of Economics 110, 641–80.

Young, A. (2000) The Razor’s Edge. Distortions and Incremental Reform in the People’s Republic of China," Quarterly Journal of Economics 115, 1091–1136.

Zhuravskaya, Ekaterina V. "Incentives to Provide Local Public Goods: Fiscal Federalism, Russian Style." Journal of Public Economics, June 2000, 76(3), pp. 337-68.

Zhou, F., Zhou, D. (Eds.), 1999. Study on Long Term Energy Development Strategies of China. China Planning Press, Beijing.

Table 1. Data Information: 29 provinces for the period 1992-2003

Variable	Data source
Gross Regional Product: added value of secondary industry (unit of 10^8 Yuan)	1992-1999: Comprehensive Statistical Data and Materials on 50 Years of New China. 2000-2003: China Industrial Economy Statistical Yearbook
Number of employees working in secondary industry (unit of 10^4 persons)	1992-1999: Communication Statistics on 50 Years of China. 2000-2003: China Industrial Economy Statistical Yearbook
Wage: Wages paid in industry (unit of 10^4 Yuan)	China Statistical Yearbook
Capital stock: estimated from annual productive net of depreciation in the secondary industry (unit of 10^8 Yuan)	1992-1999: Communication Statistics on 50 Years of China. 2000-2003: China Industrial Economy Statistical Yearbook
Wastewater: wastewater quantity measured as the weight of wastewater discharge (unit of 10^4 ton)	China Environmental Statistical Yearbooks
Waste gas: gas quantity measured as the volume of waste gas emissions, which is not treated (unit of 10^8 m^3)	China Environmental Statistical Yearbooks
Solid waste: wastes quantity measured as the discharge amount of solid wastes (unit of 10^4 ton)	China Environmental Statistical Yearbooks
Pollution abatement cost and expenditure: funds actually used for industrial environmental pollution of wastewater, waste gas and solid waste (unit of 10^4 Yuan)	China Environmental Statistical Yearbooks

Table 1. (… Continued)

Variable	Data source
Soot: Soot emission by consumption and others refers to net volume of soot emitted by fuel burning from a economic activities and operation of industrial activities. It is calculated on the basis of coal consumption (unit of ton)	China Environmental Statistical Yearbooks
Chemical Oxygen Demand (COD): Index of water pollution measuring the mass concentration of oxygen consumed by the chemical breakdown of organic and inorganic matter (unit of ton)	China Environmental Statistical Yearbooks
Lead: discharge of lead emitted by production process of industrial activities (unit of ton)	China Environmental Statistical Yearbooks
Chromium Six: discharge of Hexavalent Chromium emitted by production process of industrial activities (unit of ton)	China Environmental Statistical Yearbooks
Oil Consumption: total oil consumed as fuel in tones of coal equivalent (TCE) (unit of 10^4 TCE)	China Environmental Statistical Yearbooks
Coal Consumption: total coal consumed as fuel in tones of TCE (unit of 10^4 TCE)	China Environmental Statistical Yearbooks
Fresh Water use of fresh water in industrial activities (unit of 10^4 ton)	China Environmental Statistical Yearbooks

Table 2. Model Specifications

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Index Calculated	Base	Base (Energy)	Base (All)	Joint (All1)	Joint (All2)	Joint (All3)	Joint (All4)
Output Variables							
Gross Regional Product (GRP)	X	X	X	X	X	X	X
Waste gas				X	X	X	X
Solid waste				X	X	X	X
Wastewater				X	X	X	X
SO_2						X	
Dust						X	
Soot						X	
COD						X	
Lead						X	
Chromium Six						X	
Input Variables							
Labor	X	X	X	X	X	X	X
Capital	X	X	X	X	X	X	X
Oil Consumption		X	X		X	X	X
Coal Consumption		X	X		X	X	X
Fresh Water			X		X	X	X
PACE				X	X	X	

Table 2. (… continued)

	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
Index Calculated	Joint (Gas1)	Joint (Gas2)	Joint (Gas3)	Joint (Gas4)	Joint (Gas5)	Joint (Solid)	Joint (Water1)
Output Variables							
GRP	X	X	X	X	X	X	X
Waste gas	X				X		
Solid waste						X	
Wastewater							X
SO_2		X	X	X	X		
Dust			X	X	X		
Soot			X	X	X		
Input Variables							
Labor	X	X	X	X	X	X	X
Capital	X	X	X	X	X	X	X
Oil Consumption				X	X		
Coal Consumption				X	X		
PACE (waste gas)	X	X	X	X	X		
PACE (solid waste)						X	
PACE wastewater)							X

Table 2. (… continued)

	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21
Index Calculated	Joint (Water2)	Joint (Water3)	Joint (Water4)	Joint (Water5)	Joint (Water6)	Joint (Water7)	Joint (Water8)
Output Variables							
GRP	X	X	X	X	X	X	X
Wastewater	X			X		X	X
COD		X	X	X			
Lead		X	X	X			
Chromium Six		X	X	X			
Input Variables							
Labor	X	X	X	X	X	X	X
Capital	X	X	X	X	X	X	X
Fresh Water	X		X	X	X		X
PACE (wastewater)	X	X	X	X			

Table 3. Summary of Results (VRS): Cumulative Change in Indices

	Productivity		
Index	TFP	TC	EC
Model 1 (1992-2003)	0.10	0.10	0.05
	(0.01)	(0.01)	(0.00)
Model 2 (1996-2003)	0.15	0.10	0.06
	(0.02)	(0.01)	(0.01)
Model 3 (1996-2003)	0.20	0.16	0.06
	(0.03)	(0.02)	(0.01)
Model 4 (1992-2003)	0.13	0.13	0.04
	(0.01)	(0.01)	(0.00)
Model 5 (1996-2003)	0.20	0.18	0.07
	(0.03)	(0.03)	(0.01)
Model 6 (1996-2003)	0.22	0.23	0.09
	(0.03)	(0.03)	(0.01)
Model 7 (1996-2003)	0.21	0.19	0.06
	(0.03)	(0.03)	(0.01)
Model 8 (1992-2003)	0.12	0.10	0.07
	(0.01)	(0.01)	(0.01)
Model 9 (1992-2003)	0.12	0.10	0.07
	(0.01)	(0.01)	(0.01)
Model 10 (1992-2003)	0.13	0.11	0.07
	(0.01)	(0.01)	(0.01)
Model 11 (1996-2003)	0.12	0.10	0.04
	(0.02)	(0.01)	(0.01)
Model 12 (1992-2003)	0.12	0.10	0.04
	(0.02)	(0.01)	(0.01)
Model 13 (1992-2003)	0.15	0.08	0.03
	(0.01)	(0.01)	(0.00)
Model 14 (1992-2003)	0.14	0.16	0.03
	(0.01)	(0.01)	(0.00)

Note: Annual mean values are provided in parenthesis.

Table 3. (… Continued)

Model 15 (1996-2003)	0.10	0.10	0.07
	(0.01)	(0.01)	(0.01)
Model 16 (1992-2003)	0.20	0.20	0.03
	(0.02)	(0.02)	(0.00)
Model 17 (1996-2003)	0.13	0.12	0.07
	(0.02)	(0.02)	(0.01)
Model 18 (1996-2003)	0.14	0.13	0.07
	(0.02)	(0.02)	(0.01)
Model 19 (1996-2003)	0.08	0.07	0.05
	(0.01)	(0.01)	(0.01)
Model 20 (1992-2003)	0.10	0.10	0.04
	(0.01)	(0.01)	(0.00)
Model 21 (1996-2003)	0.08	0.07	0.05
	(0.01)	(0.01)	(0.01)

Note: Annual mean values are provided in parenthesis.

Table 4. Estimation Results of Market Productivities

Variable	Dependent variable Δ TFP_t (Market)	Δ TC_t (Market)	Δ EC_t (Market)
Δ $Patent_{t-1}$	–0.0004 (–0.87)	0.0003 (0.43)	0.000001 (1.15)
Δ FDI_t	0.0003 (3.03) ***	0.00001 (2.18) **	0.0000004 (2.00)**
Δ FDI_{t-1}	0.0003 (2.20) **	0.00001 (2.16) **	0.000001 (3.29) **
Δ CAC_{t-1}	0.0005 (1.57)	–0.0041 (–7.82) ***	–0.0000001 (–0.22)
Poll-Inten $_t$	–0.0028 (–1.17)	–0.0004 (–0.09)	0.000017 (4.41) ***
R-Square	0.9253	0.7559	0.9999
Unit root	3.07 ***	2.65 ***	2.35 ***

Note.— Δ $Patent_t$ is equal to $Patent_t$ / $Patent_{t-1}$ in this table. Values in parentheses are t-values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Table 5. Estimation Results of Environmental Productivities

	Dependent variable		
Variable	Δ TFP $_t$ (Environment)	Δ TC $_t$ (Environment)	Δ EC $_t$ (Environment)
Δ PACE $_t$	0.003302 (5.59) ***	0.0033 (4.77) ***	–0.00003 (–1.42)
Δ PACE $_{t-1}$	0.004172 (8.09) ***	0.0038 (6.36) ***	–0.00003(–1.24)
Δ CAC $_t$	0.001079(2.13) **	0.0009 (1.56)	–0.00002 (–0.84)
Δ CAC $_{t-1}$	0.000054 (0.52)	0.00003 (0.27)	–0.00001 (–1.89) *
Δ Levy $_{t-}$	0.000027 (0.24)	–0.00004 (–0.30)	–0.000004 (–0.94)
Δ Levy $_{t-1}$	–0.000120 (–1.15)	–0.0002 (–1.84) *	–0.000003 (–0.69)
Δ FDI $_t$	–0.000070 (–0.36)	–0.0003 (–1.34)	–0.00001 (–1.08)
Δ FDI $_{t-1}$	–0.000040 (–2.23) *	-0.0002 (–2.82) *	–0.00001 (–0.85)
Poll-Inten $_t$	–0.000660 (–0.16)	0.0033 (0.70)	–0.00040(–2.56) **
R-Square	0.8389	0.69880	0.9984
Unit root	2.82 ***	2.93 ***	2.70 ***

Note.—Values in parentheses are t-values. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

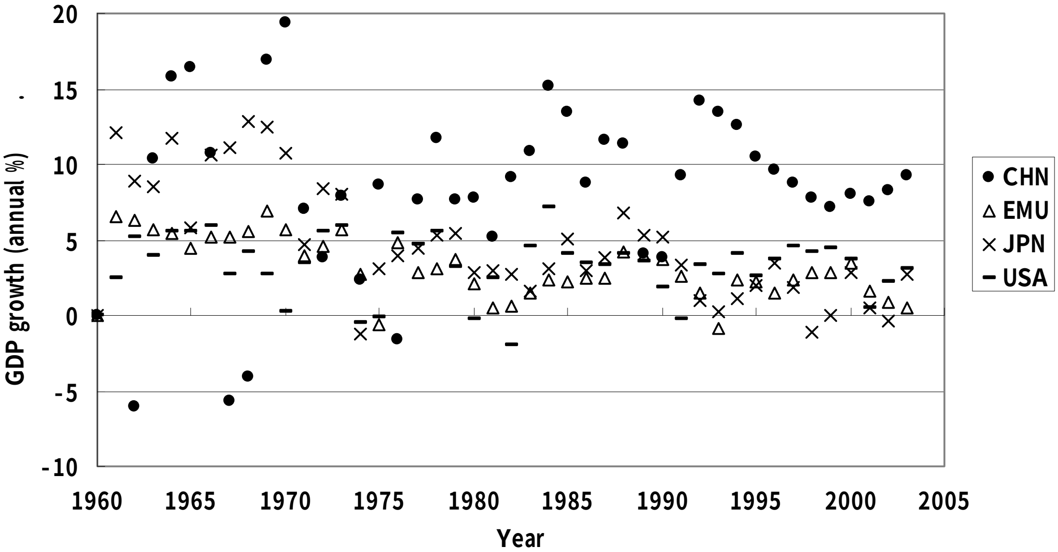

Figure 1. Annual Gross Domestic Product (GDP) growth of China (CHN), European Monetary Union (EMU), Japan (JPN), and United States (USA), Source: World Development Indicators (WDI, 2005).

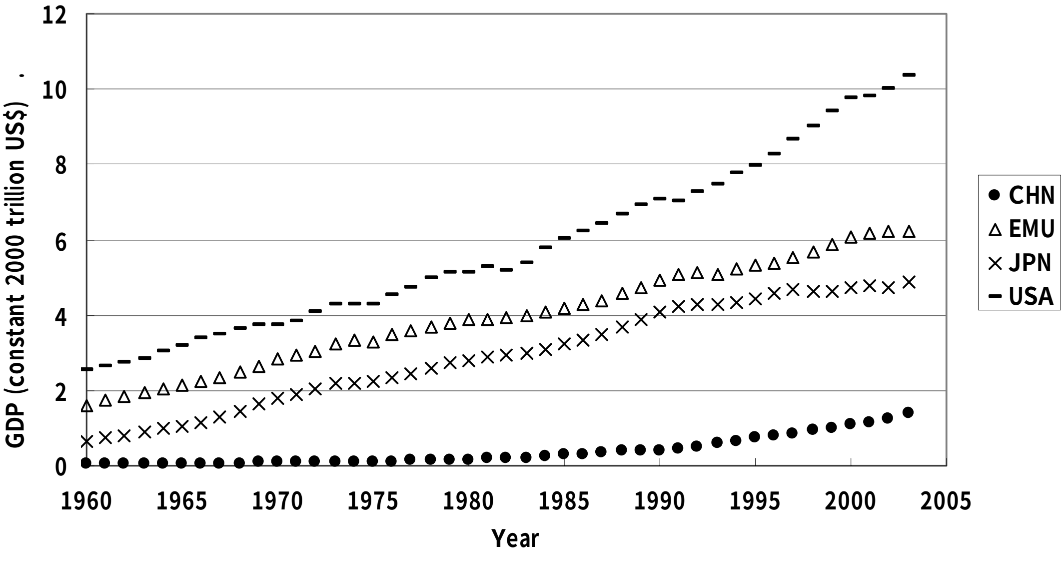

Figure 2. Gross Domestic Product, Source: World Development Indicators (WDI, 2005).

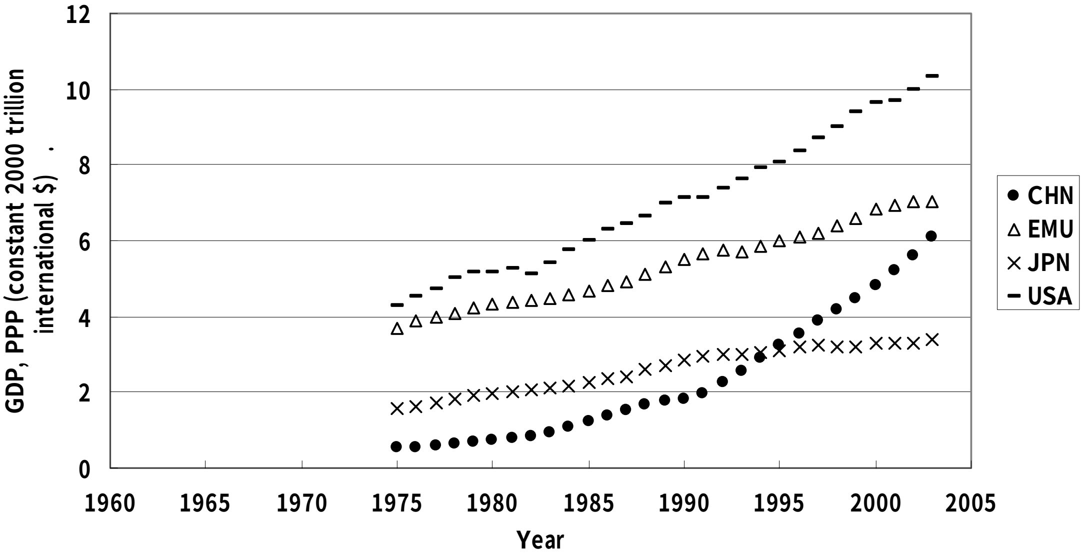

Figure 3. GDP dollar estimates derived from purchasing power parity (PPP) calculations, Source: World Development Indicators (WDI, 2005).

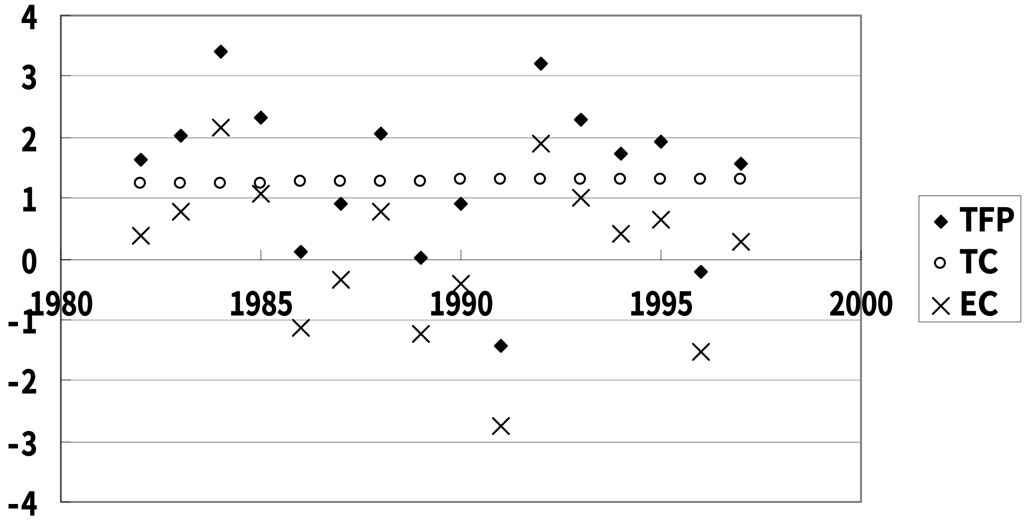

Figure 4. Total factor productivity, technological change, and efficiency change (Wu, 2003).

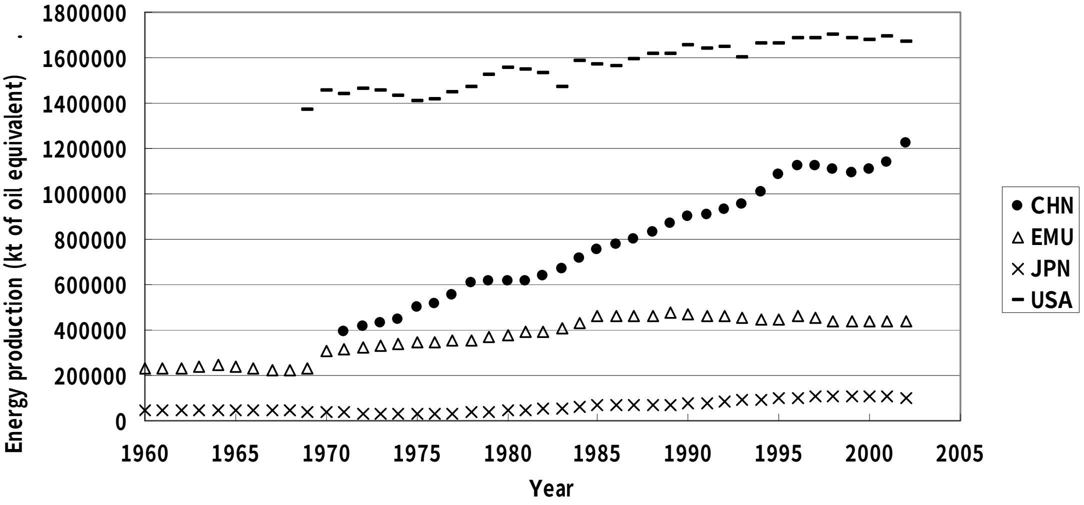

Figure 5. Energy production, Source: World Development Indicators (WDI, 2005).

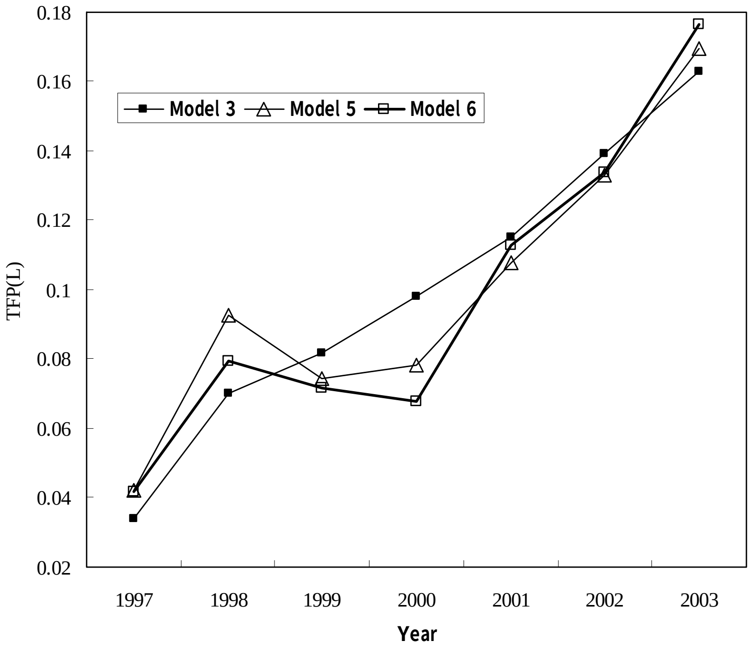

Figure 6. Joint model of waste water, waste gas, and solid waste: Luenberger productivity index.

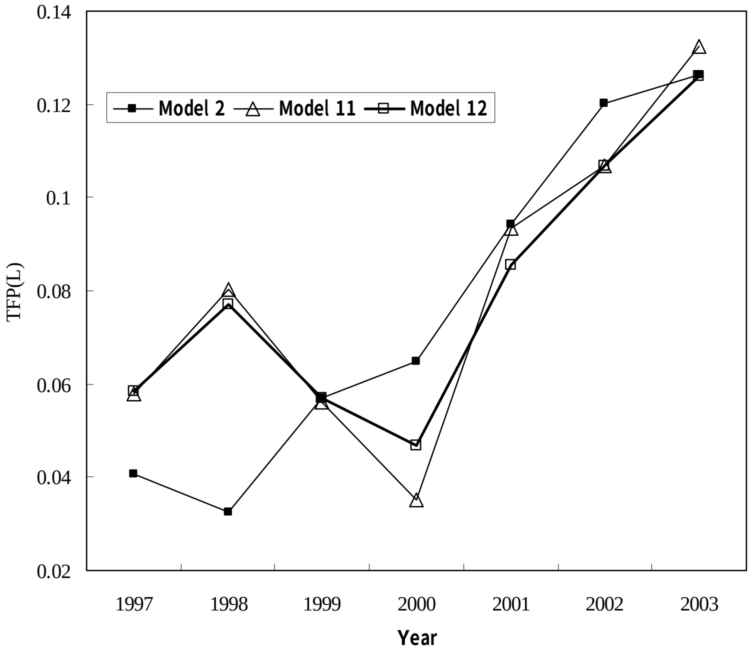

Figure 7. Joint model of waste gas: Luenberger productivity index.

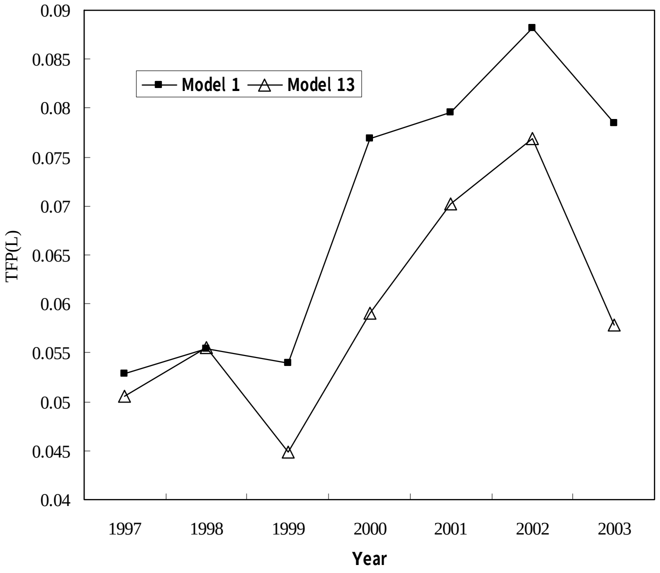

Figure 8. Joint model of solid waste: Luenberger productivity index.

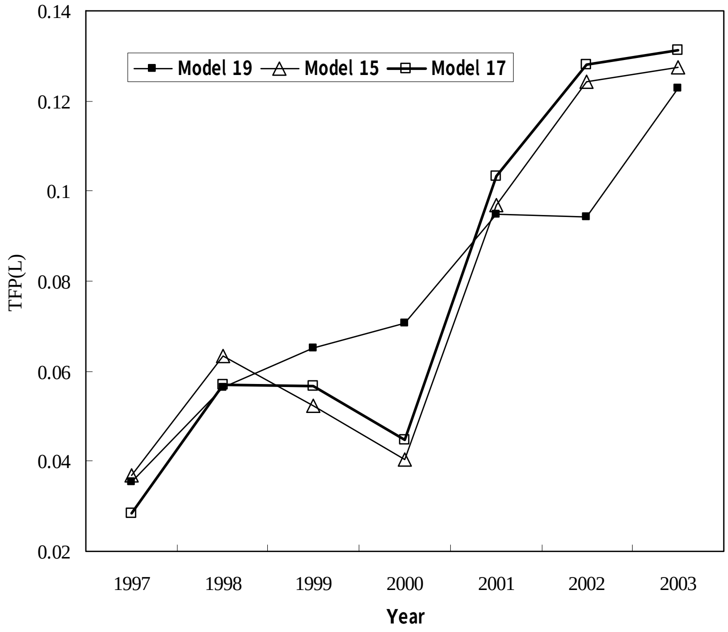

Figure 9. Joint model of waste water: Luenberger productivity index.

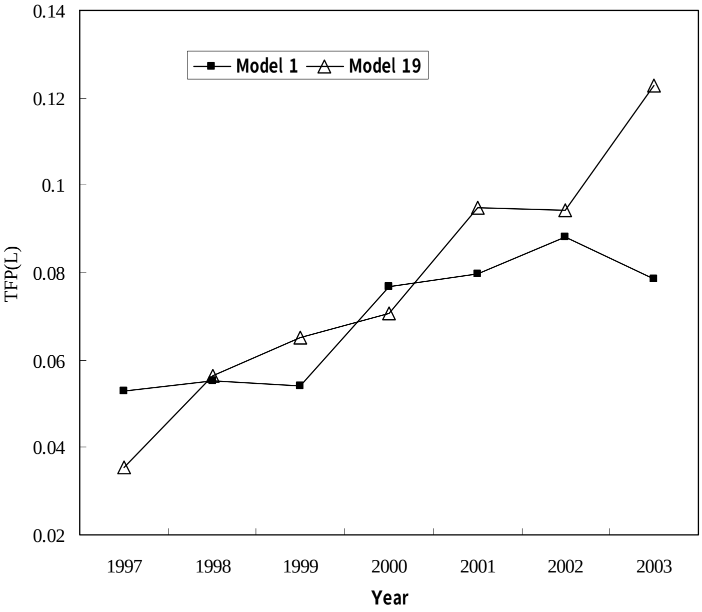

Figure 10. Joint model of water use: Luenberger productivity index.

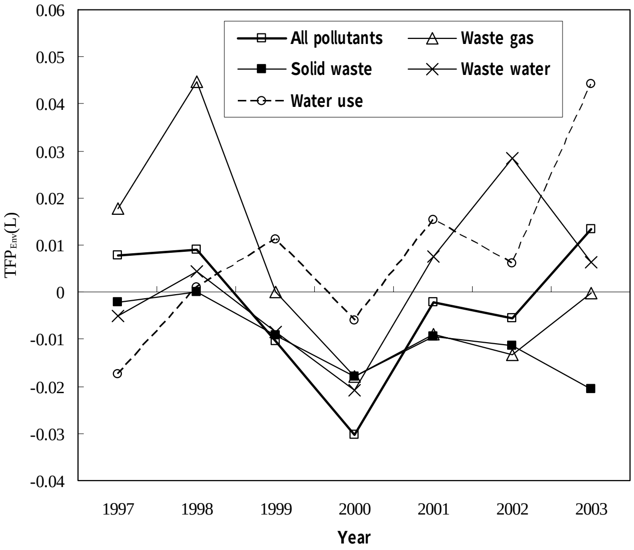

Figure 11. Environmental productivity: Luenberger productivity index (All pollutants=Model 6 – Model 3; Waste gas=Model 12 – Model 2; Solid waste=Model 13 – Model 1; Waste water=Model 18 – Model 19; Water use=Model 19 – Model 1).