Assessment of the Emission Trading Policy:
A case study for the Acid Rain Program in the United States

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Geography

Waterloo, Ontario, Canada, 2004

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Various environmental standards have been established for the sake of public health and ecosystem diversity since environmental awareness was awakened in the late 1960s. However, the results were often unsatisfactory. Either environmental goals achieved were far from desired, or regional development was hampered due to some unpractical high environmental standards.

The failure of these environmental standards resulted in innovations of environmental policy instruments to find practical environmental goals and methods approaching them scientifically. Another class of environmental policy instruments, so called economic incentive policies, is established based on environmental economics theory. A neo-classical economics framework is founded for setting appropriate environmental goals and assessing efficiency of environmental policies in reaching these goals. This thesis summarizes rationales and factors affecting the performance for environmental policy instruments under the neo-classical economic framework.

Since the acid rain program, the first large-scale implementation of the emissions trading policy, has achieved great success in reducing SO_2 emissions from the electricity generators in the United States, the emission trading policy attracted many interests in this kind of environmental policy instrument. Many countries, such as China, plan to adopt the emissions trading policy to address various environmental problems. Hence, factors leading to the success of this program should be identified. Potential risks and problems must be addressed as well lest the emissions trading policy causes some problem during implementation. Feasibility of implementing an emissions trading policy will be discussed based on these results.

Three kinds of geographic analyses, change detection, network analysis, and hot spots identification, are conducted in this thesis to study the effectiveness and efficiency of the acid rain program. It is found that the acid rain program is successful in improving the sustainability of the economic development in the United States. But the effectiveness is not as great as the high emissions cutting rate achieved in this program. In addition, the acid rain program lowers the compliance costs of achieving the environmental goal since the radius of the high quality coal service area doubles. Lastly, hot spots are found around the Ohio River valley and Los Angeles. Suggestions on integrating geographic factors into the economic framework are presented in order to eliminate the risk of causing severe environmental problems.

Finally, the feasibility of migrating the emissions trading policy to China is discussed. Further work can be conducted in this direction to realize sustainable development quicker with lower costs.

Acknowledgements

I would like to express my gratitude to a number of people who have provided assistance and support throughout my studies at the University of Waterloo.

Whatever weaknesses are present in this thesis would have been far more substantial without assistance of my supervisor, Dr. Douglas Dudycha. Thank you, Doug, for your direction and friendship. I cannot find the right question and methodology without your assistance.

I am grateful to my committee member, Dr. Jean Andrey, for spending a lot of time on reading my thesis and giving me a lot of helpful suggestions.

Dr. Brent Hall merits special thanks for his help and kindness. Brent has taken quite a long time in correcting my wording problems even though he needs not to do this. I appreciate his direction concerning logic clarification and presentation improvement in this thesis greatly.

I would also like to thank my friends and family for their assistance and support. Only they know how heavily I relied on their care and understanding throughout this project.

Finally, this thesis could not have been completed without the understanding of my wife and best friend, Huaxin Sun. I owe her a special debt of thanks for understanding me to leave her alone in China and providing me spiritual support throughout my study abroad. It is to her that this thesis is dedicated.

Dedication

To my wife, parents, and friends

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Chapter 1 Introduction

1.1 Problem Statement

Environmental awareness in the United States (US) was awakened in the late 19n60s following publication of works such as *Silent Spring* (Carson, et al., 1962) and *The Limits to Growth* (Meadows, et al., 1972). People began to realize that many human activities, especially industrialized ones, harm the natural environment and that deteriorating environmental conditions adversely affect our health and standard of living.

The concept of environmental management was introduced as an approach to managing human activities so as to minimize damage to the environment. Environment is a broader concept than resources as it includes all of the surrounding conditions and influences that affect living and non-living things (Michell, 2000). Environmental management can be divided into two parts: natural resources management and waste management and pollution control. The biosphere, a term for all living things on earth, and the environment can be regarded as a circular system: the biosphere absorbs energy and materials from the environment and dumps waste into the environment, where they become resources again.

Natural resources management is concerned with the "input" problem of conservation and supply of materials and energy. If the limited natural resources we currently depend on become depleted, our standard of living will fall unless we are able to reduce our resource requirements or substitute abundant or renewable resources for scarce non-renewable ones. This was demonstrated by the energy crisis in the 1970s. This kind of problem may be relatively easy to solve since market mechanisms will increase the price of the scarce resource, thereby encouraging reduced use of the resource and stimulating the search for lower cost alternatives

Waste and pollution represent the "output" problem of inappropriate outputs that cannot be reused or recycled. These might hurt public health or change ecosystem structure by causing species extinction or species migration to more favorable environments. Pollution is mainly caused by industrialized activities, such as chemical engineering, energy generation, and transportation. This kind of problem is more complex because it introduces externalities that cannot be eliminated by conventional market mechanisms. There must be some regulations of pollutant emissions; otherwise pollution volume will be higher than human beings or ecosystems can endure. This thesis focuses on environmental policy tools that are intended to solve pollution problems effectively and efficiently.

Environmental policy tools can be classified into two categories: Command and Control policies (CAC) and Economic Incentives (EI) policies (Blackman and Harrington, 1999). Originally, all environmental policies belonged to CAC. These policies imposed homogenous regulations for polluters' emissions based on materials processing methods, toxicology requirements and available abatement techniques. However, the results were unsatisfactory. Environmental goals achieved were far from desired. For example, the US Environmental Protection Agency (EPA) twice was forced to extend the deadline for meeting ambient air quality standards since the original environmental goals were impossible to achieve in time (Ellerman, et al., 2000). At the same time, compliance costs were often too high to support attainment of economic growth objectives. Given that implementation of CAC policies are hard to achieve the environmental goal of protecting the environment for future development while maintaining present economic growth, it was not consistent with the principle of sustainable development.

The deficits of CAC policies resulted in EI methods becoming more popular. These methods include emissions trading, emission fees, and environmental taxes. According to many case studies, EI methods are much more effective with lower compliance costs (Blackman and Harrington, 1999). Many countries plan to implement EI methods to solve various kinds of environmental problems. For example, China is going to copy the Acid Rain Program (ARP) of the United States (US), which is the first large-scale EI environmental policy using the emissions trading instrument to cut down sulphur dioxide (SO_2) emissions. So a systematic study of the ARP in the US is needed to assess its performance, identify key factors that make the program successful, and address potential “hot spots” problems. This can lead to an assessment of whether and how to migrate the emissions trading program into China.

1.2 Thesis Objectives

This thesis has the following three objectives: (1) to summarize the rationales, merits, drawbacks, and factors affecting the performance for each type of environmental policy instrument under a neo-classical economic framework; (2) to analyze the impact of the ARP on SO_2 distribution in the US, assess its effectiveness and efficiency, and identify related factors; and (3) to discuss the feasibility of implementing emissions trading policy to other countries, especially those in earlier stage of economic development.

The first objective of this thesis is to summarize the literature on environmental policy tools and the ARP from an economic point of view. Acid rain is atmospheric deposition that is more acidic than normal, including rain, snow, and fog (Holmes, 2000). It has negative environmental impacts on lakes and aquatic ecosystems, forests and soils, man-made structures and materials, and public health. Because human activities account for more than 90% of the SO_2 and 95% of the nitrogen dioxide emissions that lead to acid rain, many methods have been adopted to lower SO_2 emissions in order to solve this environmental problem.

Burning fossil fuels is one of the main sources for SO_2. Power plants using fossil fuels accounted for 60% of SO_2 emissions in the US in 1997 (Driscoll, et al., 2001). Various CAC environmental policies were implemented after the Clean Air Act (CAA) was passed in 1970. They either regulated the density of pollutant emission, or specified pollution processing techniques for every individual polluter. However, the results showed that CAC policies were somewhat ineffective. Although the overall SO_2 emission volume decreased, it remained high compared to background conditions. This was especially true for the Northeast United States (US). Meanwhile compliance costs were very high. Some generators were even forced to shut down because they couldn't meet CAA requirements in time (Driscoll, *et al.*, 2001). Local economic growth and standard of living improvement around these generators might have been hampered since they depended on energy supply given that both technology and industrial structure are hard to change in a short term.

Amendments to the Clean Air Act introduced in the 1990s permitted use of EI environmental policies to accelerate pollution reduction while lowering compliance costs. The revised act featured an innovative “cap-and-trade” approach to environmental management that sets annual SO_2 emissions caps in order to reduce total annual emissions to 10 million tons below 1980 levels by 2010 in two phases (1995-1999 and 2000-2010): This approach allows individual polluters (power plants) to lower their pollution level or to buy “pollution rights” if they cannot meet the cap requirement (U.S. EPA, 2000). Since polluters can sell surplus 'pollution rights' for profit or bank them for future use, all polluters have incentives to reduce their own emissions. This appears to have been a successful program since SO_2 emissions declined dramatically after the policy implementation and compliance costs were also very low (Burtraw, 1998).

Many studies have been undertaken trying to find methods for environmental policy tool selection and to identify factors that made the cap-and-trade approach so successful from an economic point of view. They examined the mechanisms of the policy tools for reducing pollution (Arimura, 2002, Baumol and Oates, 1975, Blackman and Harrington, 1999, Stavins, 2001, Sundqvist, et al., 2002), all related aspects of the ARP (Bailey, 1998, Burtraw, 1996, Burtraw and Palmer, 2003, Ellerman, *et al.*, 2000, Ellerman, *et al.*, , U.S. EPA, 2000, 2001a), and cost-benefit analysis and environmental policy assessment (Burtraw, *et al.*, 1997, Environment Canada, 2000, Ganley and Cubbin, 1992, Goulder, *et al.*, 1998, Griffiths, , Nijkamp, 1980, U.S. Congress, 1995, World Bank, 1997b). A neo-classical economic framework to assess and design environmental policy tools scientifically has begun to emerge from this research.

These studies identified factors that contributed to the success of the ARP and subjected emission reduction technologies to quantitative analysis. A framework for assessing environmental policy from an economic perspective can be summarized according to this literature. This framework is vital because it can be used for policy instrument selection, assessment, and optimization.

The second thesis objective is to analyze the impact of the ARP on the changing distribution of SO_2 in the US, assess its effectiveness and efficiency, and identify related factors. Several concerns have been expressed in the literature regarding the emissions trading program. For example, the "cap-and-trade" mechanism lacks limitation on spatial trading. Polluters in a particular region may purchase pollution rights, allowing them to emit greater quantities of pollution, thus creating "hot spots" having excessively high levels of pollution to protect downwind receptors (Swift, 2000). Furthermore, pollutants drift with the wind necessitating some regulation of spatial trading (Environmental Defense, 2000). Geographic studies must be done to examine these issues, but there has been very limited research to date. Few economists are familiar with geographic issues and the special properties of pollutant. Only some simple analyses such as geographic emission distribution mapping has been done with little concern for the spatial impacts of the ARP.

Unfortunately, the US EPA also overlooked the hot spot problem when the ARP was designed. Although the hot spot problem may happen, it has not occurred in the ARP (Swift, 2000). More importantly, the hot spot problem suggests some limitation rules on trading, which are contradictory to deeper deregulation for free emission trade for the sake of economic efficiency. The conflict between localized environmental problems and a globalized trading rule seems unsolvable. It is suggested that this conflict originates from the exclusion of spatial concepts and perspective within environmental economic theory. The geographic concept that reflects the environmental problem's local character can be integrated into this economic framework by adding spatial variables into consideration (this problem will be further discussed in later chapters). In this thesis, results known in earlier literature are validated from a geographic perspective to prepare for further more complicated research on the use of spatial variables in environmental economics. Second, geographic analyses are conducted on identified factors that might affect the ARP's performance, such as the effect of railway deregulation on the processing technique chosen. Furthermore, it is a good way to learn how to conduct policy analysis in a quantitative way.

The third thesis objective is to discuss the feasibility of implementing emissions trading policy to other countries, especially those undergoing economic development, and other pollutants. Given the success of the US ARP, there is considerable interest in migrating emissions trading policy to other countries and using it for other pollutants. For example, China wishes to copy the ARP for SO_2 as well. This thesis will assess the possibility of implementing a similar pollution control program in China.

1.3 Structure of This Thesis

First, the principles of environmental economics are introduced. Next, different kinds of environmental policy instruments are explained in terms of their operation, merits, and drawbacks. After the environmental policy assessment framework is established from an economic point of view, focus is given to the ARP assessment implemented in the United States, since it is the first large scale EI instrument implementation. Previous literature on assessing this program from an economics perspective is discussed. Then various geographical analyses are conducted for performance validation and hot spot problem seeking. Results and detailed discussion are presented in Chapter 4, discussing the way of integrating overlooked geographic factors into the environmental policy assessment framework. Chapter 5 discusses the possibility of migrating the ARP into China and potential decision support system building using agent-based modeling.

Chapter 2 Environmental Policies and Emissions trading

2.1 Overview

As CAC instruments were found to be more clearly insufficient for sustainable development, various environmental policy tools, such as EI tools, were introduced to integrate effectiveness and efficiency of solving environmental problems. Since CAC instruments set homogeneous standards for every individual polluter with less consideration of their own characters and situation, results of using CAC tools to solve environmental problems were not very good. Either some specific environmental goals were not achieved in time, or the costs of controlling pollution were so high that it hampered local development.

Given the drawbacks associated with CAC tools, policy makers tend to consider more factors than public health and species diversity using scientific approaches. Applying an economic framework to interpret environmental policy tools' mechanisms, assess their performances, and optimize their factors is one of the most successful scientific approaches integrating multi-criteria and multi-participant requirements into one framework. This chapter reviews the goals of environmental policies and explains their mechanisms for achieving the goal of so called "best pollution level" from an economic perspective. A methodology for assessing the performance of environmental policies is summarized based on literature.

After introducing various environmental policy tools and assessment framework in general, the ARP, the first national program implemented using an emissions trading instrument to test the feasibility of adopting EI methods instead of CAC systems, is discussed. The success of this program triggered world-wide interest in adopting emissions trading to solve environmental problems. Projected similar programs included carbon emissions trading for the Kyoto Protocol, SO_2 emissions trading in China, and SO_2 and oxynitride (NO_x) emissions trading in Ontario. However, emissions trading tools have an important problem of "hot spots" in that polluters can buy many emissions allocations and concentrate their emissions in the area causing serious local environmental problems. This problem should be carefully studied before the projected programs implementation to avoid serious damage to the environment and human beings.

Literature on the ARP's effectiveness and efficiency is reviewed systematically, discussing the potential hot spots problem and identifying factors that affect this program's performance. Further geographic analyses and discussion are in later chapters.

2.2 Environmental Economics and Sustainable Development

2.2.1 Scientific Approaches for Environmental Policy Designation and Assessment

On a general view, several kinds of scientific approaches have been brought up to consider more factors than public health and species diversity as mentioned before.

One kind of approach focuses on public participation, which allows people with different kinds of concerns to set policy together. More factors are taken into consider by people with other concerns. For example, the Canadian Environmental Quality Guidelines (CEQGs) is one of them showing future development of environmental standards, which is defined as "Numerical concentrations or narrative statements that are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of the ecosystem and the designated resource uses they support." They are nationally endorsed, science-based goals for the quality of atmospheric, aquatic and terrestrial ecosystems. They serve as environmental quality indicators and benchmarks of environmental performance. From a governmental regulatory and control perspective, this role is to deliver more effective approaches to reducing air emissions from point sources, such as power plants and smelters, as well as non-point sources of pollution and environmental stress, including nutrients, pesticides, long-range transport of hazardous substances, loss of bio-diversity and global climate change (Durrant, 2002). This framework emphasizes public-participation in the context of commitments to performance, transparency and accountability. With more collaboration with Non-Government Organizations (NGO) and business units, environmental standards will be more accurate and effective. In addition, the integration of environmental standards with other systems, such as business, is also emphasized. This effort makes polluter more willing to cut down pollution. It is another direction of the development of environmental standards.

Another kind of approach comes from engineering department implementing some mathematical models representing the multi-criteria nature of environmental problems. Conflict can be solved based on co-operative game theory to locate the best result. Resources can be allocated in two rounds. Initial allocation is used to make sure that later co-operative allocation will reach global optimization situation. Reallocation of water to achieve efficient use of water is adopted through water transfers (Gioradano and Wolf, 2001). Mathematical models have the merit of justice and opinion independent. But in real situations, many models cannot be calculated out due to vast computational demands.

Economic approach is characterized by using price as signal opening to any stakeholder. Both of above two kinds of approaches need to identify stakeholders initially. Once stakeholders are identified, extra ones are hard to add, or ones in group to drop out. Economic incentives are used to drive the system to reach the optimized situation, leaving participants free to choose their options without too many calculations. In this thesis, economic approach is preferred because it is more open and adaptive to change. This approach will be explained further later.

2.2.2 Environmental Economic approach

People began to realize the importance of protecting the environment after a doomsday scenario was depicted that our environment will collapse and human beings will be extinguished from the Earth if we maintain our current economic growth patterns regardless of the damage we do to the environment (Club of Rome, et al., 1974). This report clarifies the fact that economic growth has negative effects on the environment, which will hinder future economic growth. Activities that pollute the environment should be discouraged or even banned for the sake of future generations. However, it is unfair to deprive people of their right to improve their standard of living. Human beings need to exploit natural resources and industrialize to improve their standard of living.

To integrate consideration of economic growth and the environment, the concept of sustainable development was introduced as “development seeking to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. It aims at assuring the on-going productivity of exploitable natural resources and conserving all species of fauna and flora” (World Commission on Environment and Development., 1987). Environmental economics is one of the main theories to achieve this goal. At first, economic policies can be used to control the rate and patterns of economic growth. For example, tax is one of the most frequently used tools for controlling the development of different industries. Differentiating tax rates for industries can change industrial structure in the long term. Second, pollution is mainly caused by human activity. Economic theory is useful to understand and control it, given the assumption that people will always pursue higher welfare. If peoples’ desires are reflected in commodity prices, the market mechanism will reach the highest efficiency automatically only if the world consists of nothing but owned commodities. Hence, economic incentives can be used to support the transformation of the economic system from its current state to a more environmental-friendly one.

Environmental economics have a basic assumption that human activities inevitably lead to pollution, which can be minimized but not eliminated. Limited by available technology, we are unable to reach the ideal goal of “zero emission”. One important reason is exponential nature of the pollution processing costs. For example, the cost of eliminating 99.9% of copper (Cu) from waste water is approximately ten times of that of eliminating 99%. Polluters are unwilling to eliminate the last 0.9% of Cu due to the high cost and their limited financial resources. It has to be admitted that a better standard of living or economic growth cannot be achieved without pollution and damage to the environment in the long term accumulating damage in total. Thus, realizing sustainable development requires finding the “best pollution level” that is the optimal tradeoff between (i) pollution and development; (ii) decreasing pollution as quickly as possible while minimizing costs to reach the “best pollution level”, and (iii) encouraging use of environmental-friendly technologies that approach the ideal of “zero emission”.

Theoretically speaking, the “best pollution level” is the point where the marginal abatement cost (MAC) equals the marginal social benefit (MSB). The goal of profit maximization will drive polluters to emit pollution at this level, which has the highest economic efficiency with maximum benefit for the environment. However, many environmental problems stem from ‘market failures’ that prevent the market from reaching this point automatically (Samuelson and Nordhaus, 1998). In this context, the environment can be thought of as a public good that is free for individuals but has associated social costs, or “externalities”, associated with market activities. Like national defence that protects all people in a country whether individuals wish to buy defence services or not, pollution also affects everyone whether they like it or not. The environment could be polluted without any charge to individuals. Instead of emitting at the level where MAC equals MSB, externalities encourage polluters to emit where MAC equals the marginal private benefit (MPB). This leads to market inefficiencies that will be explained later.

This is not the same case when dealing with natural resources. Non-renewable natural resources, such as oil, are not public goods and have been included into the market already without externalities. Resource scarcity is reflected in commodity prices. Once a resource such as oil becomes depleted, its price rises greatly. People will transfer to other substitute resources with lower prices if they exist. Thus the way to solve natural resources and energy crisis and pollution problems is not the same. The former is easier than the latter.

This thesis focuses on the pollution problem, which cannot be fully addressed within a free market system. Although SO_2 harms the producer by imposing additional costs such as increased paint needed due to acid erosion and medical insurance expenses, the producer need not pay the externality costs of others who are harmed by SO_2. Hence, rational producers will only cut their pollution volumes to the level where the MAC equals MPB (point I in Figure 2.1) to minimize its compliance cost. However, since the MPB of pollution processing is lower than the MSB (the difference is the “externalities”), the producer will cut less pollution than point I would occur at the optimal level from a societal perspective (point E in Figure 2.1) without environmental regulations. Thus, the main goal of environmental policies is to force individual producers to take social costs into account so that the externalities are internalized.

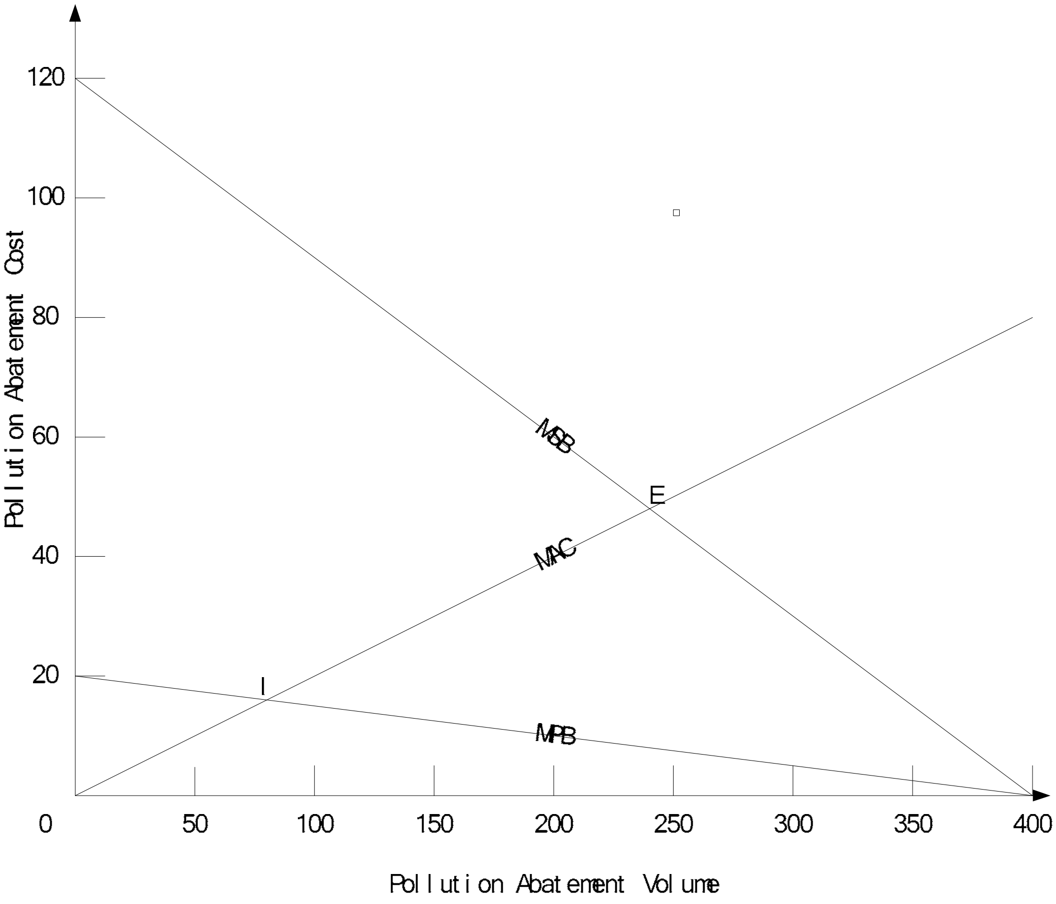


Figure 2.1: Externalities leads to inefficiency

Thus, the first problem that all environmental policies face is how to eliminate externalities so as to force polluters to reduce pollution volumes to the best pollution level. This means that we should let the MAC not equal the MPB, but the MSB instead (Samuelson and Nordhaus, 1998). Samuelson advocates that this is the responsibility of government since the externalities cannot be resolved by market forces automatically.

Alternatively, the “Coase Theorem” claims that in the absence of transactions costs and strategic behaviour, the distortions associated with externalities can be resolved through voluntary bargains struck among interested parties (Baumol and Oates, 1975). No further governmental interference, such as a Pigouvian tax defined as “a tax enacted to correct the effects of a negative externality”, is needed in this setting to achieve an efficient outcome. In fact, pre-existing tax in a Coasian setting will itself be a source of distortions (Goulder, *et al.*, 1998). But this might not be very applicable on a large scale. First, information is incomplete. Affected people may not know that their benefits are impairing due to pollution. Since negotiations for environmental problems are usually multi-participant in nature, a solution will not be perfect if only one stakeholder is neglected. Second, negotiation costs may very high and the process can be time consuming. People are reluctant to do this, but willing to let government or some other authority do this instead. This method could be much more efficient than private negotiation. Finally, in many developing countries such as China, state ownership makes property rights obscure. Thus an authority can reduce the cost of information sharing thereby lowering the cost of reaching an agreement.

However, it is commonly agreed that externalities are very hard to measure since social costs are often complex. There are always arguments about whether a certain thing can be legitimately considered as a cost. Furthermore, ecological costs are often difficult to measure. Different ecosystems have different tolerances for the same damage. There is no well-established method to quantify this, let alone convert it into dollar cost. Finally, the extent of externalities is not clear because it is hard to decide the number of people affected by one specific pollution source. It depends on various factors. Given this situation, the ‘best pollution level’ is usually decided by some authority, such as an environmental protection agency, especially for the overall goal.

To summarize, the goal of environmental policy is to eliminate externalities so that polluters will take account of social costs in their pollution emission behaviour. Otherwise, the “best pollution level” cannot be achieved. Different environmental policy tools have different approaches of forcing polluters to emit at their best pollution levels. They can be classified into several categories based on their approaches from the economic point of view, which is introduced in the following section.

2.3 Environmental Policies Classification

Classification of environmental policy tools is discussed in this section. The economic classification based on regulatory methods is introduced to assess the performance of policy tools' based on economic theory. Their mechanisms, such as how they find the best pollution level and how they force polluters to get their best pollution levels, are explained. The designation and assessment framework is based on the economic perspective discussed earlier.

In addition, two environmental policy tool classification schemes as operational policy designation guides are presented and reclassified based on the neo-classical economic framework. The traditional way of assessing environmental policies is also reclassified under the economic framework as well. Discussion shows that the economic framework can be used as a foundation for interpreting, designing, and assessing various environmental policy tools to fix environmental problems. This also implies that it is possible to design a decision support system for the selection and assessment of environmental policy tools. Environmental goals and the way of achieving them can be found out scientifically.

2.3.1 Classification

Environmental policies typically combine the identification of a goal with some means to achieve that goal (Stavins, 2001). There are various classification methods for environmental policy tools. They can be divided into four classes based on a policy's method and its effect on the environment, namely, direct regulation or indirect regulation and CAC or EI, (Table 2.1) (Blackman and Harrington, 1999). Whether an environmental policy is CAC or EI is judged by the way it forces polluters to emit pollution at the best pollution level. Traditionally CAC instruments were pervasive since instruments were merely concerned with protecting the environment regardless of economic efficiency. Specific standards were set without allowing any freedom to individual polluters. Polluters were forced to obey these standards and were given no other choices or incentive to improve. In this case, government mandates the 'best' pollution level for every polluter. In contrast, EI policies create financial incentives for abatement but do not dictate individual polluter's actions. The best pollution level in the context of the mechanism can be found by polluters automatically. In other words, CAC is a planning method, and EI is a market method. Direct environmental instruments have specific environmental goals, such as pollution emissions volume and density, while indirect instruments regulate pollution-related factors, such as production techniques and final production targets. Because this classification scheme conceptualizes policy from an economic point of view, it can be called an "economic classification scheme".

	Direct Instruments	**Indirect Instruments**
Economic Incentives	• Emission fees • Marketable permits	Environmental taxes
Command and Control	Emissions standards	Technology standards

Table 2.1: Environmental Policy Instruments Classification (Blackman and Harrington, 1999)

In addition to this classification, there is another kind of instrument so called market barrier reductions, which can also be seen as an EI form of policy (World Bank, 1997). But unlike EI instruments, market barrier reductions increase economic efficiency not by creating incentives but by lowering transaction costs. They conform with the idea of the "Coase Theorem" believing that externalities can be removed automatically with clear property rights and a fully informed environment. Three types of market barrier reductions stand out (Table 2.3) normally, (1) market creation, as with measures that facilitate the voluntary exchange of water rights and thus promote more efficient allocation and use of scarce water supplies, (2) liability rules that encourage firms to consider the potential environmental damages of their decisions, and (3) information programs, such as energy-efficiency product labeling requirements. In this thesis market barrier reduction instruments are not considered because they can be regarded as a critical complementary part of an EI instrument. When an EI instrument is implemented, the market barrier reduction method should be run at the same time. This is especially true for developing countries which do not have a full market mechanism. This will be discussed in chapter 5.3 on migrating an emissions trading program to China.

There are two authority classification schemes that many environmental policy makers reference in designation and implementation. One produced by the US Congress has twelve classes, as shown in Table 2.2 (US Congress, 1995). The other was drafted by the United Nations (UN) for sustainable development (Table 2.3). These two schemes are reclassified under the framework in Table 2.1 for economic assessment and discussed in terms of their differences to show that the economic classification schema is compatible with others. This compatibility is important if the goal is to use an economic framework to design, assess, and optimize environmental policies to realize sustainable development.

Tools That Directly Limit Pollution				Tools That Do Not Directly Limit Pollution	
Single-Source Tools		Multi-source Tools			
Harm-Based Standards	Describe Required end results, leaving regulated entities free to choose compliance methods	**Integrated Permitting**	Incorporates multiple requirements into a single permit, rather than having a permit for each individual emissions source at a facility.	**Pollution Charges**	Require regulated entity to pay fixed dollar amount for each unit of pollution emitted or disposed; no ceiling on emissions.
Design Standards	Describe required emissions limits based on what a model technology might achieve; sources used the model technology or demonstrate that another approach achieve equivalent results	**Trackable Emissions**	Allow regulated entities to trade emission control responsibilities among themselves, provided there is an aggregate regulatory cap on emissions	**Liability**	Requires entities causing pollution that adversely affects others to compensate those harmed to the extent of the damage.
				Information Reporting	Requires entities to report publicly emissions or product information
Technology Specifications	Specify the technology or technique a source must use to control its pollution	**Challenge Regulations**	Give target group of sources responsibility for designing and implementing a program to achieve a target goal, with a government-imposed program or sanction if goal is unmet by the deadline.	**Subsidies**	Provide financial assistance to entities, either from government or private organizations.
Product Bans and Limitations	Ban or restrict manufacture, distribution, use or disposal of products that present unreasonable risks.			**Technical Assistance**	Provides additional knowledge to entities regarding consequences of their actions, and what techniques or tools reduce those consequences.

Table 2.2: Brief definition of Environmental Policy Tools (US Congress, 1995)

The classification designed by the US Congress is based on whether a policy has specific environmental goals and whether the way of achieving this goal is specified. It can be converted into the former classification scheme (Table 2.1). Single-source tools specify a uniform standard for all polluters and as such, they are CAC methods. Multi-source tools can be roughly classified as EI instruments because all of them set only aggregate targets, allowing polluters to manage how to achieve these targets. Integrated permitting is the prototype of emissions trading programs and can be regarded as a transition instrument. It allows corporations to allocate their pollution reduction credit to any facility to lower their compliance cost. This is explained in detail later in the historical review on emissions trading programs. Although trading doesn't really happen under this regulation, transactions are not rare because corporations have the economic incentive to reduce pollution in facilities having lower compliance costs in order to save credits for those facilities with higher compliance costs.

Trackable emissions are emissions trading programs with a cap-and-trade mechanism that is the focus of this thesis, and will be discussed later. Challenge regulations are similar to integrated permitting with the only difference that, in contrast to setting permit caps, they specify aggregate pollution cutting credits. Subsides and technical assistance are EI instruments since they give polluters direct or indirect financial assistance on pollution reduction. However, they are not typical EI instruments for the following reasons: 1) They are complementary instruments for a CAC system to help polluters meet those standards, which cannot be implemented independently. 2) The financial incentive they create does not necessarily conform with economic principles. 3) They encourage polluters to emit at a specified environmental level instead of an individual best pollution level. For these reasons, they will not be discussed in detail later.

Pollution charge is another CAC instrument, given that a charge for pollution is fixed regardless of a polluter's emission. This gives no incentive for pollution reduction. Information reporting is hard to convert under the classification schema from an economic point of view. It has multiple functions, such as promoting public participation, monitoring policy's effectiveness, and lowering market conflicts. Since markets cannot perform on highest efficiency without fully informed participants, it can be regarded as a market barrier reduction instrument that is classified as a critical part for all EI methods. Finally, liability cannot be converted into the classification scheme. This is more a legislative issue than a political one.

Since it is extremely hard, if not impossible, to know the risk of introducing unknown environmental problems when adopting new technologies, an 'exceptional' clause should be established to make sure someone will take responsibility when an emergency occurs. It forces corporations to conduct risk assessments that are different from known damage calculations and favorite precautionary choices.

The classification scheme designed by the UN takes a broad view on environmental policies given that not all countries have a well-established market mechanism and legislation system in place. It is therefore easier to convert their items to an economic classification scheme. Policies under "using markets" and "creating markets" are EI instruments. Using environmental regulations are obviously CAC methods. Engaging the public is somewhat independent since it can be used with the combination of both CAC and EI instrument. However, it is more likely to be an EI method because it provides better market signals.

	Policy Instruments			
Themes	**Using Markets**	**Creating Markets**	**Using Environmental Regulations**	**Engaging the public**
Resource Management and Pollution Control	• Subsidy reduction • Environmental taxes • User fees • Deposit-refund systems • Targeted subsidies	• Property rights/ decentralization • Tradable permits/rights • International offset systems	• Standards • Bans • Permits and quotas	• Public participation • Information disclosure

Table 2.3: The policy matrix: policy instruments for sustainable development (World Bank, 1997)

In the following sections, an environmental policy assessment framework is introduced that subscribes to the economic point of view. Every kind of environmental policy instrument from economic classification scheme is explained.

2.3.2 An Assessment of Environmental Policy Tools

Since there are different kinds of environmental policy instruments, choosing the best one under certain circumstances is the most important issue for the policy-maker. There are three main criteria for evaluating environmental policies: environmental quality improvement, compliance cost and fairness, and flexibility for adoption and dissemination of environmental friendly technology (U.S. Congress, 1995). An "ideal environmental policy" should improve environmental quality as quickly as possible while minimizing compliance costs, providing a fair allocation of costs across all polluters, and encouraging speedy adoption of environmentally friendly technology. Environmentally friendly technologies can also be assessed in terms of their environmental improvement effect and cost. Thus the basic criteria underlying environmental policy assessment are environmental improvement effect and compliance costs, which can be measured in terms of economics.

Environmental evaluation aims at assessing the social value of changes in the quantity and quality of environmental commodities, so as to provide a tool for a trade-off between choice alternatives with different environmental and economic impacts (Nijkamp, 1980). In environmental policy assessment, these alternatives comprise different policy tools that may be used to reach some environmental goal. Because many environmental policies have specific environmental goals, the assessment seeks to find the policy tool that has minimum compliance cost.

Environmental policy assessment is a kind of Strategic Environmental Assessment (SEA), which is a systematic, comprehensive process of evaluating the environmental effects of a policy, plan or program and its alternatives (Environment Canada, 2000). SEA must be part of the total analysis, including socioeconomic, political, and technical considerations to validate the proposed policy. SEA serves to bring together, towards mutually satisfactory goals, a diverse expertise within and outside of the originating branch, service or department. The overriding objective is to improve policy and program decision making. Environmental policy assessment based on the economics framework, as a subset of SEA, can be expressed in SEA's 6 key steps in the following:

1. Study approach: environmental economics analysis framework
2. Possible options for the policy, plan or program: listed environmental policy instruments
3. Likely environmental effects of each viable option: different performances for the same program

4. What can be done to mitigate the negative effects and enhance the positive effects: to identify factors and ways of optimization
5. Potential environmental effects which remain after mitigation: risk assessment and rescue mechanism
6. Results of the analysis. Environmental policy tools selection and factors setting for policy designation

In addition to the two basic criteria of environmental improvement and compliance costs, other factors that contribute to policy effectiveness include: minimizing demands on government, using pollution prevention whenever possible, being adaptable to change and encouraging technology innovation and diffusion (U.S. Congress, 1995). Preventing pollution is the ideal solution, because the cost of pollution is far less than the cost of remediation. There must be some way to ensure that environmental policy is practical and that its performance is accurately monitored. This is a key point in environmental policy assessment. Minimizing demands on government is a requirement because they can be also regarded as a kind of compliance cost. Policies with very high demands on government are not good even if they have low compliance costs from the perspective of the polluter.

In environmental policy assessment, there are three main problems. The first is the difficulty of quantitatively linking emissions with harm, which often prevents us from relying on instruments that are explicitly risk based. The second is the inability to adequately monitor emissions, which restricts our ability to rely on performance-based approaches, even when we know the level of performance we wish to specify. The last is the lack of sufficient empirical evidence about the strengths and weaknesses of many of these instruments. This thesis seeks to solve part of above problems.

Since environmental policy assessment is an interdisciplinary study, there are several disciplines underlying it (Nijkamp, 1980):

1. physical principles accruing from the materials balance model (and thermodynamics);
2. ecological principles accruing from a systems approach;
3. jurisdictional principles associated with the property of goods;

4. socio-psychological principles emerging from social choice theory;
5. social principles related to the social carrying capacity of our society;
6. operational research principles emerging from mathematical decision theory;
7. spatial-geographical principles resulting from the existence of physical space; and
8. mathematical principle from applied non-linear mathematics.

As shown in later chapters, geographical character plays an important role in environmental policy analysis in so far as space is a medium through which actions and externalities can be transferred, while it is at the same time a constraint on further growth of many activities. However, unfortunately, geography is a field that is overlooked by many researchers. Establishing a geographical analysis methodology for environmental policy analysis is in process. Furthermore, since it is one of the essential parts of conducting environmental policy assessment, methods of integrating geographic factors into the economic framework must be found. Otherwise using an economics framework to design and optimize environmental policies is potentially unsafe and not really a scientific approach

2.3.3 Command and Control Methods (Environmental Standard and Technical Standard)

CAC instruments have the longest history of implementation to solve environmental problems. However, CAC systems give little consideration to economic issues, such as compliance costs and local development. They will be explained in the following paragraphs from an economics perspective. The way of improving CAC methods performance is implied based on this explanation.

CAC regulations specify uniform standards for all polluters regardless of their individual characteristics. There are two kinds of CAC tools, namely technology- and performance-based standards that focus on compliance cost and social benefit respectively. Social benefit is the social gain from pollution abatement. It is the counterpart of the social cost of pollution.

Performance-based standards are the oldest form of environmental regulation. They set specific environmental goals for individual polluters homogeneously. Since these standards reflect tolerance of human beings and ecosystems on certain pollutants, they indicate social benefits. Different performance-based standards may be developed for different regions, reflecting differences in social penalties. For example, China has the concept of an ‘Environmental Functional Zone’ to represent variation in social costs of pollution across different regions. Level I applies to polluters in high population density urban areas and is much stricter than Level III that applies to low density rural areas. Because the number of people affected and the self-cleaning ability of the environment are different, the social costs of pollution are not the same in these two types of region.

Sometimes, performance-based standards incorporate compliance costs in some way. This is somewhat similar to technology-based standards. Due to the outdated techniques used by older producers, which often have higher pollution emissions and abatement costs, environmental standards may be usually looser than new on procedure producers. Nevertheless, performance-based standards mainly focus on the social costs of pollution and represent different social costs using different levels of standards. This is the original environmental standard approach. However, this approach to represent social cost is limited because performance-based standards lack flexibility in differentiating social costs quickly and automatically.

Technology-based standards specify the pollution reduction methods or producing processes and equipment that polluters must adopt to lower pollution levels, while avoiding risks associated with using new untested techniques. Since technology-based standards lead to a uniform pollution processing technique, they make polluters have similar compliance cost functions according to their production scales. The main technology standards have content standards based on many criteria such as fuel, input material, and production scale.

Theoretically, performance-based standards represent MSB, while technology-based standards stand for MAC. If they cooperate well, polluters will be forced to the “best pollution level” specified by these standards. However, there are several problems preventing this from happening. Setting standards and modifying them regularly imposes a heavy burden on the government. To make standards consistent and reflect technological change quickly requires much research, the cost of which may be more than the government is willing to pay. Standards lack the flexibility of encouraging polluters to emit at "best pollution level" under changing circumstances. They are always incomplete and cannot cooperate seamlessly. For example, if all electricity generators with the same production capacity have the same emission standard, and no technology-based standards exist, compliance costs will be much higher than at the "best pollution level". This is because polluters with different technologies have different MACs. For example, the cost of natural gas burning generator is much lower than coal-burning generator. However, it is usually higher than EI methods, as some case studies have shown. One survey of eight empirical studies of air pollution control found that the ratio of actual, aggregate costs of the CAC approach to the aggregate costs of least-cost benchmarks ranged from 1.07 for sulfate emissions in the Los Angeles area to 22.0 for hydrocarbon emissions at all domestic DuPont plants (Stavins, 2001, Tietenberg, 1985).

Due to these shortcomings, governments gradually changed to using EI regulations in environmental policy. In theory, if properly designed and implemented, EI instruments allow any desired level of pollution cleanup to be realized at the lowest possible overall cost to society by providing incentives for pollution reductions by firms that can achieve these reductions cheaply (Stavins, 1998a). In the simplest models, EI methods are symmetric, but that symmetry begins to break down in actual implementation. Since all of these tools have their own character, each is best for certain circumstances.

2.3.4 EI Methods

2.3.4.1 Emission Fees

Emission fees implement the "polluter makes remediation" principle in environmental management. Fees are charged for the entire pollution volume or that part of it that exceeds current environmental standards. Emission fees have been implemented in many countries. From an economics perspective, an emissions fee is the traditional Pigouvian Tax that sets the tax rate based on the social cost for pollution, presuming that it is a function of emission volume (Baumol and Oates, 1975). Under an emission fee system, polluters choose the emission volume that they will emit. Polluters will emit at the “best pollution level” automatically for the sake of their minimum compliance costs with the consideration of both their MACs and emission fees.

The emission fee system is better than the CAC method for the following reasons, according to the OTA framework. First, because polluters are charged fees based on the social cost of their pollution, they are free to choose the pollution processing technology they will use to reach ‘best pollution level’. With this flexibility, their compliance cost is often lower than under the CAC system. Second, demands on the government are lower since there is no need for establishing technology-based standards that take account of polluters’ marginal compliance costs. Third, polluters get incentives to adopt more environmentally friend technology to lower pollution emissions, which conforms to the principle of ‘use pollution prevention when possible’. Lastly, adopting the emission fee system with the established CAC system is easier than any other kinds of environmental policy tools.

Emission fee systems get relatively good results in environmental protection. But the results vary greatly in different countries. In Western Europe, especially in Sweden, it is very effective. However, in developing countries, such as China, the result is not very good. Part of the reason is that China charges emission fees only on the pollution volume that exceeds environmental standards. Since the fees are lower than pollution processing costs, polluters prefer to submit fees instead of processing pollution. This situation is common in developing countries that lack well established administration agencies, legislation systems, and accurate monitoring networks (Blackman and Harrington, 1999).

Emission fee systems have the following drawbacks. First, these systems require accurate pollution monitoring methods so that fees could be attached directly to the polluting activities, not to some related outputs or inputs. Assuming some substitutions exist among inputs in production, the Pigouvian tax would take the form of a levy per unit of waste emissions into the environment - not a tax on units of the firm's output or an input (Blackman and Harrington, 1999). Further, emission fees introduce the problem of how to set fees properly. Ideally, fees should be consistent with the marginal social cost function based on the emission volume.

But this function might be too complex to be used as a charging rule in practice. Constitutional factors also play an important role in fee rate setting, such as whether the national or local government takes this responsibility, and whether an independent interstate administration department should be established for the sake of watershed pollution management.

An environmental tax is another kind of tax that is charged to users instead of polluters. The difference between the emission fee and environmental tax systems is that emission fees have a direct economic incentive on pollution processing, while an environmental tax is integrated with other kinds of commodity taxes with only an indirect effect on environmental protection. There are three kinds of taxes: taxes on final products, taxes on input substances, and taxes on pollution ingredients. Taxes on pollution ingredients are similar to the emission fee system; taxes on input substances can be regarded as the combination of emission fees and technology-based standards; and tax on final products is most distinct as a kind of commodity tax.

Another distinction is that emission fees are based on microeconomics theory that focuses individual polluter’s behaviour and the associated social costs. This approach needs more information than macroeconomics methods. Another requirement of the emission fee system is that it is easy to identify who is responsible for the pollution. By contrast, environmental tax uses the tax rate, a typical microeconomics policy instrument, to protect the environment. It needs less information and demands on government because the tax system is well established internationally from a “constitutional” perspective. It is also tolerant of imprecision. Blackman and Harrington (1999) conclude that the dominant impact of an environmental tax is likely to be fiscal in the short run and environmental in the long run. Since tax is based on a commodity, implementing an environmental tax is very easy. Instead of setting the “best pollution volume”, it could be just based on the commodity’s demand elasticity. If its elasticity is high, which means buyers are very sensitive to price variation, it tends to benefit the environment more because consumers will transfer to other alternative commodities. If its elasticity is low, the fiscal benefit is greater because consumers have to pay more money for the commodity (Blackman and Harrington, 1999).

Environmental taxes are popular in North Europe. However, according to Stavin (1998), the MAC is high and the result is not very good. More importantly, it raises the problem of fairness and justice. Since taxes are charged to all people, lower income people get differentially impacted because of the higher portion of the tax to their income if the amounts of consumption are about the same to everyone. It may exaggerate the problem of a "great difference between rich man and poor man" (Stavins, 1998). Hence, it is hard to apply in developing countries with high welfare contrasts. A high environmental tax might even trigger social turbulence.

2.3.4.2 Emissions Trading System

Emissions trading instruments set an aggregate emission cap on a certain pollutant in a given industry or region, and allow individual polluters to exchange emission permits with each other or save permits for future use. It is a kind of microeconomics environmental policy tool that only considers annual aggregate emissions. This means that government allocates aggregate emission volumes based on average social costs and compliance costs. In practice, because of the difficulty in estimating costs accurately, an annual allocation is settled coarsely and a "banking" mechanism, which transfers emission allocations temporally, is used to approach the best pollution level.

Operationally, the process is as follows. Initially the government allocates emission permits to individual polluters every year by some allocation model or auction. Polluters can use their permits, sell excess allocations to others ("spatial trading"), or save permits for future use ("temporal trading"). The only restrictions are that polluters cannot exceed the cap or borrow from future allocations. If a polluter exceeds its allocations, a very high sanction, much higher than the pollution processing cost, will be charged to make this action unwise.

Essentially, the emissions trading system regards emissions as a kind of resource, like fiscal resources, human resources, and natural resources. The externalities problem is internalized in this way. The market itself can solve pollution problems efficiently and automatically. Similar to technology standard in CAC instruments, it equalizes firms' marginal compliance costs. Dales (1968) demonstrated that, in theory, an emission-trading system with cap-and-trade mechanism would induce rational firms to reduce pollution at the least possible cost (Dales, 1968). Furthermore, if permits were allocated to exactly equate marginal cost among facilities, cost effectiveness would be achieved without any trading. However, since there are too many factors to be accounted for to make this allocation model possible, trading is critical to the success of this approach.

After aggregate allocation is set, initial emissions allocations can be conducted by auction or allocation models. Since there is no perfect model, auction has the highest efficiency (Goulder, *et al.*, 1998). Its effect is similar to trading for lowering compliance cost. The key feature of this policy is that it allows polluters to use trading and banking mechanisms to lower their compliance costs. Each source's marginal costs of pollution control are the marginal cost for that source instead of the aggregate cost under the CAC system. If these marginal costs of control are not equal across sources, trading among them can achieve the same aggregate level of pollution control at a lower overall cost. Trading reallocates permits so that low-cost controllers control more of their pollution, and high-cost controllers control proportionately less. Additional savings could theoretically be achieved through such reallocations until marginal costs are identical for all sources (Baumol and Oates, 1988). For example, to consider a very simple system that only has two polluters, the environmental goal is to reduce SO_2 emissions by 2 tons. The marginal abatement cost is $400 for polluter A and $1200 for polluter B. Using traditional command and control policy, each polluter would be required to cut 1 ton of emissions, resulting in an aggregate compliance cost of $400 + $1200 = $1600. Using allowance trading policy, the better solution is for polluter A to reduce its emissions by 2 tons and to sell its 1 ton emission permit to polluter B for say, $800. In fact, the price could be any price less than $1200 and greater than $400. Polluter B will be happy to buy it because this saves it $1200 - $800 = $400. The compliance cost of polluter A is $400 - $400 (from B) = $0 and the compliance cost of polluter B is $800. The aggregate cost will be $0 + $800 = $800, which is only half the cost occurred in the CAC system. Although this example is simplistic, it shows how the emissions trading program works to lower the overall compliance cost.

The emissions trading system has many merits. It requires less information and places lower demands on government. Aggregate annual emission caps can be calculated with statistical information on social costs and compliance costs. Banking can be used for accommodating uncertainty. Like other EI methods, it is adaptable to environmentally friendly technology innovation and dissemination. Competition among input markets and suppliers of abatement technology can lead to technical innovation among the various abatement options, resulting in quick adaptation of environmental innovation reducing compliance cost. Furthermore, banking builds confidence in polluters by showing government's determination on implementing this policy. With a Continuous Environment Monitoring (CEM) system and high over-cap sanctions, it assures the public that environmental goals will be achieved. Lastly, as a fully market instrument, it creates a new market and is easy to be integrated into other market exchange places, such as to sell as a kind of future or option.

Although the emissions trading system has merit and great potential for reaching sustainable development, it also has some drawbacks as well. It is restricted to direct CEM monitoring methods. Alternative methods, such as estimating emissions as a function of equipment or by subtracting other outputs from inputs, will lead to ineffective implementation. There are several reasons for this. Since fees are directly tied to a polluter's emissions, the polluter is more sensitive to uncertainties and unfairness that are bound to second-best monitoring methods. For example, if the government uses emissions factor methods to monitor an electric generator's SO_2 emission per kilowatt hour by its type of coal burning, this generator will have no incentive for any other environmental innovations but fuel switch. If measurement is not credible and consistent, trading will decrease greatly because of the imprecise emission volume the polluters have. All in all, because second-best monitoring methods have greater uncertainty and are not as creditable as CEM, emissions trading (as well as the emission fee system) regulations require more creditable and fair environmental monitoring methods. Additionally, an emissions trading system is incompatible with other environmental policy instruments, such as the CAC system, which will lower its efficiency and increase the compliance costs due to trading prevention. It has been proved that emission fees, or other kinds of environmental taxes, are a source of lowering efficiency if an emissions trading instrument is combined with second best methods. Trading should not be burdened in order to maximize performance. Thus, adopting emissions trading policy needs more time and effort than other environmental policy instruments to adapt to abandon other parallel instruments.

Given that emissions fees and emissions trading are the two main EI instruments implemented world-wide, they are compared in the following aspects. First, emissions trading fixes the level of pollution control while emissions fees fixes the costs of pollution control. Second, with trading systems as typically adopted, resource transfers are private-to-private, while they are private-to-public with ordinary emissions fees. Third, emissions trading adjusts for inflation automatically, while some types of emissions fees do not. Fourth, emissions trading instruments may be more susceptible to strategic behaviour. Fifth, significant transaction costs can drive up the total costs of compliance, having a negative effect under either system, but particularly with tradable permits. Finally, in the presence of uncertainty, both instruments can be more efficient, depending upon the relative slopes of the marginal benefit and marginal cost functions and any correlation between them (Stavins, 2001).

2.4 Emissions Trading Program Case Studies

Since the ARP implementing emissions trading is the focus of this thesis, it is discussed in more detail in this section. However, former programs implementing emissions trading tools are also studied to estimate the performance of emissions trading instruments. Economics literature on these programs is summarized to find the environmental economic framework. Factors affecting the result of these programs are also identified for future program design using emissions trading tools.

2.4.1 History of Emissions Trading Program

Emissions trading instruments are a popular EI method to address many environmental problems. There is a considerable history of local governments in the United States using transferable permits to balance some of the attributes and amenities ordinarily addressed by zoning provisions with the demands of economic growth and change (Stavins, 1998a). However, the ARP is the first large-scale program implementing emissions trading nationally.

2.4.1.1 Emissions Trading Program (ETP) and Leading Program

The oldest emissions trading program is the Emissions Trading Program (ETP) introduced in 1974. Its original purpose was to solve the dilemma between the need for new factories and strict environmental standards that forbid building any new factories in regulated regions. The program attempted to improve local air quality through the control of Volatile Organic Compounds (VOC), carbon monoxide (CO), SO_2, particulates, and NO_x. To accommodate economic growth within a CAC system, the EPA allowed new pollution sources to be built in non-attainment zones where they were not allowed under the CAC system if they met the requirement of reducing pollution from existing factories elsewhere by an equivalent amount. This policy can be seen as a kind of trading. Further “credit” trading among polluters under an “offset program” was initiated in 1977. In 1986, trading was formalized into three kinds of transactions, so called “netting”, “bubbles”, and “banking”. Netting means to transfer emission permits from established firms to new factories to avoid strict new source regulations. Bubbles, launched in 1979, regard many sources as one, imposing aggregate pollution requirements on the bubble and ignoring emissions exchanges among sources within the bubble. Banking, also launched in 1979, permits firms to save emissions reduction credits that exceed current requirements for future use. Although this program was limited, trading happens all the time. It has been implemented at the state-level in many states, such as California, Colorado, Georgia, Illinois, Louisiana, and New York (Blackman and Harrington, 1999).

At the same time, credit trading instruments were used for lead reduction in refineries. In 1985, the EPA initiated a program allowing refineries to bank lead credits, and subsequently, firms made extensive use of this option. In each year of the program, more than 60 percent of the lead added to gasoline was associated with traded lead credits, until the program was terminated at the end of 1987, when the lead phase down was completed (Hahn and Hester, 1989). It was clearly successful in meeting its environmental targets, although it may have produced some (temporary) geographic shifts in use patterns (Anderson, et al., 1990).

These policies are the prototypes for emissions trading. However, their performance was not as good as expected. According to Blackman and Harrington (1999), there were five reasons for this: A) expectations were too high, B) strict established environmental standards prevented some exchanges that would have happened under pure allowance trading, C) there were so few permits available for trading that the exchange cost exceeded the market value of the emissions reductions credits, D) the information for the permits market was limited, this violates the assumption of prefect market information to make the allocation efficient, and E) firms had a pessimistic point of view on this regulation. Many thought this regulation would be canceled. Thus, they were not willing to enter this market. Learning from this policy experiment, the EPA considered using allowance trading to replace former regulations, not just graft on them.

Program	Traded Commodity	Period of Operation	Environmental and Economic Effects
Emissions Trading Program	Criteria air pollutants under the Clean Air Act	1974-Present	Environmental performance unaffected; total savings of $5-12 billion
Lead Phasedown	Rights for lead in gasoline among refineries	1982-1987	More rapid phaseout of leaded gasoline; $250 million annual savings
Water Quality Trading	Point-nonpoint sources of nitrogen and phosphorous	1984-1986	No trading occurred, because ambient standards not binding
CFC Trading for Ozone Protection	Production rights for some CFCs, based on depletion potential	1987-present	Environmental targets achieved ahead of schedule; effect of this system is unclear
Acid Rain Reduction	SO_2 emission reduction credits; mainly among electric utilities	1995-present	Environmental targets achieved ahead of schedule; annual saving of 1 billion

Table 2.4: Major Federal Tradable Permits Systems

2.4.1.2 The ARP

The SO_2 emissions trading program was the first large-scale national EI program in the world. This program is based on the Title IV of 1990 Clean Air Act Amendments (1990 CAAA), intended to reduce SO_2 to half the level of emissions in 1980. It imposed an aggregate emission cap on SO_2 in the electricity generation industry. This program has two phases. In Phase I (from Jan. 1995 to Dec. 1999) aggregate emissions should not exceed 5.7 million tons of SO_2 for 110 of the most polluted power plants. In Phase II, beginning from Jan. 2000, a cap of 8.95 million tons per year, half of current emissions, was imposed for all existing generating units in the continental United States larger than 25 MW as well as for all new units of any size. If a polluter exceeds its permits, a penalty of $2,000 per ton of emissions will be applied. And the emissions volume that exceeds the cap has to be offset in the following year.

To assure its success, the EPA made many efforts. Unlike the ETP, there were no extra restrictions on trading based on environmental and economic benefits. All related environmental standards that might hamper trading were eliminated. The initial allocations were based on historical data from individual firms. To monitor emissions, the EPA asked all firms to install Continuous Emission Monitor (CEM) systems to make sure they did not exceed their allocations. The EPA also established a database called the Tracking and Assessment Framework (TAF) to record the exchanges that happened and their details under this program for further research on environmental policies.

This program's results were very good, even better than optimistic expectations (Figure 2.2). Firms included in this regulation emitted only 5.3 million tons of SO2 in 1995, while they had emitted 10.68 million tons in 1985. The EPA estimated that the program cut down 4.9 million tons of emission more than the former policy without this program. A robust market of bilateral SO2 permit trading has emerged, resulting in cost savings in the order of $1 billion annually, compared with the costs under some command-and-control regulatory alternatives (Carlson, et al., 2000). Although the program had low levels of trading in its early years, trading levels increased significantly over time (Anderson, et al., 1990, Burtraw and Mansur, 1999, Ellerman, et al., 2000, Schmalensee, et al., 1998, Stavins, 1998a).

This program has the best record of all environmental policy case studies. It reduced emissions of SO_2 by about 50%, better than the 30% reduction achieved in Sweden using an environmental tax. Furthermore, compliance costs were reported as $187 to $210 per ton of SO_2 removed, compared with estimates ranging from $180 to $307 (Ellerman, *et al.*, 2000). The SO_2 allowance price that reflects compliance cost has dropped from $300 per ton to $60 to $80 per ton in 1997 (Burtraw, 1998). According to Titenberg's research (1985), compliance cost of allowance trading is only 1/10 to 1/2 that of traditional CAC policies.

Figure 1

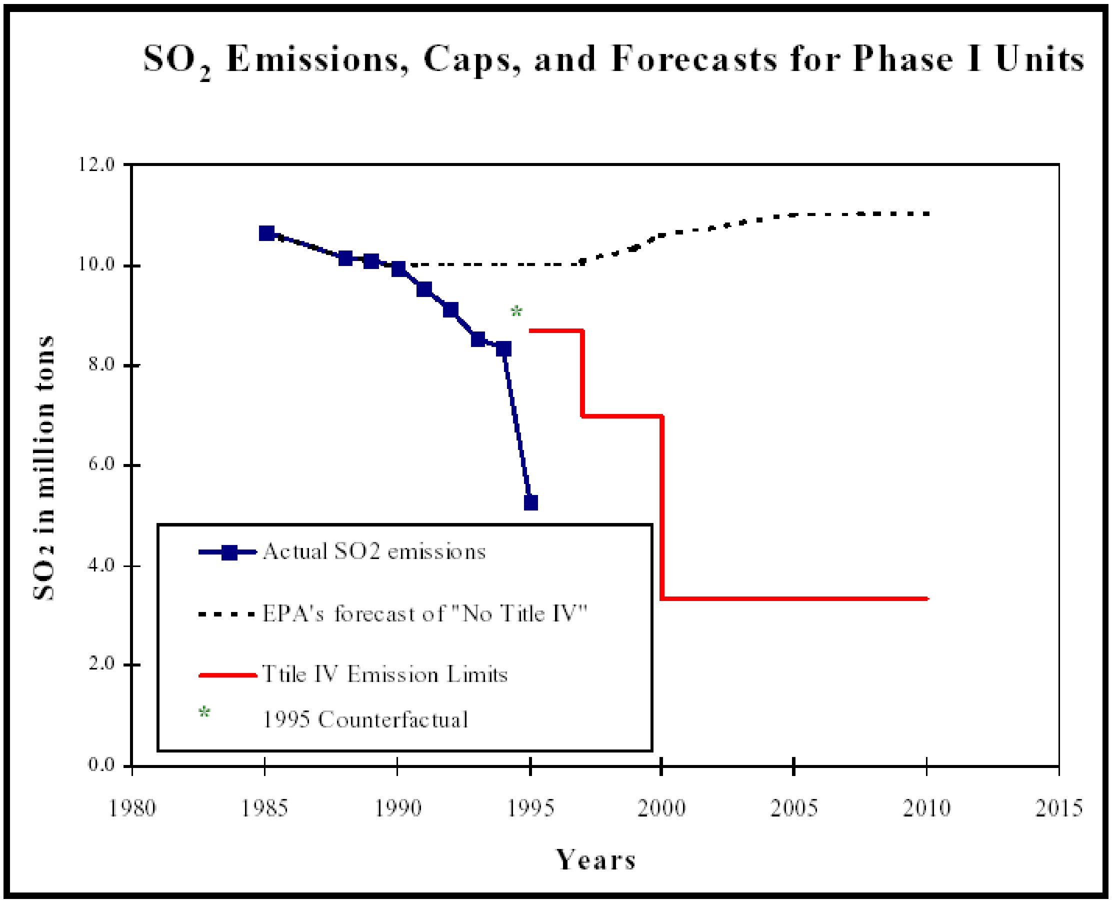


Figure 2.2: ARP result under Phase I (Pechan, 1995)

Due to the success of the ARP, many countries plan to adopt an emissions trading instrument for their environmental protection. For example, emissions trading systems for SO_2 and NO_x are becoming a new management tool in Canada. Ontario has led the way with the introduction of an emissions trading system for electric power generation and possibly for other key industry sectors, based on a mandatory cap-and-trade model, with the ability of other emitters to participate in the trading system on a voluntary basis by creating emissions credits from 2003. The United States has moved toward implementation of a regional trading program for rights to emit oxides of nitrogen, and the international community has endorsed, at least in principle, the use of international emissions trading to deal with the threat of global climate change. The details of this system are still being worked out for credit trading, but it is likely that a number of standards, certifications and accreditation mechanisms will be developed as the market for credits develops.

This thesis focuses on assessing this program to identify factors that make the ARP so successful. Suggestions on whether this success is transplantable and how to modify it to suit different environments are discussed at the end.

Researchers have suggested two main reasons for the success of the ARP (Blackman and Harrington, 1999). First, the ARP was designed to replace existing regulations, rather than being overlaid on as in ETP. Second, the use of CEMs provided accurate measurement of emissions, making regulation fairer and strengthening polluters' confidence in this program. Based on this explanation, supporters of the ARP have argued that in a fair play situation, market mechanisms provide the best way to solve environmental problems.

There are also many reasons that challenge the opinion that this good result is due to market mechanisms. Access to low sulphur coal caused by deregulation of the railroad system lowered compliance costs independent of the emissions trading policy. The same reduction in compliance costs would have occurred under the traditional CAC policy system. More importantly, since low sulphur coal is a non-renewable resource whose amount is limited in the relatively long term, switching to low sulphur coal is not sustainable. Second, it may lead to the problem of hot spots, which means one firm pollutes one region severely by buying a large volume of emission allocation via trading system. This might lead to negative environmental consequences; however, up to now, there is no evidence of this problem. Some optimists even claim that the hot spot problem can't happen. This phenomenon is further studied in the following chapters.

Furthermore, some researchers argue that the success of the ARP might not be transferable to other industries. Since the electricity generation industry is regionally monopolistic, market mechanisms may be inapplicable. Prices are regulated by local governments, so it is easy for the government to control and monitor the industry. This is one of the reasons that the EPA chose the electricity generation industry for implementing emissions trading. However,

However, since the electricity generation industry usually does not perform as a normal producer pursuing maximum profit. Declaring market mechanisms as the key features for the success of the ARP is doubtful.

In addition, the ARP set a cap for only one pollutant. What will happen when multi pollutants are included into one program is unclear. This lies in the following reasons:

a) Setting caps for multi pollutants introduces the proportion coordination problem between these pollutants. For example, burning a certain kind of coal produces 0.8 ton NO_x and 1 ton SO_2. If the caps for these two pollutants depart from this proportion greatly, polluters using this coal might not be able to make full use of their allocations except for the option of fuel-switch that increases compliance costs greatly. This is an important problem for setting annual caps and conducting initial allocations,

b) Pollutants usually interact with each other, which makes setting appropriate annual caps more difficult. If two pollutants mix together, there may be four kinds of interactions: non-interaction, simple adding, multiplying, and mitigation (He, et al., 1994). Their overall harm to the environment is most likely not equal to simple sum of individual expected harm. This is a very complicated problem involving environmental chemistry.

c) Production life cycles of polluters' products are not considered systematically because emissions trading usually concerns one pollution source with little consideration for the whole production consumption process. Electricity does not have this problem because its environmental impact after electricity is generated is negligible. However, not all products' environmental impacts can be overlooked after they are produced. Choosing the right industries for emissions trading is critical in this process.

In summary, although the results show emissions trading is an effective way of solving environmental problems, there are many issues that are not clear and require further research. Some pollutants have serious local effects plus awesome regional ones. This also adds complexitions beyond hot spots. Fortunately, Ontario will implement an emissions trading policy on both SO_2 and NO_x in the electricity generation industry, which makes the observation of pollution-interaction effects possible. Furthermore, China is going to use aggregate emissions control and emissions trading regionally, providing an opportunity to conduct research on potential hotspot problems.

Results of analyses of emission impacts have some important implications for policy. Economists have long argued that tradable emissions permits and emissions taxes are more cost-effective than performance standards, technology mandates, and other traditional forms of regulation (Cropper and Oates, 1992).

2.4.2 The ARP's Performance and Explanation

There are five perspectives for assessing the ARP's performance in the literature, namely, aggregate annual emission volume, permit price, SO_2 density and acid rain frequency, marginal compliance cost, and aggregate compliance cost (Table 2.5).

	Before implementation	**After implementation**
Annual Emission Volume	Around the level of 1980	Only half of 1980 emission level
Permit Price	Around 150	A litter greater than 150 with large variance
SO_2 Density in air	16 ~ 20 ug/m^3 (Northeast and Mid-West, 1990)	8~12 ug/m^3 (Northeast and Mid-West, 1990)
Average Compliance Cost	$ 300	$ 60 ~ 80 (1997)
Overall Compliance Cost	N/A	Saving 1 billion per year

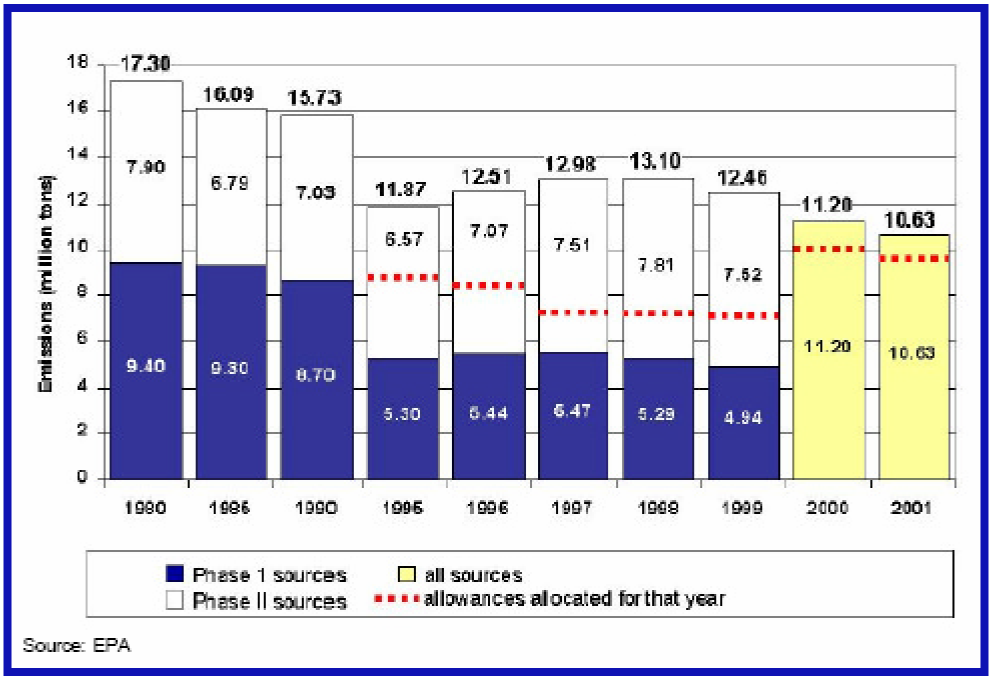
Table 2.5: Summary of data for assessing the ARP's performance

The ARP achieved great success given that annual emissions of SO_2 have been cut to 50% of original level in Phase I and wet sulfate deposition (acid rain) in the eastern United States fell by as much as 25% during Phase I (U.S. EPA, 2001a). Emissions had risen steadily before the new Clean Air Act requirements went into effect. The EPA credited this effectiveness to three factors, a sound compliance tracking system, high quality emissions monitoring systems at every source, and an expanded national dry deposition monitoring network to complement the nationwide wet deposition monitoring network (U.S. EPA, 2001a). These three factors made the permit market fair, which builds participant confidence. And the reasons leading to low permit price, which is seen as an indicator for the efficiency of the ARP, are summarized into nine under three categories in Table 2.6 (Burtraw, 1996). Another important mechanism assuring such good results is "banking". The bank represents a "win-win" outcome for the environment and for industry. The early reductions provide an opportunity for environmental recovery and improved public health at an earlier point in time than would occur otherwise, while the bank provides an opportunity for industry to lower its overall costs of compliance and the ability to ease into the more stringent Phase II (Bohi and Burtraw, 1997). Polluters still have incentives to lower emissions for future usage. This interpretation may also explain the apparent contradiction between ample anticipated trading and little real trading in that allowances are allocated on the basis of historic emissions without reference to cost.

Market Fundamentals: • Discounting of future costs. • Widespread availability of low sulphur coal. • Competition and innovation. • General equilibrium effects.
Regulatory Influences: • Sunk "uneconomic" investments in scrubbers. • Annual auction invites strategic under-bidding.
The Imagined versus Real Program: • Bonus allowances subsidies for scrubbing delay future costs. • Two phases of program segregate sellers and buyers. • Substitution and Compensation units delay future costs.

Table 2.6: Reasons for low allowance price (Burtraw, 1996)

But banking also has adverse effects. Emissions exceeded annual allocations by roughly 1 million tons each year after Phase II in 2000, as polluters began to draw down the bank. Emissions are expected to continue to be above the annual cap through the remainder of this decade as the cap gradually declines to roughly 9 million tons per year. However, because banked emission permits are finite and rely on great change of environmental technology to be accumulated, this is acceptable especially considering the indispensable impact of banking on confidence building at the beginning stage.



Source: EPA

Figure 2.3: SO_2 Emissions from Acid Rain Sources, 1980-2001 (U.S. EPA, 2001b)

Electricity producers have used two main options to lower pollution, including, scrubbers and fuel switches. Four factors contribute to the dramatic decrease in compliance costs: changes in the coal market, deregulation of rail transportation, innovations in fuel switch, and innovations in the scrubber market (Burtraw, 1996). High quality coal that has low sulphur content and high heat from the Powder River Basin (PRB) mainly in Wyoming became available at low cost for many other states. The lower costs were the result of costs for surface mining and great freight rate decreases following rail transportation deregulation. Fuel blending further lowered fuel switch costs because, generally, electric utilities were designed for a particular type of coal. Fuel switch has proven to be the most popular compliance option. Compliance costs based on scrubber technology also declined although not as much as fuel switch or blending. Under the ARP, utilities are allowed to use banking permits for excess emissions when scrubbers became inoperative instead of installing redundant scrubbers.

Cost-benefit analysis has also been conducted for ARP assessment. The results show that benefits outweigh costs (Burtraw, *et al.*, 1997). This study used the Tracking and Analysis Framework (TAF) developed for National Acid Precipitation Assessment Program (NAPAP) to assess benefits and costs, such as health effects, visibility, recreational lake fishing, and compliance cost, which is accepted widely. Based on parameters that TAF identified for social benefit measurement Burtraw (1997) proved that the ARP is beneficial. Parameters that were considered were reasonable in terms of social benefit calculation. This paper is important for finding an economic way of assessing environmental policy by conducting cost-benefit analysis. However, this paper only concerned human beings, overlooking acid rain's damages on ecosystems and biodiversity, which it means should be expanded in the future.

2.4.3 Potential Problems and Factors

The first problem of the ARP lies in the field of political economics. To protect working opportunity and the coal industry, nearly every state with substantial Phase I compliance obligations enacts legislation to promote the use of local coal (Bohi, 1994, Rose, 1995). This action will lower economic efficiency. It has even been argued that it increases compliance cost by 50% even though it is still much lower than before (Arimura, 2002).

Second, the method of initial permit allocation is another critical issue. It may have the same effect as a trading mechanism (Stavins, 1995). Provisions governing emissions allocations clearly show the effects of significant rent seeking by several different interest groups. Economically speaking, a domestic cap-and-trade system with homogeneous permits applied to control flows of fossil fuels "upstream" in the energy system, with permits auctioned periodically by the government, has the most appeal of different trading systems on efficiency and distributional grounds, though it may suffer politically because of its close resemblance to a carbon tax (Ellerman, *et al.*, 2000).

Third, emissions trading systems with tax will lower efficiency and reach to the "second best pollution level", which is apart from the 'best pollution level'. The presence of distortion taxes raises the costs of pollution abatement under each policy instrument relative to its costs in the first-best world without any pre-existing tax. The regulator's decision whether to auction or grandfather emissions rights can have equally important cost impacts (Goulder, *et al.*, 1998).

Fourth, the impact of external factors on the ARP cannot be neglected, such as institutional reformation and technology break-through. Since these kinds of factors are hard to copy, this is a critical debate on emissions trading system designation. As for the ARP, rail transportation plays an important role for the fuel switch or fuel blending option. It affects compliance behavior and cost of western utilities directly.

Fifth, the factors that limit trading and their impact on emissions trading should be identified. In ARP, State Public Utility Commissions (PUC) also play a role because they can set rules regulating trading behaviour. Their regulations and other state laws have an influence that has tended to undermine the efficiency of the SO_2 market, and if that is the case the effect can be significant. Uncertainty and PUC policies burden allowance purchases with depressing demand and willingness to pay for allowances. One study shows that, since PUCs in states with coal mines encourage local high sulphur coal usage for the sake of their local coal industry, high sulphur coal usage increased 50%. Further, the uncertainty of PUC regulations pushes utilities from the allowance market toward fuel switching/blending. Since the second effect was stronger than the first, the overall PUC regulations contributed to an unexpectedly low allowance price at the beginning of Phase I, which means PUC play a positive role in ARP (Arimura, 2002). However, whether it is also true in other circumstances is unclear.

Sixth, uncertainty is critical in the selection of all environmental policy instruments selection. It can even break the symmetry between the emissions fee system and emissions trading system (Stavins, 1995). In some cases environmental policy instrument selection depends on the relative steepness of the marginal benefit and cost curves if uncertainty concerning the costs of pollution control exists (Stavins, 1996, Weitzman, 1974). This is a very complicated issue, which is extended in Chapter 4.

Finally, emissions trading systems have the potential “hot spots problem”, which reflects the conflict between the regional character of pollution problem and trading rule’s spatial homogenous property. Individual polluters might buy so many permits and emit them in a short time causing severe regional pollution problem. In this case it seems that trading should be restricted to some extent. But, economically speaking, restricting trading regionally also leads to inefficiency. This is one of the reasons why there is not much literature on geographical analysis for the ARP. Given the fact that hot spots do not really happen in the ARP implementation, some optimists even acclaim this problem is impossible (Swift, 2000). Burtraw (2003) thinks that acid rain "hot spots" would result from the implicit, but incorrect, assumption embodied in a national trading program that SO_2 emissions anywhere in the country have the same expected environmental impact.

However, the argument above might not be correct. At first, one reason why hot spots do not happen in the ARP is that trading of SO_2 at the national level cannot lead to violation of local ambient air quality standards for SO_2 because sources must comply with local standards as well as with the national aggregate cap-and-trade program. In other words, restriction still exists even though it is not at national level. Thus, the claim of eliminating all environmental standards is a key factor for the success of the ARP is not completely true. Further, during the ARP implementation, the geographic shifts that resulted from trading during each year of Phase I show that seller and ultimate buyers of SO_2 allowances tend to be located within 200 miles of each other (U.S. EPA). This phenomenon made ARP step back to the "bubble" concept. Because the pollution level within 200 miles is about homogeneous, trading can hardly lead to a hot spot problem. Otherwise it will still happen at the "seller" point. At last, similar to regional environmental standards, social cost is not spatially homogenous. This spatial concept can be integrated into an economics framework. Social cost is able to be represented as a function of space just like the money exchange rate for different currency.

In the following chapter, several geographical analyses are conducted based on data provided by the U. S. EPA. The EPA's geographical analysis result is first validated independently. Then several statistics techniques are used to explore the spatial character of pollution for environmental policy optimization, especially for emissions trading instrument.

2.5 Summary

Based on the literature reviewed above, an economic framework is useful for environmental policy designation and assessment and compatible with former environmental policy systems and operational models. Better environmental policy-making is possible under this framework to realize sustainable development.

The ARP, as the first large scale EI method implementation conforming to economic principles, is proven to be successful in terms of its low compliance cost and high aggregate emission reduction rate. The emissions trading instrument implemented in this program has attracted many interests of adopting it into other environmental programs. Systematic studies identified initial allocation auction, banking mechanism, abandon of related former environmental standards, regulation on electricity generations, and railway reformation as factors that contribute to this program's success. All these findings are useful for further emissions trading programs designation.

Another specified aspect of the ARP is that, even though hot spots problems cannot be eliminated theoretically, there has been no real hot spot problem during the implementation of this program up to now. However, geographic analyses are needed because hot spots pare still possible. These analyses are conducted in the following chapter. In addition, geographic analyses are also a requirement for environmental policy assessment. Further, geographic analyses are done to examine this program's effectiveness and efficiency. The former is checked in terms of the changes of SO_2 spatial distribution patterns and status on growth and pollution abatement. The later is studied according to the dissemination of environmental processing technologies with lower compliance costs.

Chapter 3 Geographical Analysis Methodology

3.1 Overview

Most of the prescribed literature has studied the ARP from an economic perspective. This thesis seeks to analyze the impact of the ARP on SO_2 distribution in the US, assess its effectiveness and efficiency, and identify related factors geographically. Geographic analyses offer insights into this general objective as the implementation of the emissions trading policy has the risk of causing spatial “hot spots” problem. Furthermore, geographic analyses are one of the requirements of conducting environmental policy assessment (Nijkamp, 1980). Two criteria for assessing environmental policy are effectiveness and efficiency. Linking geographic analyses with these economic criteria is useful for improving the environmental policy assessment methodology. Therefore, effectiveness, efficiency, and the existence of hot spots of the ARP are the focus of the methodologies presented in this chapter.

The effectiveness of the ARP can be represented from a geographic perspective in two ways. The first is the spatial-temporal change of the SO_2 levels across the continental US. Given that the final goal of the ARP is to lower SO_2 levels in the US, the actual reduction rate of the SO_2 density can be used to judge the effectiveness of this program. If the SO_2 levels have not been lowered, the ARP can be regarded as ineffective. Since the ARP started in 1995, pollution levels in 1985, 1989, 1994, and 1999 can be compared and changes in these levels determined. If the pollution reduction rates became higher after 1995, it can be deduced that the program has been effective. The second way of judging the effectiveness of the ARP is to cluster data from different states in different years based on the two parameters of economic development and the pollution level. The ratio of gross economic production to pollution level can be used as an indicator representing the status of economic growth vs. pollution abatement. Higher values of this ratio indicate better sustainable development status. If the boundary of two groups identified using a clustering technique coincides with the implementation of the ARP, it can be deduced that this program has effective since it has changed the of economic development to pollution level. Geographic analyses for pollution level change detection and economic development and pollution level ratio clustering are therefore used to test the effectiveness of the ARP.

The efficiency of the ARP is tested with the compliance costs and flexibility. There are two main options to reduce their emissions: fuel-switching associated with importing high quality coal from the PRB region and scrubber installation removing SO_2 from exhaust emissions (Burtraw, 1996). Individual choices of pollution processing technologies can be predicted based on the assumption of rational producers seeking to minimize their compliance costs. Given that the compliance costs of fuel-switching, which are generally lower than scrubber installation, depend on coal freight rates relating to distance, they can vary geographically. Quicker low-price environmental technology dissemination means lower compliance costs and higher efficiency of an environmental policy. To investigate this, the service area of PRB coal can be identified and compared according to different freight rates relating to the efficiency improvement of the ARP.

The existence of hot spots, as discussed in the previous chapter, can be identified using the statistical technique of spatial autocorrelation. The hot spots problem is crucial not only because it may prevent an emissions trading policy from being implemented, but also because it shows whether environmental economic principles can be used to solve regional environmental problems without the use of spatial concepts. The hot spot problem links with the issue of whether trading should not be restricted spatially for the sake of economic efficiency. As noted above, spatial autocorrelation is used to explore the properties of SO_2 pollution and to identify possible hot spots. The global Moran’s I index is implemented to find whether there is spatial association for SO_2 pollution, indicating whether it is appropriate for homogeneous trading rules. Then a Local Index for Spatial Autocorrelation (LISA) is used to find the actual hot-spot locations.

Two supplementary tests are executed in order to validate whether the above geographic analyses. Since the original goal of the ARP is to reduce the aggregate SO_2 emission volume annually rather than concerning final SO_2 density in the US, there is an assumption that the electricity generating industry contributes most to the acid rain problem. A correlation test for the relationship between pollution levels and emissions should be done to see whether a positive correlation exists. This question is important because choosing an appropriate industry to regulate is one of the main factors affecting the performance of the emissions trading policies. On the other hand, the relationship between electricity production and gross economic production also needs to be tested to validate whether cutting electricity production is an option for polluters to reduce pollution volumes. This is also useful when addressing issues related to sustainable development. These two tests are for the preparation of an effectiveness study.

Hypotheses for testing are found based on above analyses as summarized in the following

Testing Question	Testing Item	Testing Technique	Testing Hypothesis
Effectiveness	SO_2 pollution level reduction	Change Detection for Cutting Rates	Cutting Rate is the same before and after implementation of the ARP (*)
	Ratio of GSP to pollution level	K-mean Clustering for GSP and pollution level	Border exists before and after implementation of the ARP
Efficiency	PRB Coal Supply for Fuel-Switch	Service Area Mapping in Network Analysis	Service area increases greatly before and after implementation of the ARP
Existence of Hot Spots	Global Spatial Autocorrelation	Moran's I Index	No global spatial autocorrelation exists (*)
	Local Spatial Autocorrelation	LISA	No local hot spot exists (*)
Supplemental Relationships Tests	Relationship between Pollution Level and Emissions	Correlation Index	No positive correlation exists (*)
	Relationship between Electricity Production and GSP	Correlation Index	No positive correlation exists (*)

Table 3.1: Geographic Analyses Hypotheses Summary (* means it is H_0 hypothesis for statistical test.)

In the following sections, the study area and data sources will be introduced first. Then data preprocessing steps, such as Kriging as the method to create SO_2 pollution surface, and correlation tests are explained. Methods for geographic analyses are described one by one at the end.

3.2 Study Area and Data Sets

3.2.1 Study Area

The study area used in this thesis is the continental US, which is under regulation of the ARP. This area covers 4000km from east to west and 2000km from north to south, where has been well developed and industrialized. Although the US is becoming less dependent on energy consumption by transferring its economy towards a more "service industry" one, its development depends heavily on electricity generation and consumption due to the trend of manufacturing electrification (U.S. Congress, 1990). In addition, the US has a well-established market-based economy with a strong legal and property system. All of these facts clear external market barriers to the emissions trading policy.

Because study area is so large, many geographic factors, such as climate, economics, industries, landscape, and population density, can vary greatly within this area. Hence, analyses are done mainly on the state level. The main reason for using the state level is that state is the sub-level of legislation and government unit in the US. From a socio-economic point of view, most states have several predominant industries and relatively uniform population densities. From a physical perspective, climatic conditions and elevation have relatively small variations within each state, which affect the dissemination of SO_2. Since there are few states whose radius is larger than 500km, SO_2 density is likely to be similar based on the Gaussian plume models that hace been used to evaluate point source pollution (Lu, 1999). Putting the potential hot spots problem aside, regulation areas can be expanded beyond the state level by combing several similar ones together. This is the way that EPA regulates the ARP. But since data are also available for the state level and have higher precision, state level analysis is legitimate.

Based on the socio-economic factors, physical and ecological factors, and data availability, state level is the study scale used for the geographic analyses. Various kinds of data can be converted and integrated on this level. Most information is preserved due to relatively low intrastate variations without losing the ability to address interstate problems, such as wind pattern. But higher resolution data on the county level might be better if the limitation of secondary spatial data does not exist, because the local hot spots problem can be studied with more approaches other than LISA indexes. State level study is possibly the best study scale according to the trade-off of different factors.

3.2.2 Data Sets

All spatial and attribute data used in this thesis are secondary data, mainly retrieved from different governmental departments via the Internet (Table 3.2).

All data discussed in Table 3.2 can be integrated together with some spatial and non-spatial database operations, such as select, join and spatial join, at the state level. However, the metadata for spatial data from the EPA are not very good as the datum and projection they used is not clear. Hence, location mismatches are possible in the adding data locations processes. Furthermore, the study area (continental United States) is too large to use projections for large-scale maps with high precision. Since the original data are in the format of longitude and latitude, the Albers Conical Equal Area projection was adopted to transform these spatial data into a planar form for distance measurement (ESRI, 2003). In addition, there are many elements of missing monitoring data to make precise predictions. For example, this problem is so serious that only one record for one monitoring point was found for the pollution levels in 1984, which made predicting the change in pollution levels between 1984 and 1989 impossible. Spatial data are preferred to be collected from one source because they might be different across different sources. For example, the boundary of the US is not the same between data from the EPA and from ESRI. ESRI’s was adopted in this case since the railroad network data are unavailable from the EPA data sources.

Institute	Theme	Source	Spatial Attribute	Time Range	Description
US EPA	Pollution Monitoring Data	Air Quality System (AQS)	Point Data	1982 - 2002	SO_2 density data from monitoring points
	Generation SO_2 Emissions	C-MAP: Clean air mapping and analysis program	Point Data	1988 - 1999	SO_2 emission volumes from all utility points
US Department of Energy (DoE)	Electricity Generation Capacity	EGRID program	Attribute	1995 - 1999	Detailed information for power plants
	Coal Price	Coal Data Publications	Attribute	2000	Classified data for coal price, location, and quality
ESRI	Railroad Network	US Data	Line	Unknown	Rail network on different levels
	State Boundary	US Data	Area	Unknown	State boundaries and names
US Statistics	Gross State Production (GSP)	Economic Data Publications	Attribute	1970 - 2002	In dollars
Resources for the Future (RFF)	Average Scrubber Compliance Cost	Report Paper (98-28-REV)	Attribute	1997	Summary of compliance costs in dollars
US Department of Transportation	Coal Freight	Freight Data Publications	Attribute	2000 & coarse historical data	In dollars

Table 3.2: Data Retrieving Sources

In terms of the attribute data associated with each of the feature layer, their qualities vary greatly due to their histories and the departments they extracted from. The data from the US DoE have high precision and detailed explanations. They are collected under the EGRID program and are easy to query and retrieve. But given that the EGRID program is brand new, combining them with other data to conduct analyses, such as correlation tests, is somewhat difficult. The coal price data are also good, and have been collected for a long period. But the detailed data, such as the unit price that each power plant paid for their coal, are only available for the year 2000. Two different kinds of network analyses were executed based on this difference, which will be further explained in section 3.3. The economic data from the US Statistics are good due to the long history and high maturity of this kind of data. They have the longest recorded history and are well-classified. But data from US Department of Transportation are not easy to use. They cannot be used directly and have to be converted using some formula with some knowledge of coal and transportation. This is similar to the case of the data from the US EPA. Due to the different sources of emission data and air quality data, they cannot be integrated easily. Furthermore, since the locations of monitoring network are recorded in a recent history and it might have been changed several times, joining the monitored data of SO_2 densities with monitoring points is difficult and even impossible in some instances. For instance, the output of joined data in 1985 has only one record, rendering creation of a pollution level surface impossible. The average compliance costs from the RFF are used because they are unavailable in other studies and these data from RFF are widely accepted.

To summarize, data needed for geographic analyses are relatively readily available in the US in contrast to developing countries. The US government has one of the best information collection and publication systems in the world. Although data precision, especially for the spatial data, is not necessarily very good, it is good enough for geographic analyses to be conducted in this thesis given that the units of analyses are very large, making the relative error rate relatively low. Since the analyses presented in this thesis are insensitive to uncertainty and tolerant to spatial errors of approximately 10km, which is derived from geostatistical analysis, retrieved data seem to be sufficient.

3.3 Analyses Preparation

3.3.1 Kriging

Kriging using ESRI's Geostatistical Analyst was adopted to predict the national SO_2 pollution level in raster format from the pollution data of monitoring points because some states have no monitoring points and the national SO_2 pollution level is useful in effectiveness assessment.

Three kinds of methodologies are available to explore spatially continuous data: a spatial moving average; methods based on a Triangulated Irregular Network (TIN) model; and kernel estimation (global trend) and covariogram and variogram (spatial autocorrelation) (Bailey and Gatrell, 1995). Kriging, which belongs to the last one, was selected because it considers not only the global trend like the other models, but also spatial autocorrelation as well. Spatial moving average method even excluded from the Geostatistical Analyst module since it only fits for a few simple linear cases. The TIN model cannot be used because monitoring point density is very low in some regions. This would make some triangles too angular and too large to produce an accurate surface.

The methodologies for kernel estimation and covariogram and variogram calculations are classified as deterministic methods, and include inverse distance weighted interpolation (IDW), global polynomial interpolation, local polynomial interpolation, and radial basis functions (RBF), and geostatistical techniques, including Kriging and co-Kriging methods (ESRI, 2001). Since deterministic models make the simple and possibly unrealistic assumption that there are only first-order effects involved in the surface predictions and no residual spatial dependence, a geostastisitcal technique is used to consider the effect of spatial autocorrelation (Bailey and Gatrell, 1995).

Since the Kriging methods rely on the notion of spatial autocorrelation, they first quantify spatial data structure, and then produce predictions surface based on this structure. To explore residual spatial dependencies, Kriging makes an assumption that all of the random errors have second-order stationarity, meaning that the random errors have zero mean and the covariance between any two random errors depends only on the distance and direction that separates them, not on their exact locations (ESRI, 2001). Therefore, deterministic models will be used first to remove the first order effects on the data (density variation). In fact, there is a conflict between the requirement of knowing spatial dependence for choosing an appropriate deterministic model to estimate a trend and the requirement of detrending spatial data for exploring the covariance structure. One possible way of overcoming this problem is by iterating the modeling of the covariance structure. This requires first detrending the data with a trial spatial dependence model first to get better residuals for re-estimating covariance structure, and then removing the trend with a better deterministic model, and so on so forth, until stability is achieved (Bailey and Gatrell, 1995). Given that ESRI's Geostatistical Analyst does not have this function, a proposal selection can be achieved by using the ordinary Kriging, which estimates the first-order effects as part of the prediction process simultaneously. The deterministic model can be chosen that is consistent with the air pollution models.

Given that co-Kriging is the extension of simple Kriging to improve the prediction of the value of the primary variable at a general point by considering covariate information of more than one variable of interest, Kriging was selected for surface prediction due to the fact that there is only one variable representing the SO_2 pollution level. Aside from indicator Kriging, probability Kriging, and disjunctive Kriging, which are not designed for continuous data, ordinary Kriging, universal Kriging, and simple Kriging, rely on the data being normally distributed. Hence, a transformation was required to transfer data into a normal distribution.

With decisions made as to the most appropriate model to create a surface of SO_2 pollution level, ordinary Kriging with the second-order trend estimated by local polynomial interpolation and a log transformation was chosen to predict the SO_2 pollution level across the study area. Parameters were optimized based on calculations by ESRI's Geostatistical Analyst. Results based on different models can even be compared with the criteria of the standardized mean nearest to zero, the smallest root-mean-square prediction error, the average standard error nearest the root-mean-square prediction error, and the standardized root-mean-square prediction error nearest to one (ESRI, 2001). As noted above, ordinary Kriging was preferred to universal Kriging due to its simplicity with fewer parameters to estimate. This reduced possible sources of errors.

Some parameters and options were customized due to the ARP. First, 90% local polynomial interpolation was used to remove the first-order trend because SO_2 is likely to disseminate within around 500km according to the Gaussian plume models for point source (Lu, 1999). And local polynomial interpolation is the best deterministic model available in the Geostatistical Analyst module that fits for most cases. Second, a log transformation with second-order trend estimation is adopted according to the Gaussian plume model's formula (Formula 3.1). At last, eight directional zoning for spatial dependence measuring is chosen in recognition of the existence of wind pattern in the US. All above decisions are validated with real data explorations in Chapter 4, which will be further explained with statistical results.

$$C(x,y,z)=\frac{Q}{2\pi\mu_x\sigma_y\sigma_z}\cdot\exp[-\frac{1}{2}(\frac{y^2}{\sigma_y^2}+\frac{z^2}{\sigma_z^2})]$$

Formula 3.1: Gaussian Plume Model for Point Source

Where C denotes pollution density at the point of (x,y,z)

Q denotes the emissions

x, y, z are the coordinates of plume in three dimensions

All other parameters are constants expressing regional atmosphere characters

All decisions in producing the SO_2 pollution level surface are summarized in Table 3.3:

Decision to be made	Chosen Option	Brief Explanation
Prediction Model	Ordinary Kriging	The simplest geostatistical model with great flexibility and the consideration of spatial structure
Data Transformation	Log	Data Observation and Gaussian Formula
Detrend Model	90% Local Polynomial Interpolation	Gaussian Model and SO_2 pollutant's characters
Monitored Records to be used to Create Pollution Level Surface	Annual 2nd maximum value	Largest number of valid records with typical (highest correlation coefficient) values within all records
Records selected dealing with Data Duplication	Maximum value	Highest correlation coefficient (typical) with other records and being concerned from a public health perspective
Searching Distance	Optimized distance near to 500km	Gaussian Formula and geography implications
Directional Segmentation	8 Angular Sectors	The existence of wind pattern across the US
Semivariogram/Covariance	Spherical	Default setting that fits for most cases
Neighbors to Include	5 or at least 2 for each angular sector	Default setting that fits for most cases

Table 3.3: Options and Parameters Selections in Creating a SO_2 Pollution Level Surfaces

3.3.2 Supplementary Correlation Tests

In addition to using the ordinary Kriging to create the SO_2 pollution level surface in preparation for the effectiveness and efficiency tests of the ARP, two supplementary correlation tests were conducted first in order to study whether the SO_2 emissions from power plants have a significant effect on the overall SO_2 national pollution level and seemed to determine whether the power production capacities are critical to regional economic developments.

The first question is important in choosing the right industry to regulate. If cutting emissions in the electricity generation industry has little effect on lowering the SO_2 levels, making effort on implementing this program is unwise. On the other hand, this question is critical in the effectiveness assessment using the national SO_2 level. Linking these two factors together makes it possible to use more detailed air quality monitoring records to study the effectiveness of the ARP with longer recorded history and higher reliability rather than the secondary incomplete emissions data used in this thesis.

The second question relates to whether reducing electricity generation is an option for polluters to reduce their emissions. If economic development does not highly depend on power consumption, power plants can choose to cut down electricity outputs to lower their emissions in order to conform to their emission caps without doing any harm to regional economic development. Otherwise the electricity generating industry is important for economic development, suggesting its importance for realizing sustainable development.

Since these two issues correspond to the two proposed geographic analyses for effectiveness assessment of the ARP, they should be examined ahead of conducting the effectiveness tests.

3.4 ARP Effectiveness Assessment

The effectiveness of the ARP is represented in two ways from a geographic perspective. One is the spatial-temporal change of SO_2 levels across the continental US. Given that the final goal of the ARP is to lower SO_2 level in the US, the actual cutting rate of SO_2 density can be used to judge the effectiveness of this program. For this purpose, pollution levels in 1985, 1989, 1994, and 1999 were compared and change detection analysis was conducted. If the pollution cutting rates became higher after the implementation of the ARP in 1995, it can be assured, all other things being equal, that this program was effective.

The other way of judging the effectiveness of the program is to cluster data from different states in different years based on the two parameters of economic development and pollution level. States were divided into three classes representing best, good, not very good status in sustainable development. The ratio of gross economic production to pollution level was used as an indicator of sustainable development. Higher values of this ratio indicate a better sustainable development status.

3.4.1 Temporal Change of SO_2 Distribution

In this analysis, Kriging was used first to get the SO_2 pollution level across the continental US from monitoring point records in 1985, 1989, 1994, and 1999. Given that the ARP began to be effective in 1995, pollution level change between the five-year interval between 1994 and 1999 shows the effectiveness of this program. Pollution levels in 1985 and 1989 are used because of the data availability and the interest in attempting to stabilize cutting rates under the CAC system. However, since the quality of the data set assembled for 1984, which should have be used instead of 1985 for a five-year interval change detection, was insufficient to create a surface, pollution data from 1985 were used as a reference for effectiveness assessment. Four SO_2 pollution level maps for these years were outputted based on a logarithm scale starting at the density level of 0.0005 with 2 times increasing on one level. The values can be easily compared because of the color change, as one level decrease implies around a 50% reduction rate.

Raster overlay was used conducted for pollution level comparison on a five-year interval basis. The pollution level generally goes down annually even before the ARP's implementation, due to the existence of the CAC policy, independent of whether the ARP was effective according to the cutting rates. If the ARP has a higher cutting rate, it can be concluded that it is effective.

The data processing diagram for change detection is shown in Figure 3.1:

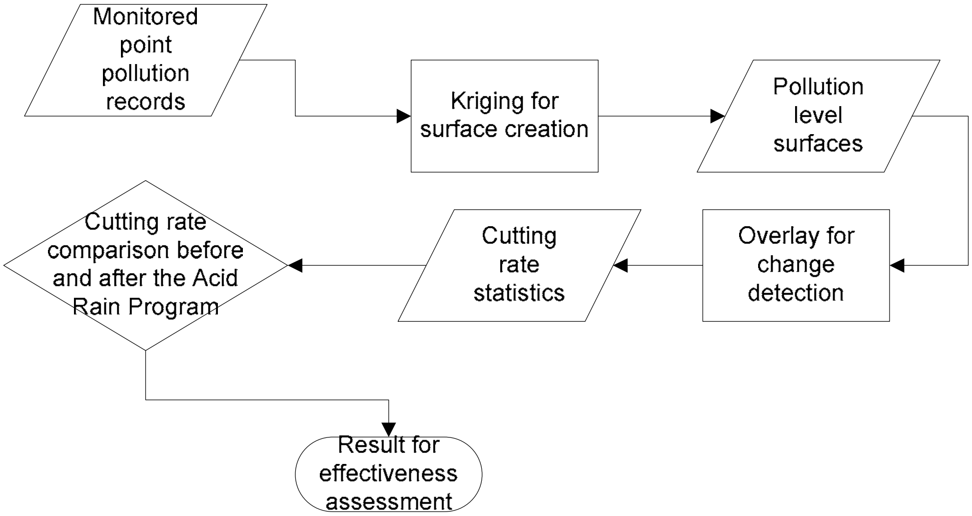


Figure 3.1: Data Process Diagram for Change Detection of 1985, 1989, 1994, and 1999

3.4.2 Economic/pollution Level Ratio Clustering

The spatial-temporal analysis undertaken in this thesis has two steps as follows: 1) do K-mean clustering on the variable of GSP and pollution level for all states from 1988 to 1999 to find their common characteristics; 2) use K-mean clustering for every state annually to see whether the ARP was effective.

According to environmental economics theory, the pollution level will generally increase as the economy expands because most economic development comes from industrial actions, which are the main pollution sources. Hence, the ratio of economic production to pollution level can be used as an indicator for the sustainable development. If data are plotted, making pollution level as Y-axis and economic development as X-axis, a line from left-up to right-down should appear in time line because environmental policies forced states to cut down their pollution levels and there is little evidence of negative economic growth. The ARP can be judged as “effective” if there is an obvious “gap” between the point for 1994 and 1995 that can be detected by K-means clustering.

K-means clustering has another merit that it can also extract common characteristics in states. States with similar economic/pollution ratio can be classified together for further study to identify factors that affect sustainable development. Samples states can be selected to study the sustainable development indicator later.

The data processing diagram is in the following Figure 3.2:

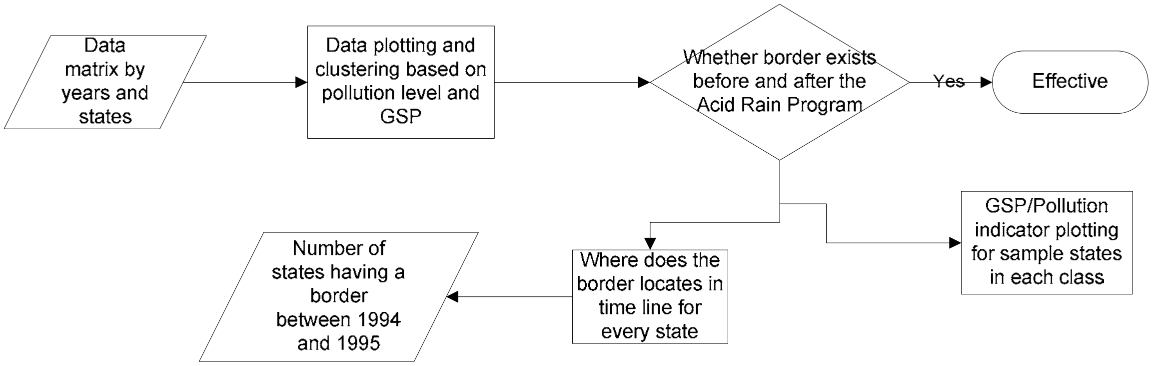


Figure 3.2: Data Process Diagram for Spatial-Temporal Analysis

3.5 Technology Dissemination Study

One of the main merits for implementing an emissions trading policy is that it has great flexibility for accelerating environmental-friendly technology dissemination so far as it gives an economic incentive to do so. In this way, both the efficiency and flexibility of this policy are higher than in the CAC instruments. However, whether this theoretical merit really exists in the ARP should be tested. Quick technology dissemination with lower processing costs increases compliance efficiency. Pollution processing technology change is an interesting topic within the ARP.

Given that a fuel-switch to high quality coal from the PRB region has lower compliance costs than scrubber installation, it has become the preferred method of SO_2 emissions reduction. However, its dissemination depends on coal freight rates, whose compliance cost gets higher as distance increases. Once this cost becomes greater than scrubber installation, polluters will choose to use scrubbers. Thus facilities adopting a fuel-switch are projected to form an area around the PRB region. The change of this area's extent shows extra efficiency of the ARP. On the other hand, it indicates the extent of deregulation in the railway system to lower freight rates that contribute to the success of the ARP. An emissions trading program might not be very successful if this factor plays an important role because rail way system deregulation is hard to transfer and not every country has high quality coal as in PRB.

Due to transportation capacity and usage frequency, only Level I railroad (main line sections) were used in this analysis. This accelerates the spread of the spatial analysis greatly without weakening the final conclusion given that Level I railroads cover most area in the US and dominate the commodity transportation traffic volumes.

According to EPA report, scrubber installation and fuel switch are the two main options that polluters use to reduce their SO_2 emission (Burtraw, 1996). So, this model only focuses on polluter's decision on selecting pollution processing techniques between above two choices.

A basic assumption underlying this model is that every polluter is a "rational producer", pursuing the goal of maximizing their profits, which is equivalent to minimizing compliance costs. They want to choose a processing method with the lowest processing cost at a specified production level. Average processing costs will be calculated out for fuel switching and scrubber installation first. Then a comparison is conducted based on these values in order to identify the service area for the PRB coal depicting technology dissemination.

In this analysis, service areas are identified because the processing costs for fuel switch varies geographically as a function of coal price, unit freight rate times, and transportation distance (Formula 4.1). The border lies on the line where the two prices are identical.

However, as noted earlier, data availability is limited. There are detailed data with information on receipts, average delivered cost, and quality of fossil fuels by every electric utility and plant in 2000, but no detailed historical freight rate data for different qualities of coal. On the other hand, there are historical coal freight rate data, but no information on the quality of coal that power plants used to calculate the compliance cost. Given this situation, two kinds of service area analyses are employed. One deals with historical data focusing one service area change using coal freight rates in different years. In this analysis (shown in Figure 3.3), the rail intersection in Level I nearest to the middle of Wyoming is selected as the original point sending PRB coal to calculate the transportation distance. The final result can be used to validate literature's findings that adoption of PRB coal has expanded from around 400 miles to 900 miles after the implementation of the ARP (Ellerman, *et al.*, 2000). The other analysis concerns present possibility of importing more PRB coal to lower compliance cost after 2000 using detailed freight data in 2000. Since many plants adopted the fuel-switch option in 2000, potential states are identified simply by comparing using PRB coal and present coal without considering transportation distance (Figure 3.4).

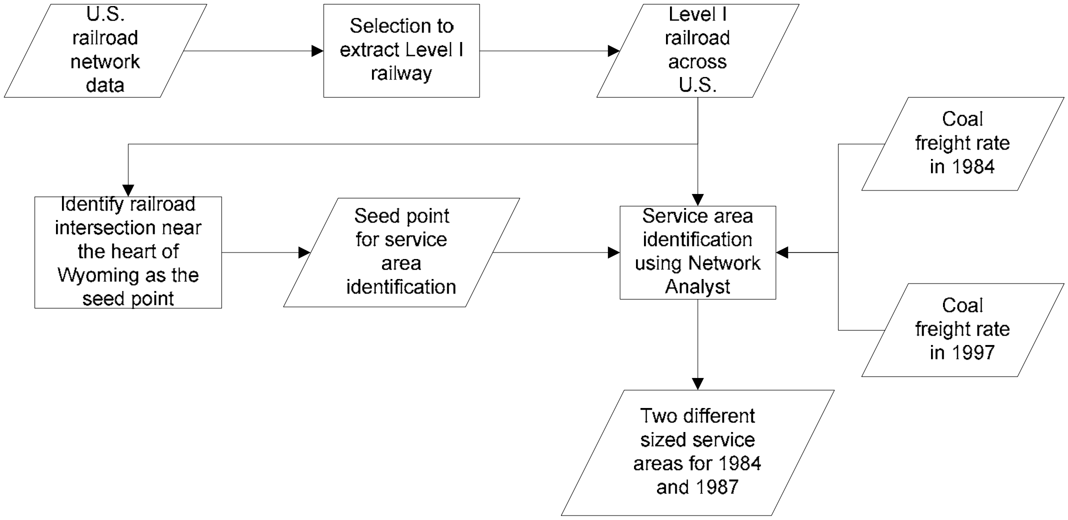


Figure 3.3: Data Process Diagram for Technology Dissemination

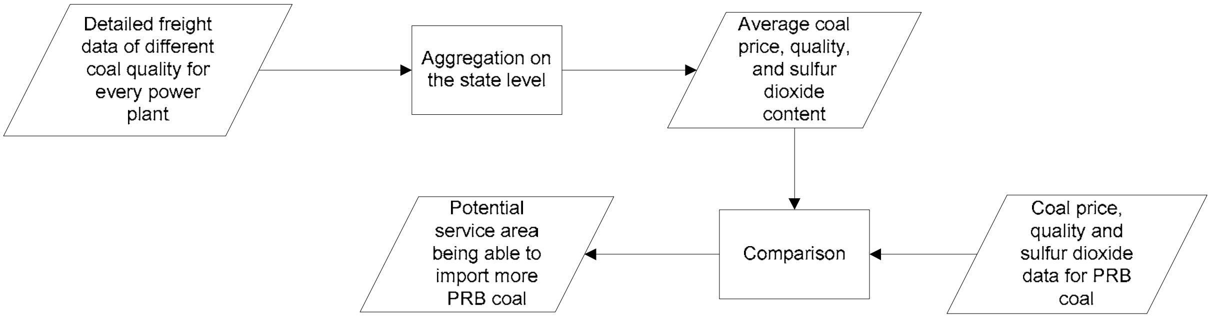


Figure 3.4: Data Process Diagram for Future PRB Coal Service Area Identification after 2000

There are some flaws in this model: a) In particular due to the limitation of the service area analysis, the PRB area is denoted by its central point with the main railway intersection identified subjectively. More analysis should be done to determine whether this is used in the real project. b) Only the PRB region is considered, since it is only the main source. However, other minor high quality coal sources exist, which can be added by including more supply points in this analysis. c) Price for transferring the railroad is overlooked because it is low and rarely changes. It can be added as a constant cost to the freight calculation.

Although this model is somewhat crude for only considering the PRB area with average coal price regardless of its quality, it is easy to expand the approach to a true analysis once data needed are available. Adding more coal-providing sources with different scrubber processing costs is not difficult. It is able to expand to describe complex cases in the real world.

If the results show that service areas expand greatly after the railroad deregulation, there are several implications. First, the emissions trading policy has good flexibility adopting a better pollution processing technology with lower cost. Second, railroad deregulation is an important factor making the ARP successful, which is hard to replicate to other countries. Lastly, the ARP has a higher efficiency than former CAC instrument because it adopted better technology quicker.

Since the option of trading emissions allocation is overlooked in this model, further analysis of the relationship between service and trading is possible. The other two options, trading and banking, can be added since polluters with lower processing costs than the former year tend to sell or bank their emission allocations. Some simple spatial analysis, such as buffering and a spatial join, can be used to deepen our understanding of polluter's behaviour and geographical factors in future work.

3.6 Hot Spot Detection and Explanation

The hot spots problem is the original problem that leads to geographical analysis on emissions trading policy that is assessed in this thesis. It stems from pollution problem's regional character, which is related to various factors, such as pollutant properties, geographic situation, polluter's location, climate, and demographic distribution. By contrast to the homogeneous trading rules advocated by many economists, the risk of pollution hot spots suggests the need for restrictions on trading. Thus, whether hot spots are possible is critical in emissions trading policy designation. If they exist, decision-makers need to design complementary regulations on trading. If not, emission allocations should be traded freely to maximize the effectiveness and efficiency of emissions trading policy.

In this analysis, a Microsoft Excel macro program for spatial autocorrelation calculation, the so called Rookcase, is used for irregular monitoring network data exploration (Sawada, 1999). Different searching radii from 50km to 900km with 50km intervals were used to explore the geographical structure. Common features were extracted for further explanation and discussion.

Two analyses are conducted in this case. The first one is computation of the global spatial autocorrelation to test whether global trading is appropriate. The second is local spatial autocorrelation analysis to identify hot spots in order to examine the risk of regional pollution problems.

Different radii were used because spatial autocorrelation is scale-dependent, suggesting different spatial structures might exist (Goodchild, 1986). If spatial autocorrelation disappears within a certain distance, this means that point pollution levels can be regarded as independent of each other, and this distance can be used to find the regional zoning scales.

Within one region, the pollution level tends to be homogeneous due to pollutant diffusion and other factors. Trading within this distance might be inappropriate since there is no “pollution dissemination” between these regions; and the pollution level in a buyer’s region can accumulate to a level that causes the hot-spot problem.

Global spatial autocorrelation and LISA are used for different purposes. Positive global spatial autocorrelation indicates the national SO_2 pollution levels tend to be homogeneous. Spatial emissions trading is reasonable because the overall pollution levels will increase with little change on the pollution pattern. This question relates to choosing the “right pollutant” having high positive global spatial autocorrelation to implement the emissions trading policy, which is more suited as a trading mechanism. On the other hand, since global spatial autocorrelation is the sum of individual sample LISAs, positive global spatial autocorrelation implies a high possibility of having hot spots (Anselin, 1995). In this case, regional regulation on trading emissions to hot spot areas is needed.

Conducting a LISA analysis with different radii to find hot spots might lead to different points since the number of involved points in calculating confidence intervals is different. Further rationale underlying this phenomenon might be able to rationalize with common hot spots in all possible distances. If these points exist, suggesting pollution densities around these points have a large variation and can reach a very high level, corresponding regulations should be made lest they cause pollution problems. It can also be used to explain why hot spots have not occurred under the ARP although it cannot be eliminated theoretically since pollution levels around hot spots identified in the following chapter are not too high to exceed thresholds to cause real problems.

In the following chapter, detailed explanation is provided for the methods introduced have and results are represented and discussed to validate the ARP and identify factors that affect it. The results from the geographical analysis are explained in the context of environmental policy optimization and migration possibilities will be further discussed, especially for the emissions trading policy.

3.7 Summary

This chapter has presented the methodology of geographic analyses for assessing effectiveness, efficiency, and existence of hot spots of the ARP. Geographically testable questions based on environmental policy assessment criteria. These questions were articulated embodied as a set of hypotheses for empirical analysis.

After introducing the study area and reviewing data quality and sources, analysis preparation processes were explained. The principles, theory, options, and parameter settings of geostatistical analysis were presented to validate the appropriateness of the methods used to create pollution level surfaces. As an important technique for predicting a continuous surface using sample point data, Kriging was explained. Correlation tests were also explained to validate choosing the right industry to regulate and the importance of electricity generation industry on sustainable development.

The processes of assessing effectiveness, efficiency, and existence of hot spot problems are presented in the following chapter. Questions, such as whether the ARP is successful and whether geographic analysis is critical under a scientific environmental policy assessment framework, will be answered based on the analytic results.

Chapter 4 Analyses Results and Discussion

4.1 Overview

In this chapter, results of the geographic analyses are presented. Reasons leading to these results are explored. Conclusions about the success of the ARP and the role of geographic analysis on emissions trading policy designation are derived based on these analyses.

4.2 Analyses Preparation

4.2.1 Pollution Surface Prediction using Kriging

Pollution patterns for 1985, 1989, 1994, and 1999 were obtained by predicting pollution densities using monitoring point data. Kriging was used to interpolate from the original point data to create continuous pollution density surfaces. The classification scheme used in this chloropleth map is logarithmic starting from 0.0005. A one-class reduction implies a cutting rate of 50%.

Records of 2nd highest annual value for each monitoring point are used in predicting national pollution level surface instead of annual average pollution level because the number of records with correct average pollution are far fewer than ones with maximum data. Most average pollution values are obviously wrong. For instance, there are 676 out of 875 records having an average value of 1 but having 2nd highest value no greater than 0.756 in data for 1998. Given that the pollution level data are continuous, the average values of these records are obviously wrong. In addition, then highest values of records are useful due to the consideration of public health. Since high density of SO_2 can cause public health problem in a short time, such as several hours, highest density data are more important than the average level since health insurance would have to be paid as a counterpart of social benefits. Furthermore, the distribution of 2nd highest annual values is more reasonable based on the character of SO_2 as a pollutant. Its frequency distribution is the best one that fits the Gaussian Plume Model, which has been proved to be effective in predicting air pollution disseminations from point sources.

Finally, selection of using 2nd highest records is valid because these records are the most represLentive ones. The correlation rate between 2nd highest records and average ones is moderately high at around 0.55 if all the obviously wrong records are excluded in 1998. While the correlation rates between 2nd highest records with other highest records are also more than 0.5. This example shows that using 2nd highest records can preserve most of the data and be even more reasonable.

Seen from these four time series pollution pattern, it can be found that high pollution density mainly concentrates in the Ohio River Valley (ORV), including Ohio, Indiana, West Virginia, and Kentucky (Figure 4.1). The ORV has the highest density with largest area, which is the focus of the ARP. The other region with high pollution density is around the PRB, including Wyoming, Montana, and Idaho. But it is lower than ORV. It is interesting that the SO_2 pollution level in California is very low, although it is one of the most developed areas in the world. This phenomenon might be due to the strict regional environmental standards and abundant financial resources for pollution reduction there. Both CAC policies and the emissions trading instrument are effective in terms of pollution level reduction. Pollution density has decreased greatly over time.

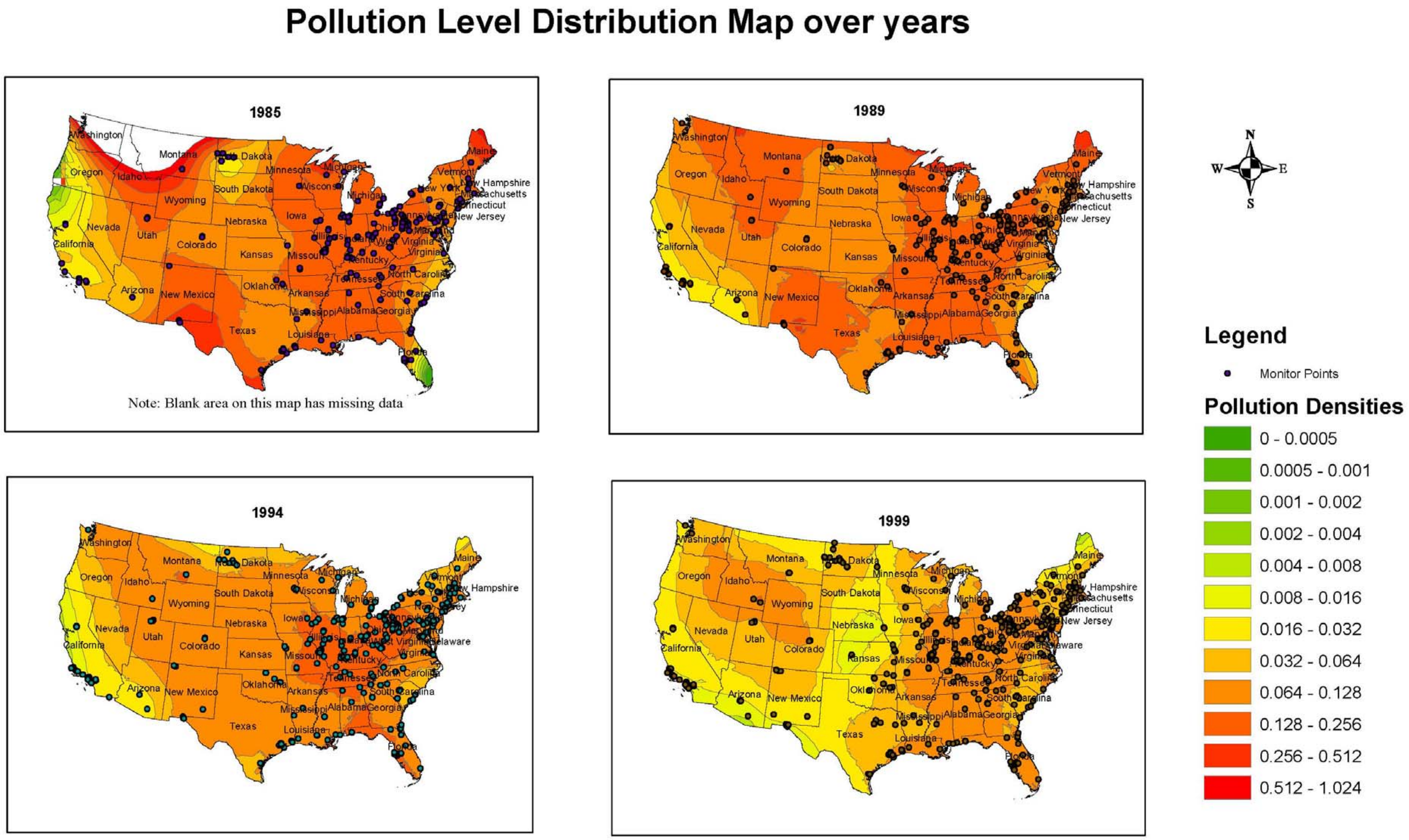


Figure 4.1: Predicted National Pollution Level

The ARP also produced a more homogeneous pollution pattern across the US as shown in Figure 2.1. The states that have reduced their emissions most are those that were most polluted, while states with low pollution levels maintain similar pollution densities, even with some accretions. But since the pollution cutting rates have not increased greatly, the achievements of the ARP are not as great as some economists acclaimed from the effectiveness perspective. However, on the other hand, given that industries without annual caps usually emit more pollution volumes when they grow, the effectiveness of the ARP might be reduced by other industries not under regulation of the ARP.

The main decision of using logarithm transformation and second-order trend analysis to produce pollution level surfaces is supported based on spatial data exploration. All three kinds of transformation - none, log, and Cox-Box - were tried to fit the normal distribution pattern with the functions of histogram and normal QQplot in Exploratory Spatial Data Analysis (ESDA). Logarithm transformation proved to be the best one. In addition, records of 2nd highest value were also found to be the best ones to form normal distribution under the logarithm transformation. The second order trend pattern was selected based on the trend analysis module in ESDA. Given that data form the “U” shapes on both X-axis and Y-axis in 3D spatial data view, the second-order trend pattern is obvious.

The global spatial autocorrelation and outliers can also be found using variogram and Vonoroi map modules in ESDA qualitatively. These results will be discussed further to validate results achieved using Moran’s I and local Moran’s I indexes in section 4.5.2. Summarily, global spatial autocorrelation and outliers around the ORV and Appalachia Region were found. But directional spatial autocorrelation was not found.

4.2.2 Correlation Test and Indicator Validation

As mentioned in Chapter 3, indicators should be found to measure the effectiveness of policies. Two basic questions are critical here, a) whether controlling emissions from the electricity generation industry is effective, which means their emissions account for the major part of overall SO_2 emission in US, and b) whether cutting production capacities is an option for polluters to reduce emissions without hurting economic development. The former can be tested with the correlation coefficient between the pollution level and emissions aggregated on the state level. For the latter one, the correlation test for GSP and electricity capacity is appropriate.

4.2.2.1 Pollution Level and Emission

The goal of environmental policy is to realize sustainable development by lowering pollution levels and natural resources consumption while keeping an appropriate rate of economic growth. Choosing the right industry to regulate in order to maximize this effect is one of the most important factors in the success of any emissions trading policy tool. In this case, SO_2 emissions from power plants should count for the majority of overall emission volumes leading to the acid rain problem in the US. Although it is reported that power plants emit around 70% of the total SO_2 volumes in the US annually, the relationship between the pollution level and power plants' emission volumes still needs to be tested using the final monitored data. Correlation tests will be done on the state level annually. If a positive correlation exists, it implies that controlling power plants is a wise choice for SO_2 emissions reduction. Otherwise the ARP could be targeting the wrong industry.

Since the environmental monitoring network for air quality is more pervasive than emissions monitoring devices, historical data of SO_2 densities across the US are easier to retrieve. Change detection and pollution pattern study are done according to overall pollution levels, not really emission reductions. If there is no correlation, this method will turn out to be invalid. To do correlation test, pollution and emissions data are aggregated on the state level. They are tested using Phase I data every year from 1988 to 1999. The result is in the following Table 4.1:

Year	Pearson Correlation Coefficient (r)	Significance (1% level, two tailed) (r = 0.372)
1988	0.556	Significant correlation
1989	0.540	Significant correlation
1990	0.605	Significant correlation
1991	0.600	Significant correlation
1992	0.494	Significant correlation
1993	0.640	Significant correlation
1994	0.702	Significant correlation
1995	0.494	Significant correlation
1996	0.506	Significant correlation
1997	0.508	Significant correlation
1998	0.680	Significant correlation
1999	0.635	Significant correlation

Table 4.1: Correlation result for emissions and pollution level

Seen from this table, the correlation coefficients are stable at around 0.6, but ranging from 0.494 to 0.702, indicating that positive correlation exists and suggests that power plants are one of the main contributors of SO_2 emissions. Therefore, the pollution level can be used as an indicator of emission volumes reduction in the ARP.

4.2.2.2 Economic Development and Electricity Production

Another question is whether electrical production is critical in economic development. Economic growth is important in improving the standard of living and keeping society stable. If the electrical production has little effect on economic growth, reducing electricity outputs will be an option for power plants to cut their SO_2 emission volumes. Otherwise the way of setting emission caps should not be too rigid if the cap is set proportional to the historical emissions. Thus, the relationship between economic development and electricity production should be tested.

All the data are aggregated at the state level. A correlation test is done between the state electricity generation and the Gross State Products (GSPs) every year.

Year	Correlation with capacity	Correlation with net generation
1996	0.858	0.812
1997	0.855	0.803
1998	1.000	1.000
1999	0.970	0.820
2000	0.821	0.759

Table 4.2: Correlation result on state level

The electricity productions (or consumption) show a strong correlation with GSPs, which is fairly constant over time. This result suggests that the electricity production is critical to economic development. Energy consumption has long been regarded as a good indicator for economic development, especially in the industrialized nations. If adopted technologies are on the same level, industrial outputs will directly relate to their energy inputs, more specifically, electricity inputs at present. Since the demands for electricity lack elasticity, reducing pollution emissions volumes by cutting electricity outputs is not an option.

However, this conclusion might be weakened by the fact that the correlation coefficient between economic development and the electricity capacity is stronger than with the net generation. Since the electricity industry is regulated under state regulatory bodies, this phenomenon implies that planned capacity might be set proportional to economic development, although the economy is transferring to a new status that does not rely on electricity consumptions so heavily.

4.3 Spatial-Temporal Analysis

4.3.1 Change Detection

Raster calculator is used in calculating the abatement rates with a five-year interval from 1985 to 1989, 1989 to 1994, and 1994 to 1999. The rates were obtained by dividing the pollution level in the latter year by the one in former year. Given that this rate represents the remaining pollution level, the smaller this rate is the better the result is. Seen from the statistical information of the output raster files, it can be concluded that the ARP is more effective because the average cutting rate is 0.638 after the implementation of the ARP in 1995, lower than the lowest one with 0.730 under the CAC system. The paired test shows that the cutting rate after the ARP is higher than before with 99% confidence (Table 4.3).

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference				
					Lower	Upper			
Pair	after vs before (ARP)	-9.27E-02	.4706	1.838E-03	-9.74E-02	-8.79E-02	-50.416	65535	.000

Table 4.3: Cutting Rate Comparison before and after the ARP

Furthermore, the two rates of 1994-1999 and 1989-1994 are compared by dividing the former one with the later one. Resultant raster data can be used to comment on the effectiveness of the ARP. Rates obviously less than 1 indicate that the ARP is effective, and vice versa. Given that this operation is also done using the raster calculator, the distribution map of these rates show the spatial benefit distribution of this program. This can even be used to locate potential selling and buying regions because polluters in regions with ratios less than 1 tend to sell emission allocations to polluters in regions with ratios greater than 1.

From this map, it can be found that the cutting rates in more polluted area, such as the ORV, are higher than before the implementation of the ARP (Figure 4.2), while the cutting rates in less polluted area, such as California and New York, are lower than before. This pattern conforms to the former conclusion that pollution levels across the US became more homogeneous. But areas with lower cutting rates under the ARP are not the ones with high volumes of emission sales, indicating that other factors, such as the technical improvement, also play an important role in pollution level reduction.

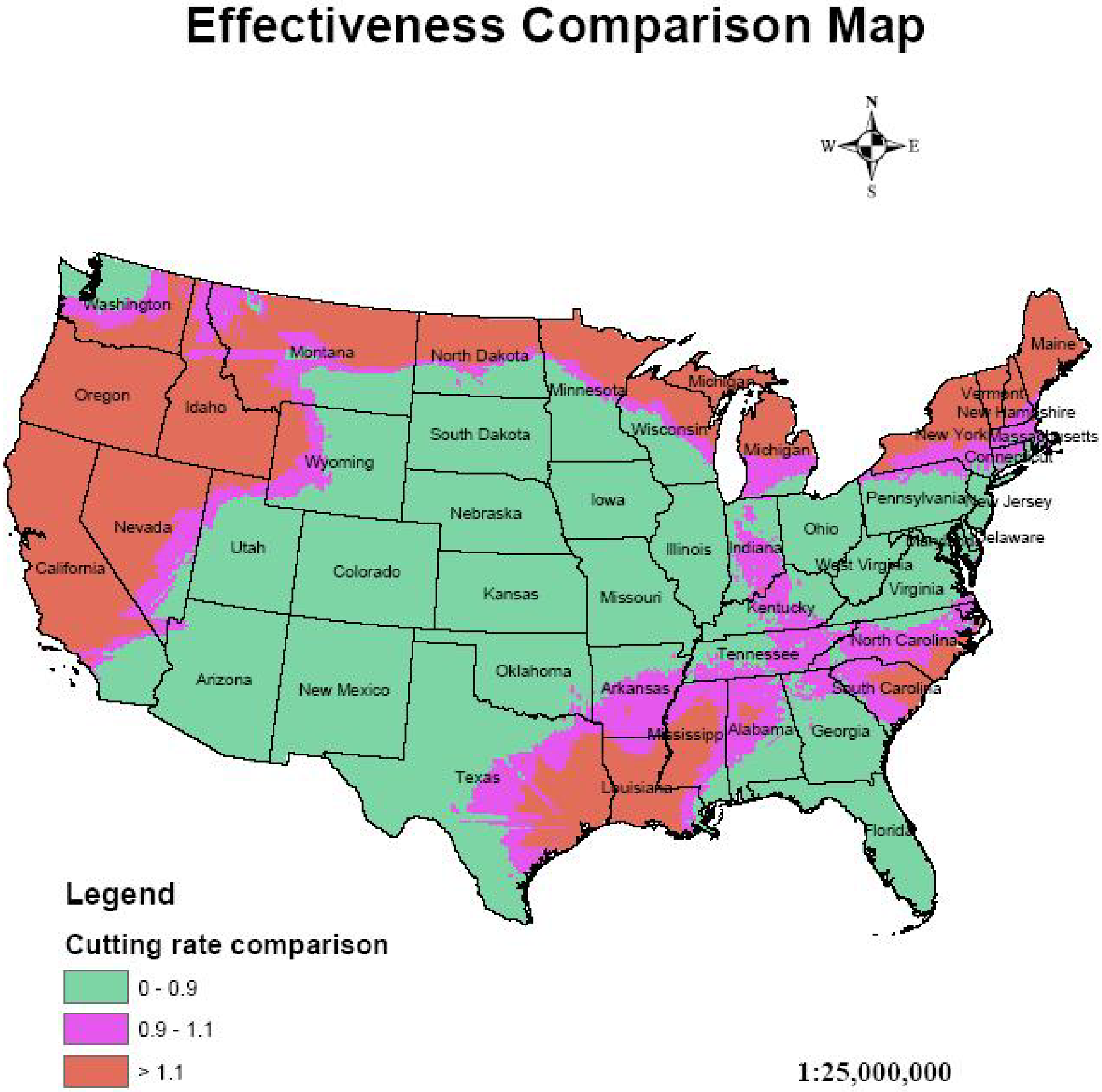


Figure 4.2: Pollution Level Abatement Comparison

4.3.2 Spatial Temporal Clustering for Sustainable Development

Spatial-temporal analysis is a more detailed study to analyze the ARP's effectiveness from the economic development and pollution abatement perspective. It has several characteristics: a)

It uses another statistical approach, K-means clustering, to validate the effectiveness of this program. In contrast to change detection, clustering can contribute to multi-criteria assessments. b) it concerns the relationship between pollution level and economic development. The concept of sustainable development can be expressed in this way. The ratio of GSP to pollution level links these two major factors together for consideration. This has another advantage which is that this ratio varies greatly and is easier to cluster since the pollution level is low. c) It can be used to identify some patterns for further studies. It can be rationalized to produce new knowledge on the emissions trading policy, sustainable development, and energy industry.

First, all pollution and GSP data are collected for every state from 1988 to 1999. A scatter plot is watched with GSP on the X-axis and pollution level on the Y-axis after the standardized process. (Figure 4.3)

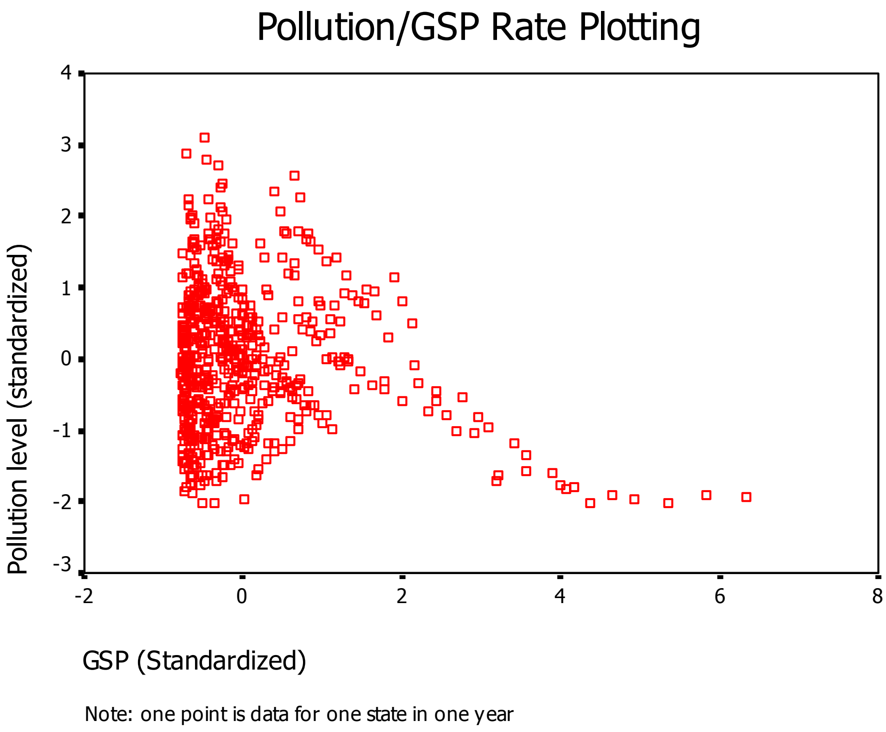
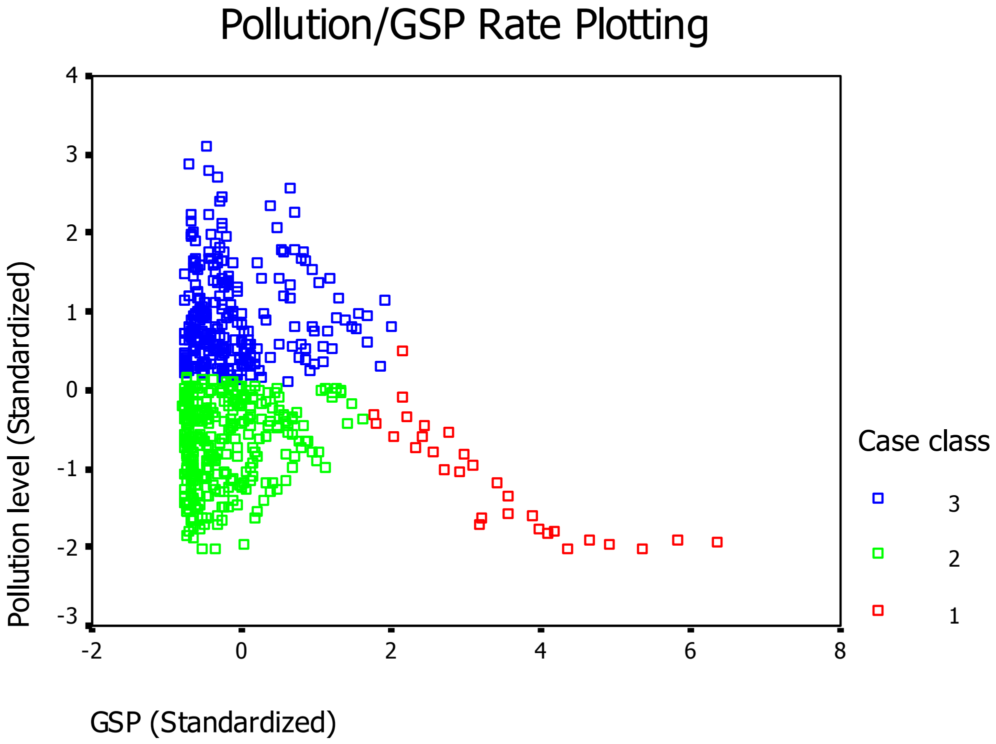


Figure 4.3: Scatter Plot for Pollution and Economic Development

Point pattern can be easily found in this figure. One cluster exists for low volume of X, and a curve runs from bottom right corner to the top left. States with similar development/pollution ratio can be extracted as one group. Since the curve is very long and hard to be clustered as one, the classification scheme of three-group is adopted. These groups can be interpreted as “good”, “better”, and “best” sustainable status. States in class I have the best development with less pollution, while ones in class II have the lowest development with more pollution. (Figure 4.4)

This classification is a relative scheme. There are always some states identified as “good” one, which need to improve. Clustering is an effective technique for data mining in common feature extraction. Further research can be done based on this to identify factors affecting sustainable development.



Note: one point is data for one state in one year

Figure 4.4: Classification for development/pollution rates

The emissions trading program can be regarded as effective if the following statement is true: cases for most states in 1988-1994 are in Class 1; cases from 1995 to 1997 belong to Class 2; and cases from 1999 sit in Class 3.

Cluster	Number of Cases
1	30
2	296
3	250
Sum	576

Table 4.4: Clustering Report on Number of Cases in each Cluster

However, the results show that above is not true. Only around half states have data in different years in different classes. Since many of them have borders between 1994 and 1995, the ARP might be effective. But there are also half the states that only belong to one class. This classification does not provide enough information to judge the effectiveness of the ARP. Analysis should be done for each state individually to damage the effects of these geographic characters in order to make fairly assess policy effectiveness.

A typical scatter plot for individual state is in the following. As GSP increases and pollution is reduced, a curve is expected to appear chronologically. Given the environmental policy changes between 1994 and 1995, a gap should be found there. K-mean clustering can be done for every state to divide the data into two groups. If the border is just on 1994 and 1995, it implies that the ARP is successful.

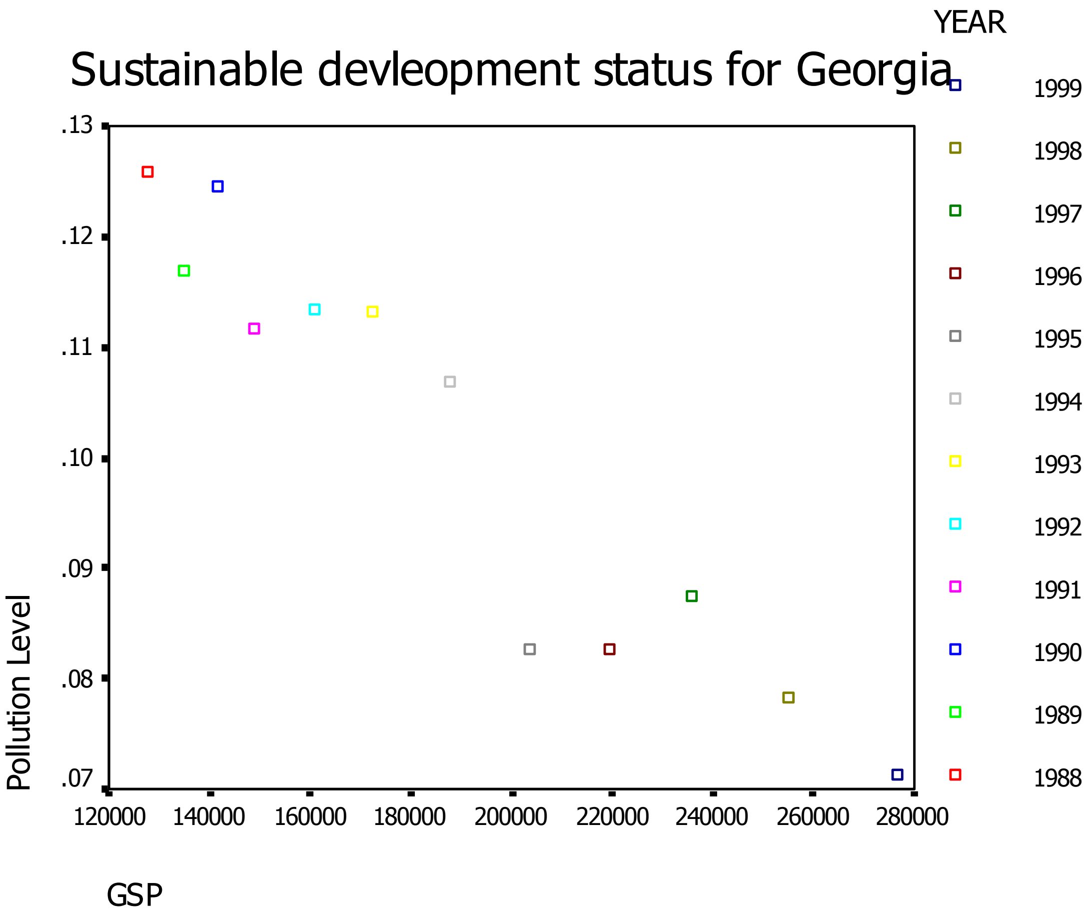


Figure 4.5: Sample scatter point for Georgia

Seen from above table, there are 29 out of 48 states (60%) locating their group border between 1994 and 1995, indicating that the ARP is effective. But this result is not as great as the EPA has claimed from the combined consideration of economic development and pollution abatement (U.S. EPA, 2001b).

State	The lastest year before change	The earliest year after change
Alabama	1994	1995
Arizona	1994	1995
Arkansas	1994	1995
California	1995	1996
Colorado	1995	1996
Connecticut	1994	1995
Delaware	1994	1995
Florida	1994	1995
Georgia	1994	1995
Idaho	1993	1994
Illinois	1994	1995
Indiana	1993	1994
Iowa	1993	1994
Kansas	1994	1995
Kentucky	1994	1995
Louisiana	1994	1995
Maine	1994	1995
Maryland	1994	1995
Massachusetts	1995	1996
Michigan	1993	1994
Minnesota	1994	1995
Mississippi	1993	1994
Missouri	1994	1995
Montana	1993	1994
Nebraska	1993	1994
Nevada	1994	1995
New Hampshire	1994	1995
New Jersey	1994	1995
New Mexico	1992	1993
New York	1995	1996
North Carolina	1994	1995
North Dakota	1993	1994
Ohio	1994	1995
Oklahoma	1994	1995
Oregon	1994	1995
Pennsylvania	1994	1995
Rhode Island	1995	1996
South Carolina	1994	1995
Tennessee	1994	1995
Texas	1994	1995
Utah	1994	1995
Vermont	1994	1995
Virginia	1994	1995

State	The lastest year before change	The earliest year after change
Washington	1995	1996
West Virginia	1994	1995
Wisconsin	1994	1995
Wyoming	1994	1995

Table 4.5: State Clustering Result

4.4 Technology Dissemination

There are two main options that polluters can use to reduce emissions: scrubbers and fuel-switching (Carlson, *et al.*, 2000). Before the implementation of the ARP, scrubbers had been the prevailing technique. Many factors contributed to this phenomenon. First, CAC policies encouraged, even specified, scrubbers as the standard pollution processing technology. Since the CAC systems lacked flexibility, polluters were reluctant to adopt the fuel-switching technology. Second, state governments usually encouraged electricity generators to use local coal for the sake of local economic development and employment opportunity regardless of the quality and price of coal from other places (U.S. EPA, 2001c). Finally, the coal freight rate was not low enough before the ARP because innovations after the rail road deregulation had not yet had their full effects.

Assuming that polluters seek the lowest compliance cost, the price of high-quality coal plays an important role in polluters' decisions. Given that coal price is determined by the sum of the original coal price and coal freight rate, rail road deregulation might be a big contributor if freight rates decrease greatly (Figure 4.6).

In addition, mine-mouth coal prices change little over the years. For example, the coal price in PRB, which produces highest quality coal with lowest prices in the US, didn't change from 1987 to 1993 (Ellerman, *et al.*, 2000). Therefore, decreases in the freight rates account for the main difference in coal prices before and after the implementation of the ARP.

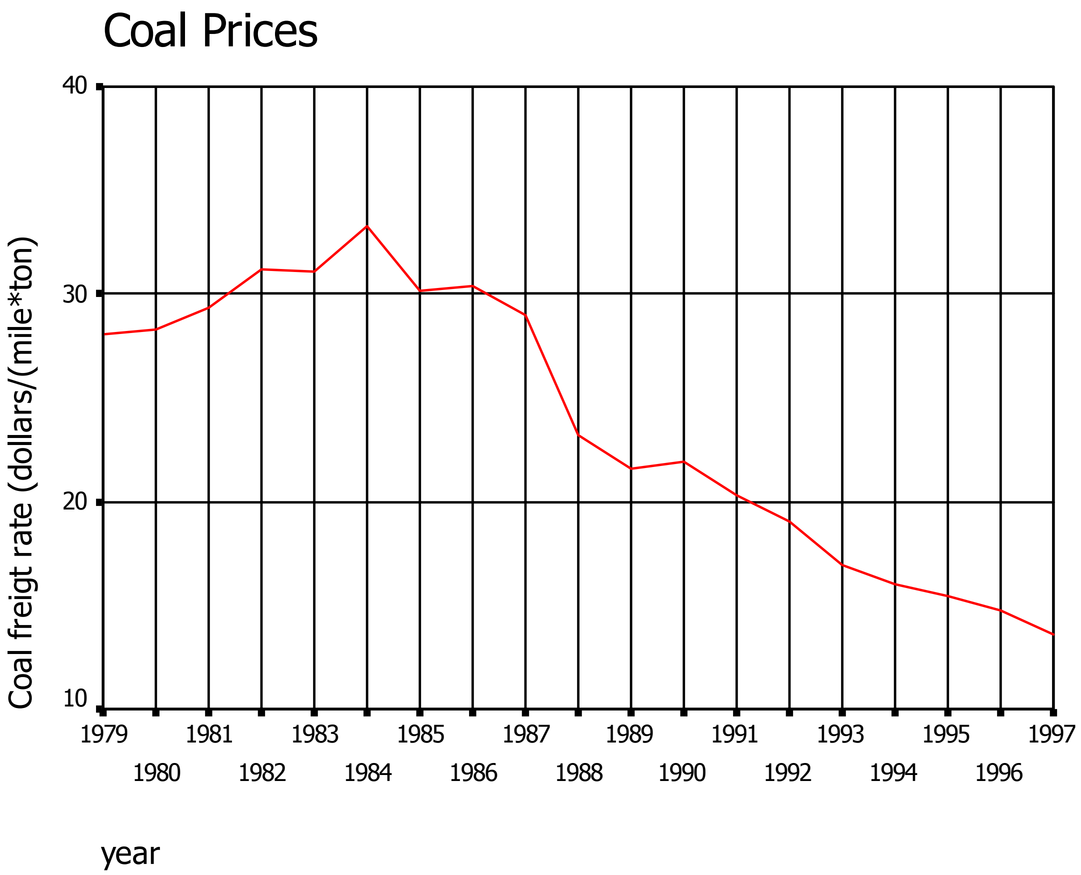


Figure 4.6: Coal Freight Rate Change

A simple model for the environmental processing technology selections can be established in the following. Since the price of scrubbers across the US is about the same, fuel-switching technology dissemination can be represented by its service area with comparing the prices of fuel-switching and scrubber installation. The cost of fuel switching increases with distance via the rail network from the mine site. The border of this service area should be the line where the delivered coal price equals the cost of scrubber installation.

The average processing cost for scrubber per ton was obtained from the US Department of Energy. Overlooking the initial installation cost of the fuel-switching, which has been proven to be low, the processing cost of fuel-switching is calculated using Formula 4.1.

$$C = \frac{50 \cdot (P_{PRB} \cdot H - P \cdot H_{PRB})}{S \cdot H_{PRB} - S_{PRB} \cdot H} + F \cdot \frac{50 \cdot H}{S \cdot H_{PRB} - S_{PRB} \cdot H} \cdot D$$

Formula 4.1: Compliance Cost Calculation for PRB Coal

In this formula:
C: Average Switch Cost per ton SO_2
H: Cents per MMbtu
P: Coal price (dollar) per ton
D: Distance from generation to coal source (km)
S: Sulphur content per ton (%)
F: Coal Freight per ton per km

Comparing C with scrubber processing cost can produce the final result. Because of limited data availability, this analysis was conducted as two parts. The first assumed that high quality PRB coal was used to substitute for coal with average quality. Based on the data from US DoE, the radius of service area increased from 385 miles in 1984 to 955 miles in 1997 (Figure 4.9). This result confirms the phenomenon that the use of PRB coal expanded to around 900 miles after the ARP (Ellerman, *et al.*, 2000).

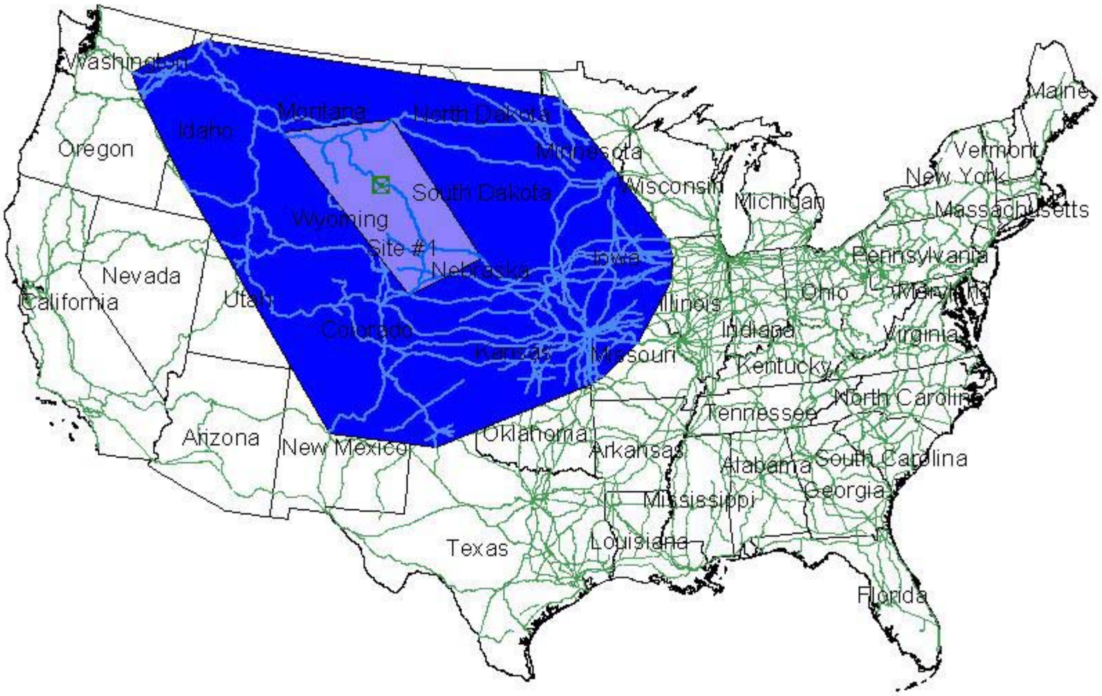


Figure 4.7: PRB Fuel-switch Service Area Changing (1984 and 1997)

Another analysis used detailed data for power plants in 2000 to identify states that might benefit from further fuel-switching options (Figure 4.10). This result confirms Ellerman's result as well. The only difference is that the result in this thesis adds Oregon instead of Texas in the service area. Others are the same for plants adopting fuel-switching. Even though the data used were collected after the implementation of the ARP, which means they had used fuel-switch as an option for emission cap compliance, it proves that it is still profitable to do so.

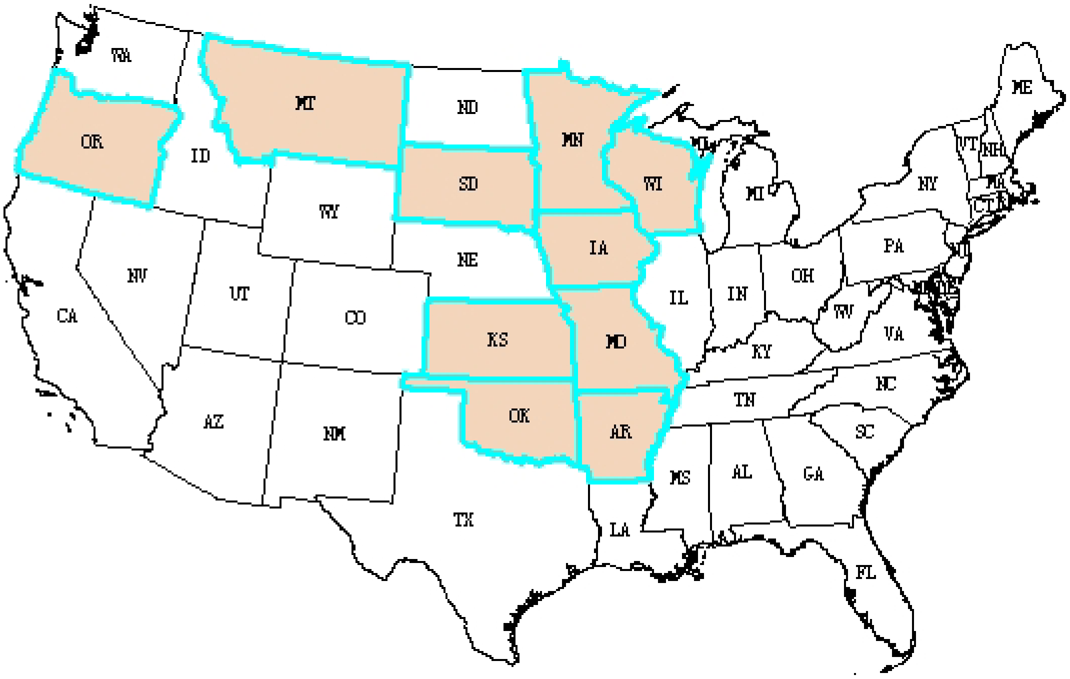


Figure 4.8: States that might be benefit from fuel-switch to PRB coal

This result has two meanings. One is that the merit of flexibility in the emissions trading policy is true. It has been reflected in the ARP implementation. This program accelerates the dissemination speed of better environmental technology. The other is that the rail road deregulation has contributed to the success of the ARP greatly. Without dramatic freight cutting following deregulation, compliance costs after the implementation of the ARP would have been much higher. Hence, it weakens the migration potential of the emissions trading policy to other countries because this factor is hard to migrate at the same time. Policy makers should be cautious on the possibility of successfully migrating the emissions trading policy.

4.5 Spatial Autocorrelation and Hot Spots Problem

According to the Geography First Law, geography has a basic principle of spatial autocorrelation (Tobler, 1970). This property can be measured by Moran's I and Getis C indicators.

Positive spatial autocorrelation implies clustering exists. Zero spatial autocorrelation means events happened are independent geographically. Positive spatial autocorrelation is more appropriate for spatial emissions trading. Hot spots exist if the z-score for LISA is very high, because pollution density tends to cluster in some places (Anselin, 1995). Trading emission allocations to hot spots could create severe regional pollution problems.

Searching distance (km)	**Moran's I index**
10	1.379
20	0.841
50	0.360
100	0.419
150	0.299
200	0.255
250	0.216
300	0.191
350	0.149
400	0.104
450	0.112
500	0.106
550	0.089
600	0.068
650	0.064
700	0.064
750	0.057
800	0.055
850	0.054
900	0.056
1027.854 (maximum)	0.047

Table 4.6: Global Spatial Autocorrelation Result for 1988

Generally speaking, this result shows spatial autocorrelation. But it is only on a low degree. And the degree decreases as the searching distance gets larger, except for 20 km due to the number of sample points fallen within it. This result is consistent with pollution dissemination and climate models for sulphur dioxide. And it is a global spatial clustering pattern regardless of the searching distance adopted (Sawada, 1999). All z-scores with different searching distance are greater than the one with 99% confidence interval. This implies that the global pollution level tends to be homogeneous, making spatial trading less harmful. This also implies that, statistically, hot spots are more likely, which can be found by LISA.

This can be confirmed with semivariogram for pollution level in 1988 (Figure 4.7): All the points seem to from two parallel curves (Figure 4.9). This also indicates minor positive spatial autocorrelation exists. But since it seems that there are two classes that depart each other, the variance of estimation will be high.

Monitoring and plant points are very near, but the number of monitoring points is far less. The distances between plants are much less than their distances to monitoring points.

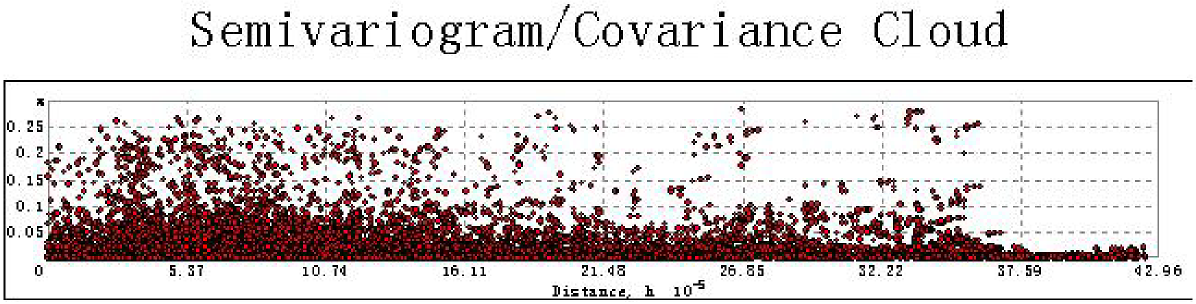


Figure 4.9: Semivariogram for 1988 SO_2 pollution level

Since spatial association exists regardless of searching distance, which means pollutant can disseminate across the whole US as a kind of “second order” property, global trading is an appropriate method. In economics terms, it can be seen as a kind of measurement for “spatial externalities” because the extent of pollution destruction of the environment relates to pollution density. Given that spatial association exists, externalities do not change greatly spatially for SO_2. Thus, it can be concluded that it is unnecessary to limit global trading considering the pollutant’s characteristics.

Local Moran’s I index is used to detect where hot spots are. Similar to global SA testing, different radii are tested to extract hot spots. A 99% degree of confidence is used for identifying hot spot points. After mapping them together, it is found that common points exist. They are mapped on Figure 4.8. This pattern is similar with 1999 although hot spots in 1999 were identified only based on one certain searching distance (Table 4.10).

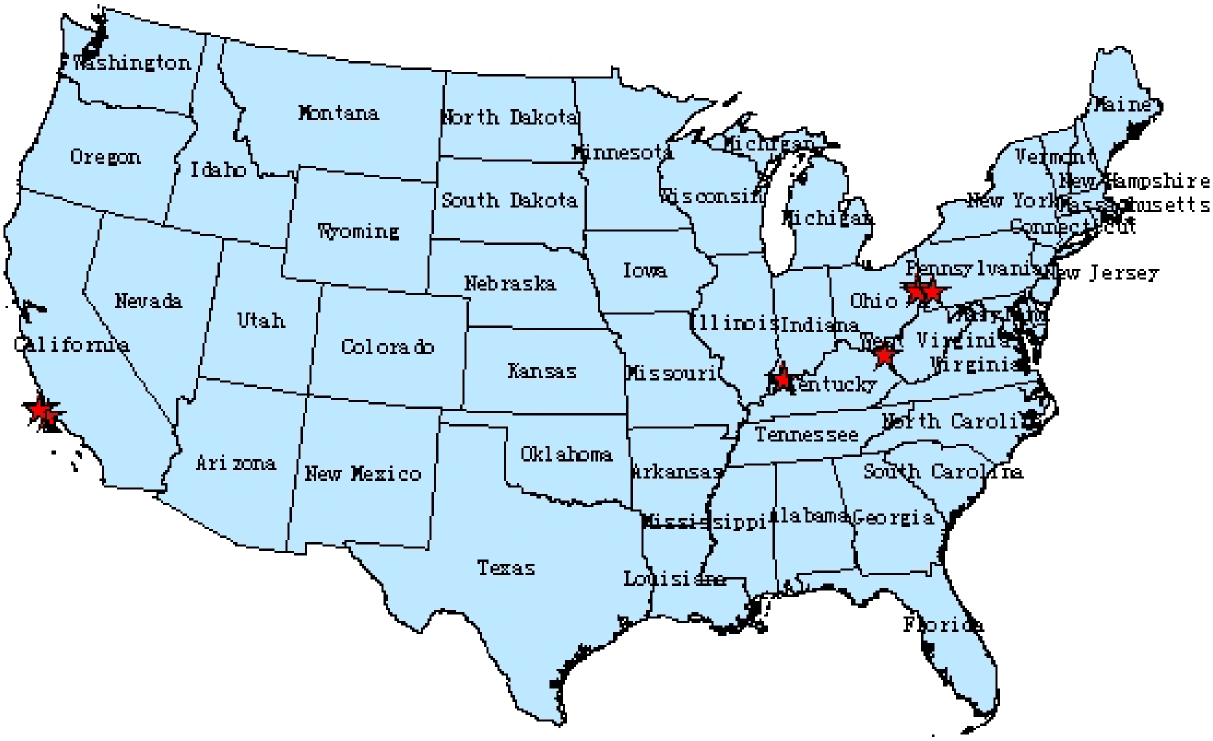


Figure 4.10: Hot spots Points (11 points) 99% possibilities (1988)

It is easy to find that hot spots are located basically in two areas: Ohio Valley and Los Angeles. Los Angeles has the highest environmental standards in the world. Given that local air quality standards are still effective under the ARP, they prevented these potential hot spots from being a real one. Thus, even though hot spots problem doesn't exist under the ARP, it is not the case as some economists thought. It is still the traditional CAC standards that protect Los Angeles, not the emissions trading policy itself. The standards are so strict that there is no electrical generation with 50km from Los Angeles. The formation of these hot spots can be explained by surrounding mountains, which force pollutants to accumulate within a small area.

Figure 4.11: Hot spots Points (50 points) 99% possibilities (1999, radius: 500)

In the Ohio Valley, 19 generation sites are found within 50km of hot spots using buffering. Emissions data in 1996 are used to test whether electric generation's mean of emission is different from selected generations. From the result, it can be concluded that generating stations near hot spots have much lower emission level than the average (Figure 4.7). This is another explanation for why hot spots problem did not really occur in the Ohio Valley.

One-Sample Test

	Test Value (average emission volume)= 24454.37597					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hot Spots Emissions	-2225.543	18	.000	-24149.11	-24171.91	-24126.32

Table 4.7: Mean Test for Hot spots Emission level and Average Emission Level

4.6 Summary

Based on the geographic analyses, it is found that the ARP is effective since the cutting rate of pollution level under this program is higher, at least not less, than before and the majority of states improved in their development/pollution ratio. On the other hand, this program is not as successful as the US EPA claimed judging by the half cutting rate of aggregate SO_2 emission volumes from power plants. Whether the effectiveness can be further improved by including more small power plants is not clear at this time. More studies need to be conducted in the near future.

Given that the service area of fuel-switching with lower compliance costs expanded greatly after the implementation of the ARP, more than 200%, the ARP has higher efficiency too. The potential saved compliance costs can be calculated by multiplying plants' capacities with the difference between the costs of fuel-switch and scrubber installation. Furthermore, this phenomenon demonstrates that the emissions trading policy has good flexibility in adopting more environmental-friendly technologies. However, since the deregulation of rail road contributes to the success of the ARP, it is doubtful that this program will be as successful as other countries because railroad deregulation is a factor that is hard to transfer.

Hot spots do exist around Los Angles and the border of Ohio and Kentucky. Regulations for selling emission allocations to these regions should be established if all traditional CAC systems are removed. Several reasons might explain why these hot spots have not caused regional pollution problems. First, local air quality standards, i.e. CAC tools, are still effective at preventing polluters from emitting pollution too much. This is contradictory to economists' advocation of removing all related CAC policies when implementing emissions trading tool to maximize the performance. Second, low population density and no sensitive area, such as lakes, around these points are another explanation. At last, power plants within a 50km distance of these hot spots are relatively small. They cannot produce high pollution volumes in a short time leading to severe local environmental problems. However, this analysis implies that global spatial autocorrelation and LISA should be done to study the character of pollutant and proposed region, making sure that hot spots will not cause problems.

In the following chapter, suggestions on integrating geographic analysis into the neo-classic economic framework will be presented. Steps toward building a prototype of a Decision Support System for emissions trading program designation, assessment, and optimization are proposed. In addition, factors of emissions trading program are identified based on literature and analyses conducted in this thesis. Discussions on migrating the ARP into China are presented at the end.

Chapter 5 Result and Discussion

5.1 Analyses Findings and Explanations

Change detection for the SO_2 pollution level shows that the ARP is effective due to the accelerated cutting rate after the implementation of this program. But this result is not as great as the fact of around a half emissions reduction for the power plants in Phase I. One possible explanation is that some other industries might have expanded their emission volumes in these years. The final environmental benefits from implementing this program are not so astonishing. This result seems contradictory since the pollution level usually went down even under the CAC system. This phenomenon might be explained by the environmental goals set under CAC system, which may be too tight or loose to get the best pollution level. If they are too loose, polluters will cut their pollution emissions only to the level specified by standards since they do not have incentive to cut more. Environmental damage will be greater. By contrast, if standards are too tight, economic growth might be slowed down because producers have heavier burden on the environment. On the other hand, since the annual SO_2 emission cap is also set according to historical volumes, the same problem may occur when more small-scale power plants are included in the ARP. This will be further discussed later.

In addition, pollution levels became more homogeneous under the ARP, which might be credited to trading. Power plants with unused emission allocations tend to sell them to others with EIs. This can lead to a more homogeneous pollution distribution because polluters with lower MAC usually have larger emission volumes making surrounding areas more polluted. On the other hand, since more than 85% of spare emission allocations were banked rather than traded, pollution distribution can be more homogeneous as this program continues. Since Phase II includes more power plants since 2000, banked allocations might be used to fulfill requirements for new participating plants, making pollution levels higher in the near future (Ellerman, *et al.*). In fact, the real annual emission volumes in Phase II have exceeded the allocated caps. This phenomenon has two meanings. One implies that environmental goal of cutting aggregate SO_2 emissions by 50% is too tight when including small-scale power plants because the increasing speed of MACs is usually quicker than the decreasing speed of production scales (exponential growth versus linear growth). The other is that the banking mechanism is critical in approaching the “best pollution level”. Polluters have EIs to optimize their emission allocation uses plan. Temporal trading with clear environmental goals partially removes uncertainty on finding appropriate emission caps to get the “best pollution level” and leaves this decision to individual power plants, alleviating the burden on the government greatly. Hence, different areas get different benefits under the ARP. Initially more polluted areas gain more environmental benefits due to the higher pollution emission reduction rates, while initially less polluted areas have more economic benefits because they have lowered their compliance costs from trading and increased their economic outputs. The cutting rate comparison map (Figure 4.2) confirms this conclusion, showing areas having higher effectiveness also have higher pollution levels. It is reported that the most polluted states in the ORV have the highest cutting rates (Ellerman, *et al.*, 2000, Pechan, 1995, U.S. EPA, 1996, 1997, 1998)

The effectiveness of the ARP can be tested from a sustainable development perspective. The ratio of GSP to the pollution level is used to present the status of sustainable development since it combines the two factors of economic development and the environment into consideration. Higher ratio means better sustainable development status. This program is successful given that around 60% of states improved their development/pollution ratios more quickly after ARP when similar clustering is done for every state separately removing factors other than policy difference. And change detection of pollution level above also supports this conclusion. But it did not get a distinguished result from the final result point of view as the EPA showed in emission volume reduction since 60% is not a dominant rate. The ARP made the national SO_2 pollution level more homogeneously, suggesting lower cutting rates in states with higher development/pollution ratios after this program’s implementation.

The ARP has gained great efficiency from adopting fuel-switch using PRB high quality coal rather than traditional scrubber installation. As the coal freight rate decreased after the railroad deregulation, service area of the PRB coal has expanded from around 400 miles to 900 miles. Many power plants within this area have chosen fuel-switching as an emission reduction technology due to its low compliance cost. The difference between compliance costs of fuel-switching and scrubber installation can be regarded as cost savings or achieved efficiency. It is estimated at around 1 billion dollars a year (Burtraw, 1998). This phenomenon also demonstrates the flexibility of the emissions trading policy. EI created under the ARP drove polluters to adopt fuel-switch with lower compliance cost, leading to rapid expansion of the PRB coal service area. Otherwise this service area would not stretch so quickly with no EI under the CAC system, even if coal freight rates decreased greatly.

Furthermore, this analysis also proves the importance of spatial analysis in environmental policy assessment. Since there are always some pollution processing technologies that rely on centralized points, whether they are supply source points in this case, or process sinking points such as sewage plants, locational theory and spatial analysis are crucial in deciding optimized efficiency and are not as hard to calculate out as money to integrate into economic framework. More complex models should be developed dealing with more realistic situations in environmental policy assessment from an economic perspective. On the other hand, since high coal freight rate reductions have contributed to the success of the ARP in Phase I, it is doubtful if adopting the emissions trading instrument in other countries will be as effective as in the US. Emissions trading policy tool is more appropriate for problems of fully utilizing existing pollution processing techniques with lowest compliance costs rather than creating new techniques. Although innovators also get EIs to find better environmental-friendly technologies, no extra efficiency will be achieved before these kinds of technologies are produced. Therefore, the emissions trading policy is better to be initiated under the circumstance that extra efficiency can be attained with existing techniques. And high environmental risk might occur if emission cap is set inappropriately due to the high uncertainty in finding the best pollution level.

In summary, the ARP is successful given that it leads to lower pollution levels, higher development/pollution ratios, and lower compliance cost.

On the other hand, relatively poor data quality might undermine my conclusion. My spatial analysis is based on pollution monitoring points that measure general air quality standard, not pollution source emissions. These belong to different categories under CAC instrument. Emission standards measure the output pollutant density, usually at the end of stack. Pollution densities allowed under emission standards are hundreds of times greater than the air quality standards. Air quality standards mainly concern public health and ecosystem tolerance and are much lower than emission standards because human beings and the other life forms cannot endure high density of pollution. Furthermore, air quality data are usually monitored near ground in order to measure pollution's damage to people, potentially leading to higher error because data values are low.

Rail reformation that leads to very low coal freight rate, which makes high quality coal from PRB available widely, made quick fuel-switching dissemination possible. This phenomenon also shows good flexibility and low compliance cost of the emissions trading policy. But it also implies that the institutional problem is not as important as people claim. It depends on some great changes in external factors. It is a way of accelerating change. But its effectiveness is doubtful if there is no technical change.

Banking is also critical in the success of this program for improved efficiency. It is a good way of dealing with uncertainty. Since regulatory targets are such that marginal control cost is rising over time faster than the relevant rate of interest, it creates incentives for power plants to cut more emission even though they might not be clear on their short-term marginal compliance cost (Environmental Defense, 2000). And due to the difficulty of finding accurate annual emission caps that ought to be equal to the national best pollution level ideally, annual caps are always different from the best pollution levels. Banking is vital for eliminating this difference by allowing banking allocation for future use. If the cap is bigger than the best pollution level, polluters can bank part of their allocations. If it is smaller, they can use the part they banked. Unless the cap in the first year is less than best pollution level, which is unlikely to be the case given that it is set according to historic data, banking serves as a method for getting best pollution level automatically. In addition, banking prevents an accumulate effect by encouraging polluters to reduce emission volumes earlier. Earlier pollution emissions have greater negative environmental effects if emitted volumes are the same. It is beneficial for the environment not only in the short term, but also in the long term.

5.2 Hot Spots Problem and Discussions

According to LISA test results, hot spots are found around Los Angeles and the ORV, indicating that hot spots problem cannot be eliminated under the emissions trading policy. But hot spots found in LISA tests have two important differences from the concept of hot spots in the literature. In the literature, hot spots refer to small areas where pollution levels exceed normal levels and cause some severe environmental problems. As indicators of local spatial clusters and as diagnostics for local instability, hot spots found by LISA might not have pollution levels higher than thresholds causing environmental problems. But regions around hot spots have the potential to be even higher pollution level than recorded. Many factors, such as industrial structure, climate, and landscape, contribute to the formation of hot spots. Hot spots around the ORV are mainly caused by landscape and fuels used by around power plants. The other ones at Los Angeles may attribute to industrial structure and landscape. Therefore, the hot spots problem is still possible if generators around hot spots bought too many allocations. It cannot be eliminated theoretically for the emissions trading policy. Rules restricting power plants around hot spots to import emission allocations should be established lest cause severe local environmental problems.

There are several reasons for why no hot spots cause environmental problems under the ARP. First, by contrast to the promotion of “free trade” to eliminate all related environmental standards bounding trade actions, local air quality standards are still effective in preventing harmful emission import. Since local air quality standards are based on public health rules and local situations, they vary spatially unlike the homogeneous trading rule. Polluters have to consider these standards to decide the amount of allocations to import. Tradings that may cause environmental problems are restricted according to these standards. Second, the effect of trading on pollution shifting is less than generator location. Since SO_2 has relatively long dissemination distance while emissions from power plants have high densities, distances between power plants and their emission volumes have greater effect on regional SO_2 pollution levels. After a couple of decades of implementing CAAA, the problem of inappropriate generation location has been almost solved by relocating or shutting down generators if they cannot meet all environmental standards. This should also be credited to the CAC system. Third, the demand for electricity is highly inelastic. Combined with the fact that pollution emissions are proportional to electricity production, it is unlikely for polluters to use their allocations in a very short time since extra electricity outputs can hardly be sold. At last, no significant trends can be discerned in the flow of traded allowances on a regional level under the ARP. Net inter-regional trades of allowances constitute only 3 percent of all allowances used (Environmental Defense, 2000). Summarily, unlike optimistic belief that the emissions trading instrument does not have a hot spots problem, which is the reason for restricting trading, the hot spots problem remains for decision makers to consider if they want to use emissions trading instrument to address environmental problems. The ARP does not have this problem due to the mature CAC system that has been implemented over a long period.

Solutions to eliminate the hot spots problem include zoning with different MSBs, especially around the hot spots from an economic perspective. Rules restricting inter-zone trades ought to be added like “currency conversion”. But economic efficiency will not be lowered in this way because best pollution levels with highest efficiencies are decided based on not only MACs, but also MSBs. Since trading is an option for polluters to lower their MACs, polluters at different locations do not take variances in MSB into consideration under homogeneous trading rule. The assumption of “certain amount of emissions does the same harm to the environment regardless of location”, which means homogeneous MSBs in economic terms, is unrealistic. Reduced tradings are the ones that should not happen since polluters have different associate MSB around. Due to different geographic situations, such as population density, distance to pollution source, atmosphere stability, and ecosystem sensitivity, MSBs vary spatially. This assumption underlying free trading allocation is inappropriate.

MSB has spatial differences because factors that form it are heterogeneous. These factors are public health, visibility, ecosystem stability, and material erosion. In practical econometric models to calculate MSB, public health, visibility, and recreational lake fishing are considered, which form the majority of MSB and easy to measure (Burtraw, *et al.*, 1997). Since hot spots are small regions that cluster locally and have high variances of the pollution densities, they can be zoned as areas with high MSBs. In this way, the hot spots problem can be solved since lower emission allocations will be imported into this kind of areas than other zones with lower MSBs.

First, heterogeneous demographic distribution makes social marginal benefit vary spatially. Population density is one of the most important factors in determining the number of people that are likely to be affected by pollution in public health. The more people get sick by pollution, the higher cost should be paid. In addition, age distribution also plays a role in public health issue. Given certain amount of a kind of specified pollutant, children and older people are more possible to be affected. Thus, MSB is heterogeneous instead of homogeneous, which is an assumption underlying emissions trading instrument.

Second, different ecosystems at different locations have different sensibilities to pollution. Given the same amount of a certain pollutant, some ecosystems may not be affected, but some of them will change, even collapse. In the case of recreational lake fishing, a kind of ecosystem focusing on some specified fishes, their sensibilities to SO_2 are still different according to water volume, flow volume, and fish species. Ecosystem also has a spatial component.

Third, different materials have different marginal costs. The damage to constructions like buildings varies spatially. Plastics are much harder to erode than iron. Related to the distance and directions from the pollution sources, it is also different. But these factors don't change greatly. It can be overlooked in MSB zoning.

Last, visibility can be modeled with recreational and residential benefits, even possibly with air plane postponed, to present the MSB of pollution processing. Since visibilities at different locations can be different because of atmosphere conditions, such as stability, temperature, density of other pollutants such as particles, they are usually different in different regions.

In this case, dividing the whole country into different zones, especially areas round hot spots, might be a good idea to solve this problem. This method has several merits. First, even though trading will be more complex as some rules will be added, it keeps the basic trading rule in a simple form. Conversion between two places with different MSBs is difficult to be done due to the complex MSB functions. This is especially true given that there is little literature on how this function varies spatially. Clustering places with similar MSB functions into several zones and then giving different conversion factors to them can be an effective solution. It is also applicable because these places tend to be clustered spatially. Second, this method is easily adopted because zoning has been formed by local environmental standards. Places were divided to implement different levels of environmental standards based on their local situations. This scheme can be used first, then improved one step by step. Lastly, zoning is easy to implement using a simple technique, such as clustering. It doesn't need many data and is intuitive for replication and training.

Therefore, the hot spot problem is possible under the ARP. The reason it does not happen might lie in the fact that inter-state trading is scarce due to legislation and constitutional reasons (Environmental Defense, 2000). Policy should be modified to differentiate MSB to regulate spatial trading behaviour.

5.3 Emissions trading Policy Designation

There are several questions that should be considered in work to design a policy to address some environmental problems using the emissions trading instrument (Colby, 2000). This scheme is widely accepted in literature. The only question not covered in Table 5.1 is the issue of coordinating the emissions trading policy tool with the existing tax system, which usually decreases efficiency of the emissions trading tool (Fischer, *et al.*, 1998). All of these issues will be explained separately.

Features	Conflicts/Considerations
Nature of right to be traded	• Duration of right (perpetual or limited?) • Right to use, to consume, to waste • Forfeit due to non-use • Bankable for future use
Initial allocation of tradable right, to whom?	• How get tradable rights? • At what cost?
Initial allocation of right, how much?	• Historic use levels of degradation • Historic users want permits for full customary use
Trading mechanism	• Regulator control vs. 'free market' • Privacy of transfers vs. public info on trades/prices
Trading approval process *	• Transaction costs increase with more complex process • Process must account for externalities and public goods
Accounting/Monitoring	• Costs for verifying information • Costs of measurement devices • Reliance on voluntary reporting vs. official verification
Enforcement/Compliance Incentives*	• Enforcement cost • Agency loyalties to resource users • Politically difficult to prevoke permits
Fees to cover administration cost*	• Should resource users cover all costs? • Should tax payers bear some costs?
Linking use values to resource condition	• Users want certainty in use levels • Environmental advocates want use adjust to resource conditions
Limiting Entry	• New entrants want 'in' at zero cost
Equity constraints on transfers	• Constraints limits market gains • Communities linked to low-value users lobby for protection

Table 5.1: Emissions trading policy design features (Cobloy, 2000)

Summarizing both case studies from the literature and analytical results in this paper results in the following comments on the emission trading instrument.

First, the criteria for selecting pollutants to be regulated should be based on their lasting time, dissemination abilities, and importance to certain environmental problems. Since the emissions trading policy instrument internalizes externalities by making emissions an exhaustible resource, pollutants should be able to last a long time to be easily monitored and counted for emission volumes. If pollutants are inconstant, uncertainty about consumed emission permits will be very high, which make polluters reluctant to participate the emissions trading programs. In addition, pollutants can disseminate to relatively larger areas leading to more homogeneous pollution patterns, making spatial permit trading safer. The global Moran's I indicator can be used to test whether proposed regulated pollutants are appropriate. Higher Moran's I indicates higher positive spatial autocorrelation for these pollutants, which are more suitable for the emissions trading instrument. Lastly, pollutants to regulate ought to be the main products to cause certain environmental problems. Successful programs implementing the emissions trading instruments have regulated pollutants such as SO_2 and chlorofluorocarbon (CFC) with longevity longer than several months. From this point, emissions trading program under the Kyoto Protocol is expected to be good since CO_2 meets all the criteria. But an emissions trading program to regulate Biological Oxygen Demands (BOD) for water pollution is doubtful since it can not last for a long time and disseminate quickly in water.

The industry to regulate should have the following characteristics: First, it has adapted to regulation. The ARP is successful because the electricity generation industry has long been regulated, and can make adaptable and sensible responses to policy changes. By contrast, programs for western US water quality protection implementing emissions trading have not been successful in part because the agricultural industry has not been used to regulation (Cobloy, 2000). Second, it is better to regulate industries with point sources because they are easier for government to monitor and regulate. Emissions from areal sources or line sources are hard to count. Further, emission contributions are difficult to credit to individual polluters for clear properties. Thirdly, the industry to regulate should count for the major emission volumes for certain pollutants. The emissions trading instrument needs great efforts to implement, such as monitoring network installation and institution establishment. As geographic analyses in this paper show, counting for the majority of aggregate emission volume is even helpful for others to conduct policy analysis since pollution level data is easier to retrieve. Lastly, the industry to regulate is better to be without oligarchic markets (Cason, *et al.*, 2003, Zhang, 1998). This is one of the factors for the unsuccessful case in fishery protection (Cobloy, 2000).

The initial allocation transfer is sometimes better to be auctioned rather than grandfathered. Auction is critical for preventing associated rent-seeking behaviour within an interest-group, affecting the allocation of rights to pollute (Ellerman, *et al.*, 2000). Furthermore, there is no model that can allocate emissions reflecting their individual best pollution level perfectly, although it is theoretically possible and would make trading useless. In addition, like stringent CAC standards for new sources, grandfathering gives rise to entry barriers for new sources to enter the market because they must buy their emissions permits while existing sources obtain theirs for free (Grubb, *et al.*, 1998, Stavins, 1998b, Zhang, 1999). Furthermore, auction can deliver signals on permit prices and raise revenues for compensating affected stakeholders directly. On the other hand, grandfathering emissions sources could also save considerable expenditures because they only have to pay for additional permits as needed. Thus, it increases the political acceptability of an emissions trading scheme (Baumol and Oates, 1988). In summary, individual governments should be left free to devise their own ways of allocating permits on the ground that they have many differences (Zhang, 1998, 1999). The best initial allocation scheme depends on case situations when implementing specific programs.

Since trading is the key feature for the emissions trading instrument to minimize compliance costs, proper designation of a trading mechanism is critical for the success of the emissions trading instrument. Both kinds of tradings, banking (temporal) and trading (spatial) ought to be restricted in some way. As mentioned in the former chapter, banking is critical in approaching the national “best pollution level” and building participants’ confidence on the emissions trading program. This mechanism can lead to the “win-win” situation that polluters lower their compliance costs as the compliance costs generally increases while the environment get more healthy due to the reduced risks from the accumulation of pollutant. But “borrowing” emission permits from the future is forbidden for similar reasons. Spatial trading is important for polluters to minimize their compliance costs and approach their best pollution levels at the same time. But MSB zoning is better to be established to eliminate the potential hot spots problem. In addition, implementing program in different phases is a good idea to initialize the emissions trading instrument gradually because it will make this program more acceptable for established emission sources.

Regulations other than the emissions trading instrument should be eliminated because it can increase the compliance cost greatly. The compliance cost under the ARP in Phase I was two to three times under PUC regulation than it was projected to be because some PUCs encouraged the use of local coal for the sake of the employment in coal mining industry (Burtraw and Palmer, 2003). This kind of regulations should be removed to increase efficiency and dissemination of better environmental technologies. On the other hand, the uncertainty of PUC regulations pushed utilities from the allowance market toward fuel-switching. The overall PUC regulations contributed to an unexpectedly low allowance price at the beginning of Phase I under the ARP, which means the price signal under the ARP was distorted (Arimura, 2002). And pre-existing tax system should be eliminated like PUC regulations. Pre-existing tax interacting with allocation trading distorts the price as the signal reflecting the average compliance cost. It can also double compliance cost (Fischer, *et al.*, 1998).

A monitoring and recording system for emission tracking is preferred to be CEM that is independent to emission volumes estimations based on inputs or outputs. Since emissions trading uses a cap to make pollution a kind of resource to eliminate externalities, counting emissions accurately is critical to make it effective and fair. Monitoring methods, such as input calculation, cannot be used for the sake of flexibility. If emission is calculated as a function of input coal used, polluters will lose incentive to install scrubber even though it is an effective technique. Trading tracking system is another important component for the emissions trading instrument. It can make the system transparent, build trust within participants and make further studies on optimizing its performance possible. A good Allowance Tracking System (ATS) should be able to provide information on aggregate trades and emissions with timely emission data reports for public participation and policy modification (Lile, *et al.*, 1997).

Policy uncertainty is another important issue. Uncertainty about social benefits is much larger than uncertainty about compliance cost. It is very hard to measure accurately. These two uncertainties have positive correlation in case for air pollution (Stavins, 1996). This implicates that MSB zoning is better not to be based on real functions, but indicators for simplicity and tolerance to uncertainty instead. However, generally speaking, the emissions trading instrument has less uncertainty than an emission fee. This is one of the reasons why emissions trading is more favorable than the emission fee now.

All the above points are issues that should be considered at the stage of emissions trading program implementation. Geographic analysis can be useful in deciding implementation scale, selecting pollutants to regulate, compliance costs estimations, and MSB zoning. In the following section, situation of air quality in China will be introduced. A proposed program is discussed and some suggestions made about adopting emissions trading instruments to China.

5.4 China Situation and Purposed Emissions Trading Program

5.4.1 China Situation

China established her first comprehensive Environmental Protection Law in 1979. This is a mixed system adopting both a CAC system and an emission fee instrument at the same time. But China mainly depends on CAC policies. The emission fee is only an accessory to CAC system. More importantly, China regards the emission fee as a kind of economic compensation (Zhang, *et al.*, 1998). By contrast to charging fees based on the emission volumes under a normal emission fee system, China charges fees only on the volumes that exceed the environmental standards. Emission fees are more like the fiscal sources of subsidy and environmental protection system maintenance than a tool to correct the externalities in China.

However, all these environmental policies are not very effective in protecting the environment. Air quality in China is still deteriorating. According to the World Bank (1997a), China's environmental cost is still very high. Pollution levels for particulate and SO_2 in many Chinese cities are two to five times higher than World Health Organization (WHO) standards. This occurs for two reasons. The first is that China only charges emission fees for the pollutants that cause the greatest damage to the environment. This rule encourages polluters to emit more pollution if they can produce different kinds of pollution averagely. The second is that the charged fee is much lower than the average MAC of polluters. Thus, even polluters who have pollution abatement equipment prefer to submit emission fees instead of reducing pollution (World Bank, 1997a).

There are economic, technical, and political reasons underlying this phenomenon. The economic reason is that Chinese firms do not have the financial resources to process pollution. Charging emission fees according to environmental economics principles might make firms unprofitable. This will prevent people in China from pursuing better living standards via local economic development. It is especially true in China since she is in the early stage of development and the desire for rapid economic expansion is strong. The "best pollution level" in China might even be lower than current economic development status due to institutional and structural reasons. First, MSB in China, especially for public health, is higher than many developed countries due to overpopulation. But, this difference is not reflected in the environmental standards. Second, due to former industrial distribution and structure problems, the best pollution levels for many polluters are under the profitable line. The best way of protecting the environment is to close those polluters.

Relatively outdated production and pollution abatement technologies in China make the cost of pollution abatement too high for polluters to afford. International funds, loans, and technologies are needed to solve this problem. In addition, limited to poor financial resources and low staff educational level, environmental monitoring methods are also primitive. The monitored data have large errors and are unreliable. For instance, the normal monitoring method for air quality is visual inspection of the opacity of flue gases (Xi, 1995). Although opacity indicator is mainly for measuring particulate density, it is used for estimating all air pollutants' densities in China assuming pollutant densities are highly correlated. Charged fees are calculated based on pollutant density measured by visual opacity inspections. Given that pollution densities cannot be measured separately, charging fees only on the 'worst cast pollutant' avoids high errors in estimating emission volumes.

Due to the political and institutional problems, polluters usually do not have enough incentives to take actions on environmental protection. For example, sewage and waster water are usually central processed in several large waste water treatment plants that gather polluted water from all polluters. In this way, charged emission fees should be transferred to the wastewater treatments as construction and maintenance expenses for processing wastewater. However, emission fees are withheld in the State Environment Protection Agency (SEPA). Wastewater treatment plants are unable to get this money. Hence, although a large volume of wastewater needs to be processed, some wastewater treatment plants only run under half of their planned processing capacities to save maintenance expenses. This kind of problem is formed historically. The government system should be revised to be more capable of solving environmental problems.

5.4.2 Proposed Program

5.4.2.1 Aggregate Emission Control

Based on these unsuccessful experiences compared to the success of the ARP in the US, SEPA plans to adopt the emissions trading instrument gradually in China to address the main environmental problems. In the ninth 'five-year plan', China SEPA began to implement so called "One aggregate emission volume control and two environmental standards compliance" that means setting annual caps and incorporating aggregation emission standards into traditional environmental standards (SEPA-China, 1997). In the next 'five-year plan' SEPA is going to continue establishing emissions trading system on a wider extent and in a more normalized and standardized approach.

In ninth "five-year plan", SEPA has established emission volume caps and allocation rules for all main pollutants and related monitoring and management systems (SEPA-China, 1997). Twelve main pollutants were taken into aggregate control. Three of them are for air quality: particle, SO_2, and dust; eight are for water quality: Chemical Oxygen Demands (COD), hydrocarbon (CH), cyanide, arsenic, mercury (Hg), lead (Pb), cadmium (Ca), and chromium ion (Cr^{6+}); one is for solid waste: industrial solid waste emissions. The goal of this project is to cease the trend of deteriorating environment and ecosystem damage and to improve some cities environment quality locally.

The way of allocating annual emission permits is to grandfather them based on historical data and pollution discharge coefficients. Permits are allocated according to several factors, such as administrative area, population, socio-economic development plan, industry structure, infrastructure development, current pollutant emission volumes, type of environmental functional zones, environmental standards for sources, pollution background density, and current environmental management system. Trading is not allowed in this system. But they deal with all kinds of pollution

The former emission fee system will be changed to charges fee according to the total emission volumes instead of volumes that exceed the environmental standards, and will charge with high fines for exceeding the annual emission caps. Implementation of emissions trading is listed in the plan as initial experiments through pilot projects.

5.4.2.2 Some Pilot Emissions Trading Programs in China

SEPA has launched some emission trading pilot projects. There are three local cases in Jiangsu Province, Zhengzhou city, and Shanghai metropolitan.

SEPA plans to implement the emissions trading program from 2003 if pilot projects run well. Characteristics pilot projects in China include the following: a) They are mainly implemented on small scales. But since China plans to move into the national scale, trading rules must be settled carefully. b) The emissions trading programs are not limited to air pollutants, but consider all kinds of pollutants. Based on the US experience, emissions trading program for pollutants such as water pollution are not very successful (Cobloy, 2000). This might be due to weak dissemination ability for water pollutants. c) CEM will not be installed to monitor polluter's real emission volumes. Both SEPA and private polluters do not have enough financial resources to support this network.

5.4.3 Important Considerations for Transferring Emissions trading to China

The following points are identified as important problems that need to be addressed when designing the emissions trading instrument to solve environmental problems in China.

CEM network is important because flexibility is one of the key features of the emissions trading instrument. Second best monitoring method can make it inflexible. For example, if emission volumes are calculated according to the processing techniques and input volumes, polluters will have no incentive to do a fuel switching. In addition, emission volumes should be monitored accurately and fairly since they represent financial resources under the emissions trading program. Furthermore, Chinese enterprises are unable to afford CEMs, especially for small scale polluters in primeval industries. The selection of environmental monitoring method needs careful attention.

As a proposed low cost alternative solution, the SEPA plans to test a kind of environmental monitoring technology named “sources analysis technique” for emissions trading program. This method relies on the government to monitor pollution volumes to avoid cheating. No in-site monitoring equipment is required, but some centralized monitoring points exist. The SEPA can identify individual polluters who are responsible for a certain amount of emissions based on the knowledge of emission characteristics. If this method is successful, it will become prevalent in countries at their early development stage because of its low cost and fairness.

Since the SEPA plan to implement parallel systems of emissions trading and environmental standards, compliance cost might be increased in this case. But this problem is not as serious as it is in US because former emission fee systems are ineffective with low fee rates. Even if polluters were forced to submit emission fees at the same time, it is still lower than the allocation prices, which reflects average compliance cost. So parallel systems will not increase the overall compliance cost greatly and affect polluter’s behaviour very much in China

The SEPA also plans to establish a trading tracking system similar to the ATS. However, it is questionable because China has different institutional structure. Information sharing is encumbered due to the centralized government structure in China. Each department is only responsible to the upper government with no need to cooperate with others. So, it is better for China to establish an integrated branch to supervise emissions trading program independently.

Similar to the US, power plants are the main contributors to the acid rain problem. China even has her own sources for high quality coal in Shanxi Province. Thus, copying the ARP to China is a natural idea in the next step of implementing the emissions trading instrument. This idea is supported by the fact that environmental damages paused by electricity production are large and are mainly imposed on regions far away from the electricity plant, which is suitable for a national program. In addition, since the damages caused per unit of particulate, NO_x, and SO_2 emissions are much higher than pollution treatment and prevention costs, polluters are more likely to be profitable if externalities are internalized as a kind of exhaustible source to sell (Zhang and Duan, 2003).

5.5 Suggestions

In this thesis, geographic analysis is added to former economic analysis for the ARP assessment and hot spots identification. It is found that the ARP is superior to its predecessor. But the hot spots problem still cannot be eliminated.

All of the three kinds of analyses, spatial-temporal clustering and change detection, hot spots identification, and service area identification for environmental-friendly technology dissemination, can be extended. More statistical analyses can be done in spatial-temporal clustering for further discussion in geographic characters' effects on the emissions trading policy analysis. Clustering for the development/pollution ratio needs to be done first. Further explanation for the status formation, such as institutional contribution, physical geography contribution, technology contribution, can be studied. This will leads to better knowledge not only on pollution and development, but also on the whole evolution process of how the emissions trading instrument affects our society and protects our environment.

As for the technology dissemination model, scripts can be written for automation so that it can deal with more complex situations, such as more supply points. Service areas could become discrete if different local coal prices are considered. More importantly, the dimension of time should be added as price evolution function in order to show the real dissemination process intuitively. Finally, the mechanism of adding new technology needs to be considered.

Moral's I and LISA index is employed to detect the hot spots. Optimizing searching radii can be further used for zoning areas. Regions, whose pollution level is 'homogeneous' within while 'heterogeneous' with its neighborhood, can be divided out. Like bubble mechanism, trading within this region is encouraged since pollution level remains the same. Intra-region trading will be inspected to make sure it is appropriate. It is also useful in spatial data mining system if the rationale and methodology of this process can be extracted and automated.

To eliminate potential hot spots problem without decreasing economic efficiency, spatial clustering for MSBs might be a solution. A spatial concept is integrated with environmental economics theory seamlessly in this way. It can be another hot problem in spatial socio-econometrics. However, whether it is applicable is still unclear given that the uncertainty of measuring MSB is much higher than the MAC.

Another interesting question is building agent-based model for emissions trading program optimization. It can be a useful Decision Support Tool (DST) for environmental policy makers. It has the following merits: a) Agent-based model builds the bridge between micro- and macro- economics. "Macro parameters" in emissions trading instrument, such as cap setting, initial allocation method selection, and compliance cost prediction, can be calculated out by studying micro individuals' reaction behaviour. Once macro parameters are input, the final scenario, such as pollution level, compliance cost, technology adopted, can be produced. Decision makers can optimize their policy by choosing different scenarios. Agent-based model can also deepen our understanding of the relationship between micro-agent behavior and macro parameters. b) An agent-based model can show the whole evolution process dynamically. Once initial parameters are set, all of the other parameter at every time stage can be got as the pattern evolutes. c) As a "social lab" the agent-based model can also be used to reduce the number of pilot projects. Not only can it save money and other resources, but also it can test policy without causing social conflicts.

In my proposed DST, point-to-point system (P2P) will be used for building distributed spatial data warehouse as the base of the whole DST. Agent-based modeling can be adopted to study polluters' behavior with several pollution processing options on micro level. Multi-Criteria Decision Analysis (MCDA) technique and Data Envelope Analysis (DEA) that is a step further from MCDA are useful in identifying options and performance assessment (Ganley and Cubbin, 1992). Different effects of aggregate pollution control and emissions trading can be tested out when trading is added into pollution processing options as one brand new method. Spatial statistical techniques can be used on macro level to extract knowledge such as relationships between different aggregate caps and final pollution distribution patterns. Several regional optimized options will be summarized out for decision maker to assess and select.

It will be helpful in migrating emissions trading program to other countries and deepening our understanding on the way to optimizing it.

Appendix A: Calculation steps for compliance costs of the PRB coal

The Formula 4.1 is got in the following steps:

$$C = \frac{50 \cdot (P_{PRB} \cdot H - P \cdot H_{PRB})}{S \cdot H_{PRB} - S_{PRB} \cdot H} + F \cdot \frac{50 \cdot H}{S \cdot H_{PRB} - S_{PRB} \cdot H} \cdot D$$

- Available data: Heat energy per ton (H) (mmBtu/ton), Sulphur content (S) (%), Coal price (P) (dollars/ton), Freight rate (F) (dollars/(ton*mile))

- Denotion: data on the PRB are denoted as (H_{PRB}, S_{PRB}, P_{PRB}); data on other locations are denoted as (H, S, P)

- Step 1: To switch 1 ton of local coal, the amount of coal need is H / H_{PRB}.

- Step 2: The change amount of sulphur content in this switch process will be [S - S_{PRB} * (H / H_{PRB})] / 100. Based on the chemical reaction formula, which is $S + O_2 = SO_2$, SO_2 change amount will be [S - S_{PRB} * (H / H_{PRB})] / 50

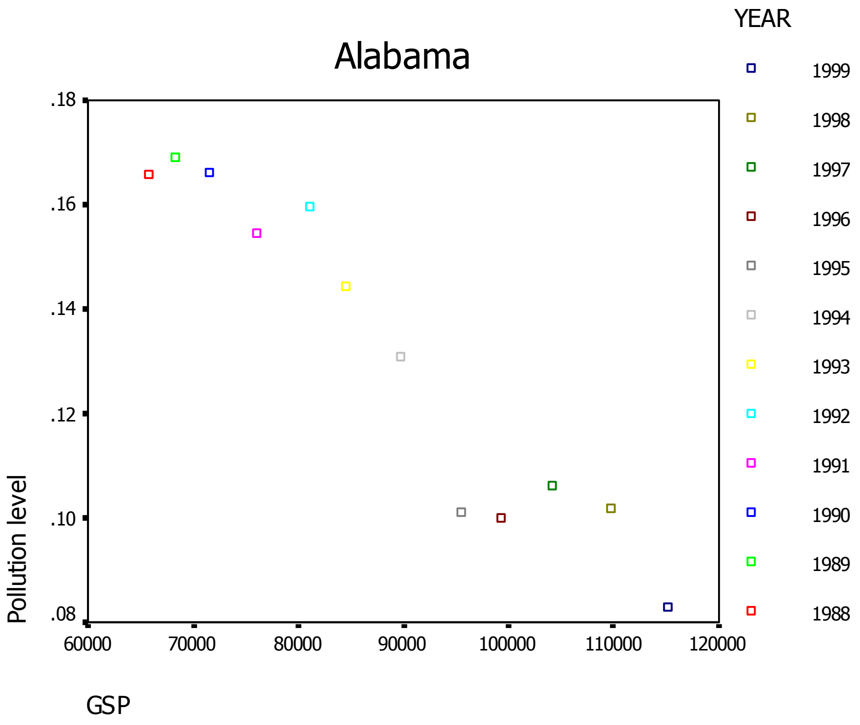
- Step 3: To reduce 1 ton of SO_2 emissions, the amount of local coal needed to be replace will be $\frac{1}{\frac{S - S_{PRB} \cdot \frac{H}{H_{PRB}}}{50}} = \frac{50 \cdot H_{PRB}}{S \cdot H_{PRB} - S_{PRB} \cdot H}$. And the amount of PRB needed will be

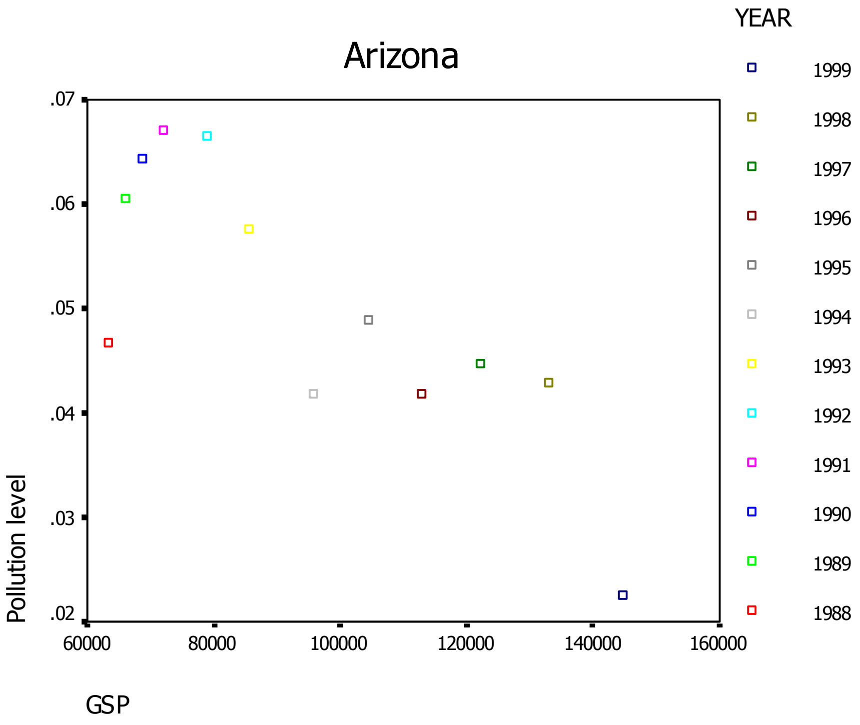
$$\frac{1}{\frac{S - S_{PRB} \cdot \frac{H}{H_{PRB}}}{50}} \cdot \frac{H}{H_{PRB}} = \frac{50 \cdot H}{S \cdot H_{PRB} - S_{PRB} \cdot H}$$

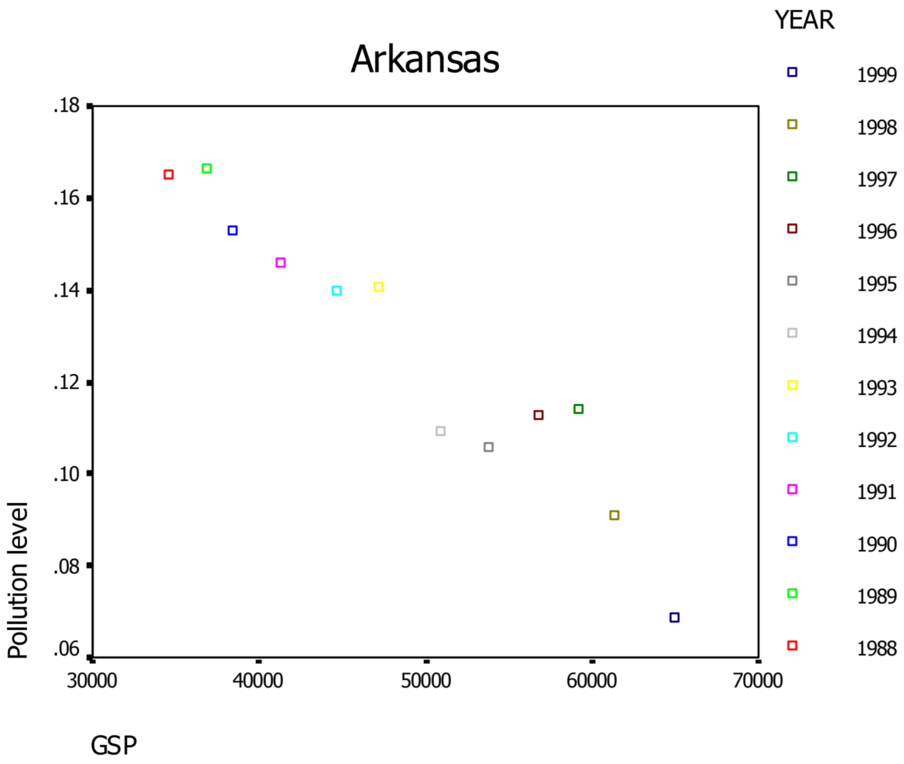
- Step 4: The price changed during this fuel-switching process will be $P_{PRB} \cdot \frac{50 \cdot H}{S \cdot H_{PRB} - S_{PRB} \cdot H} - P \cdot \frac{50 \cdot H_{PRB}}{S \cdot H_{PRB} - S_{PRB} \cdot H} = \frac{50 \cdot (P_{PRB} \cdot H - P \cdot H_{PRB})}{S \cdot H_{PRB} - S_{PRB} \cdot H}$

- Step 5: The aggregate compliance cost will be this fuel-switching cost plus freight in the following: $C = \frac{50 \cdot (P_{PRB} \cdot H - P \cdot H_{PRB})}{S \cdot H_{PRB} - S_{PRB} \cdot H} + F \cdot \frac{50 \cdot H}{S \cdot H_{PRB} - S_{PRB} \cdot H} \cdot D$

Appendix B: Spatial-temporal clustering



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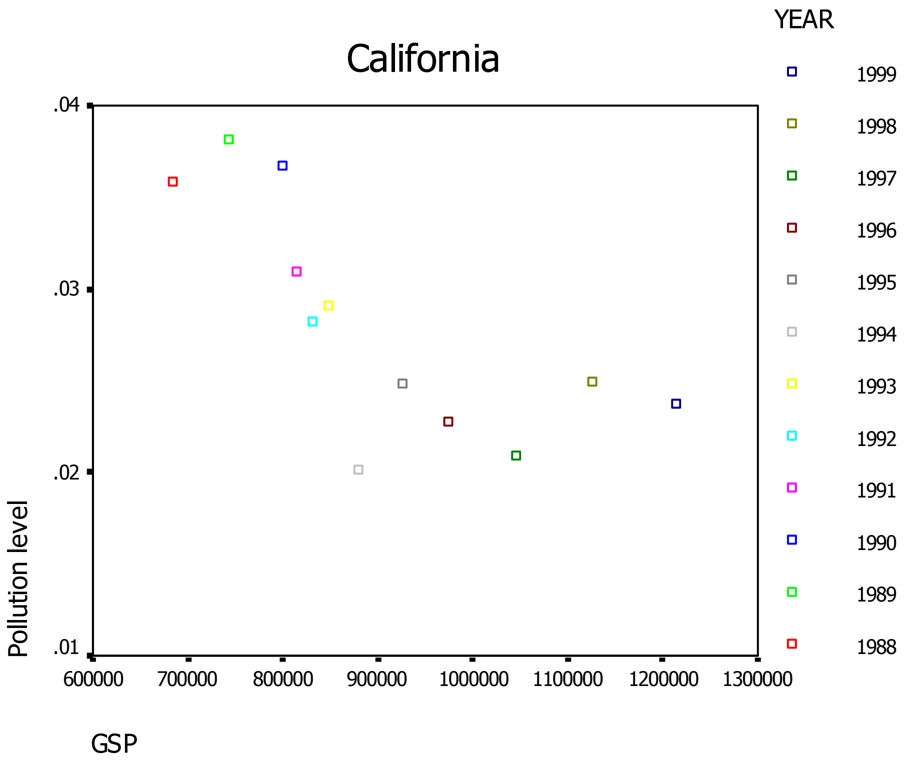
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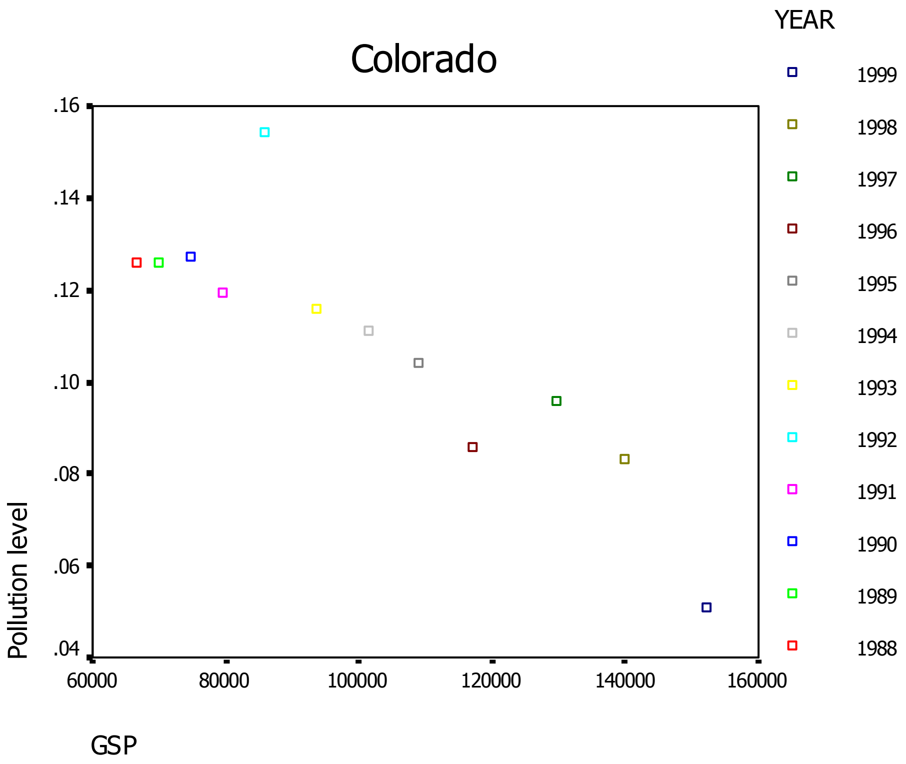
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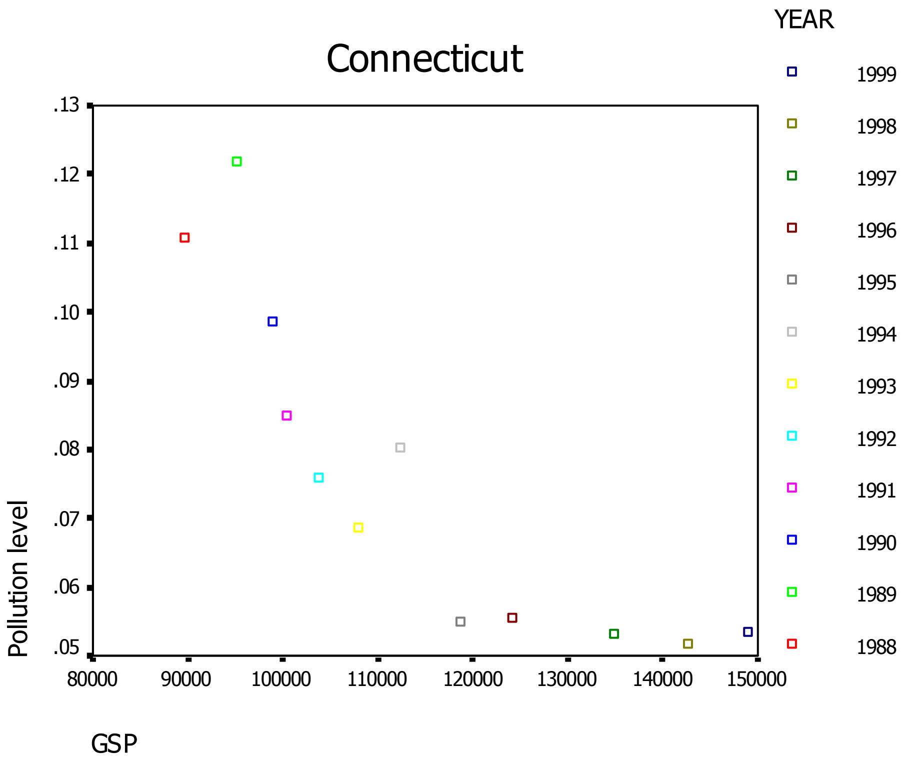
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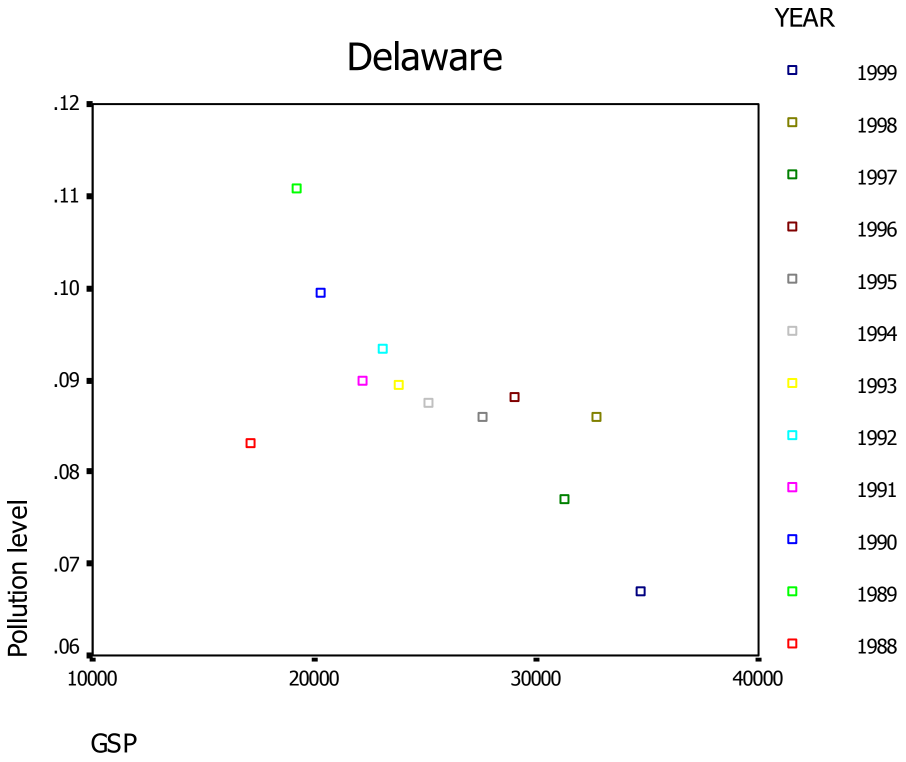
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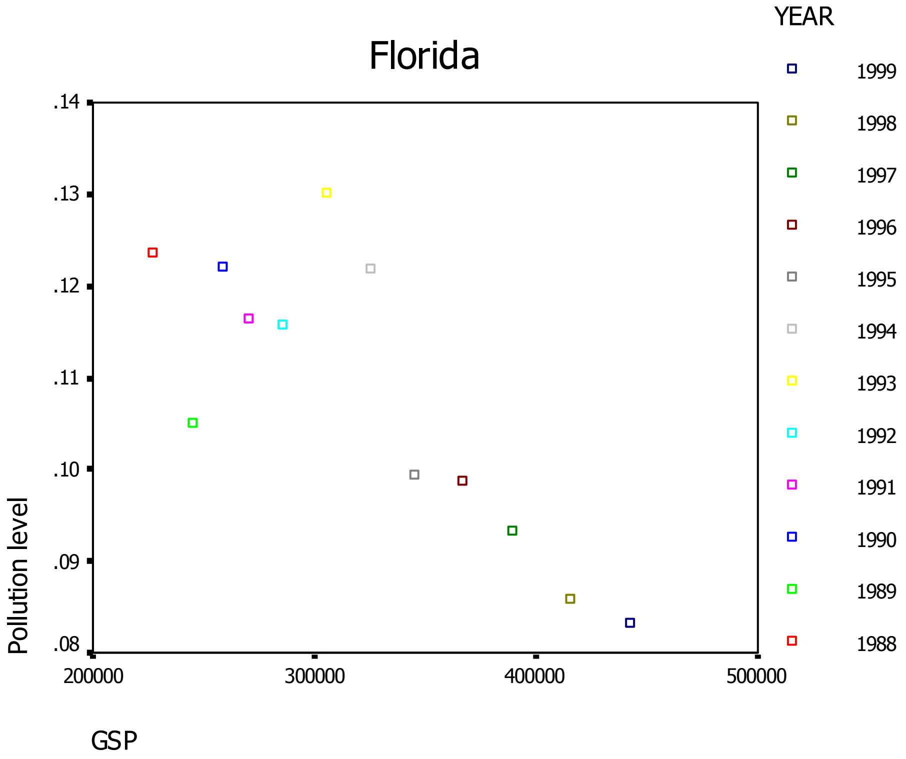
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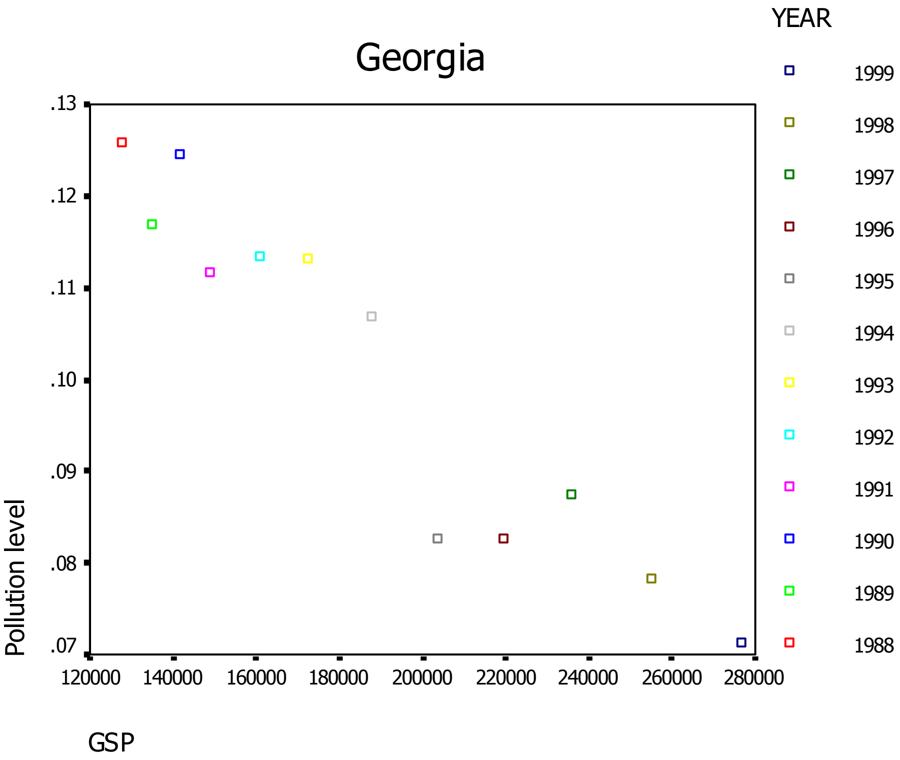
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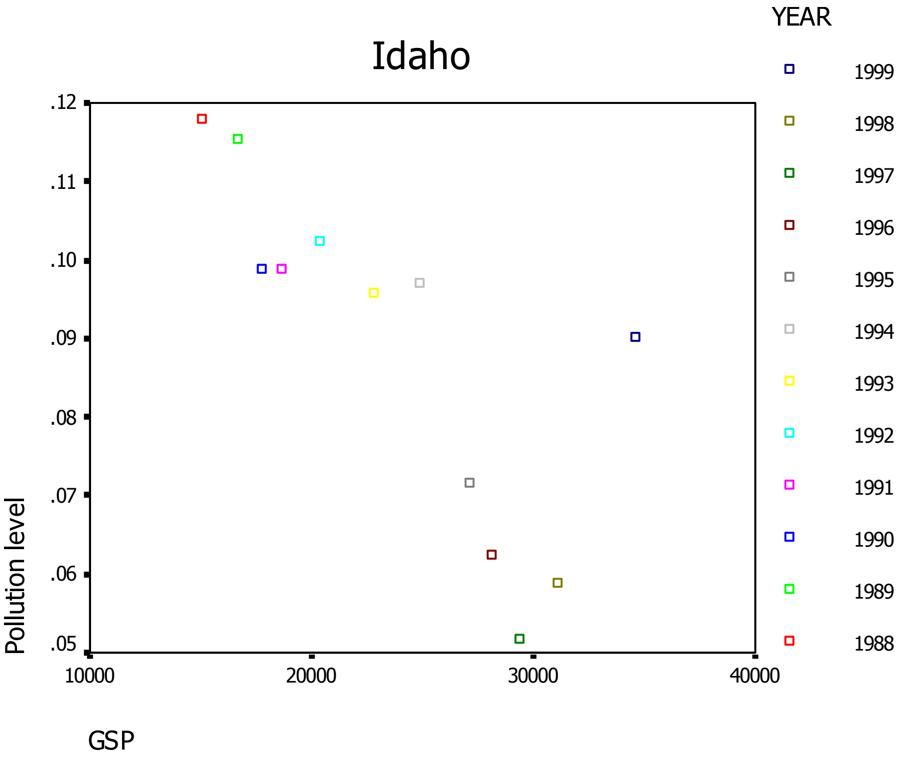
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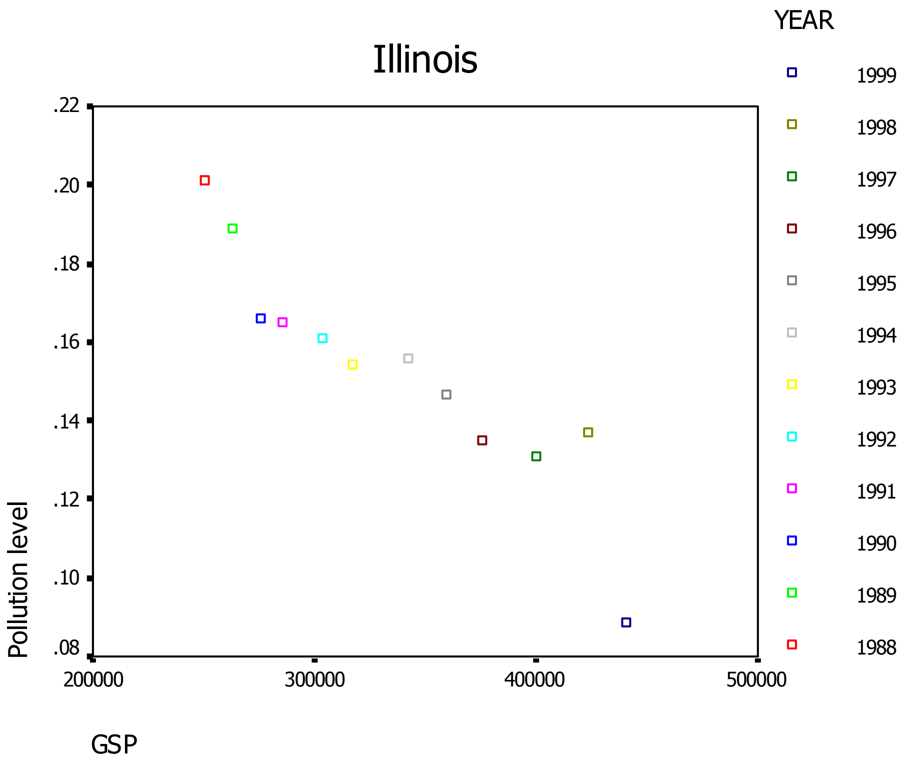
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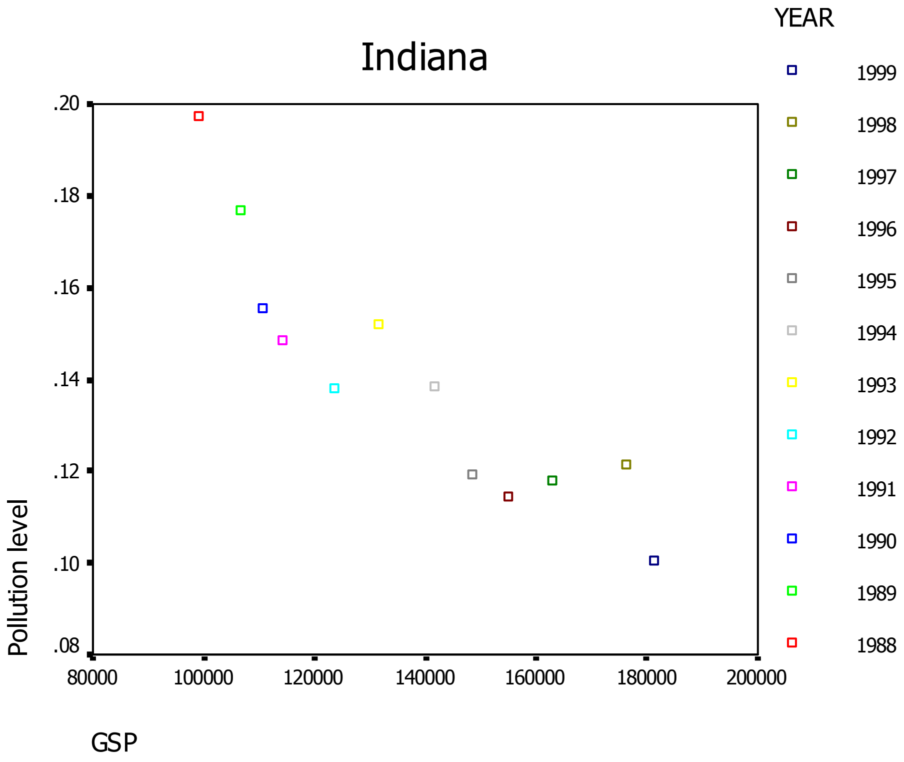
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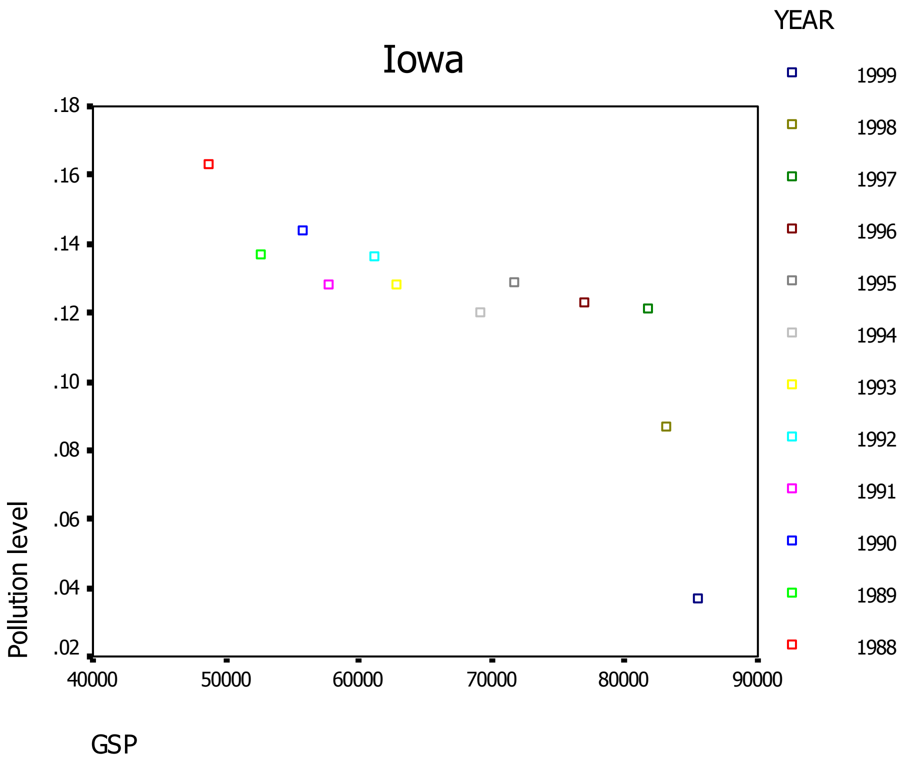
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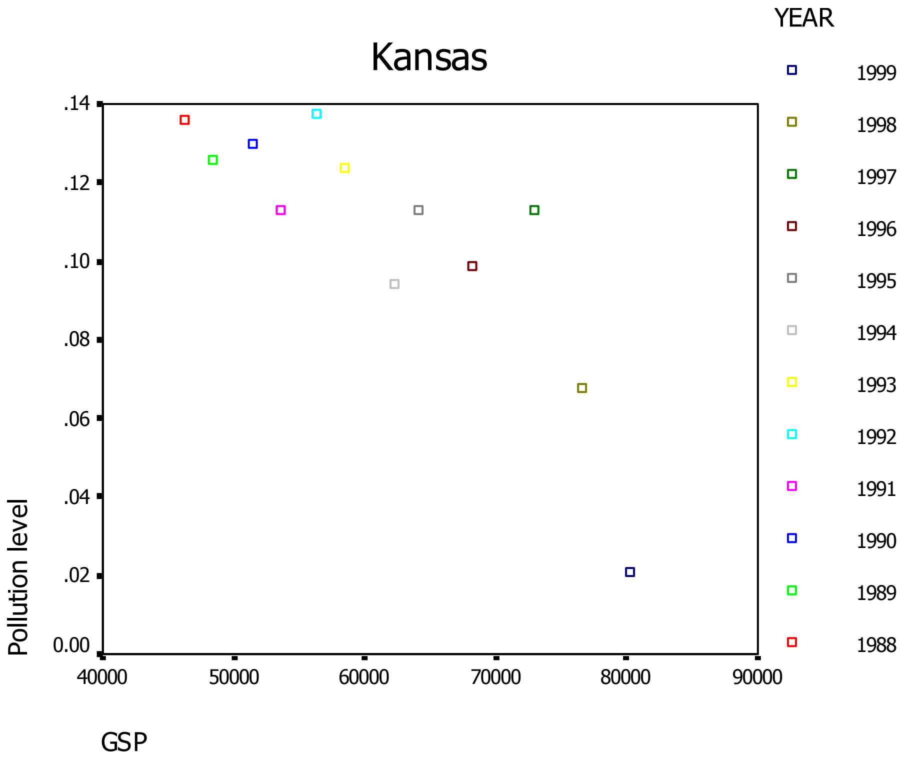
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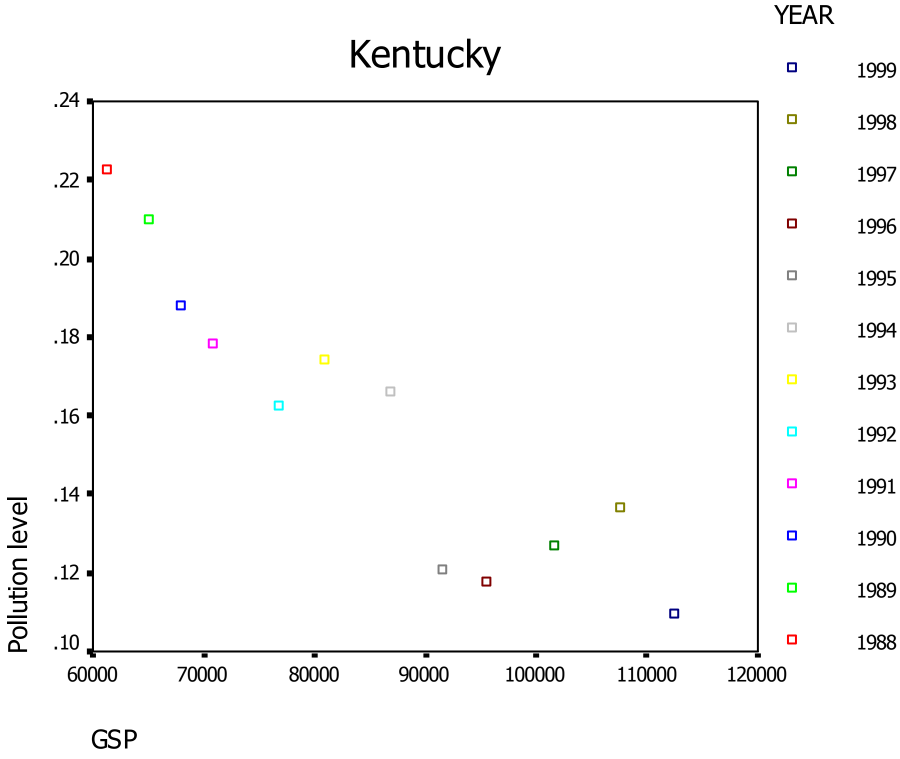
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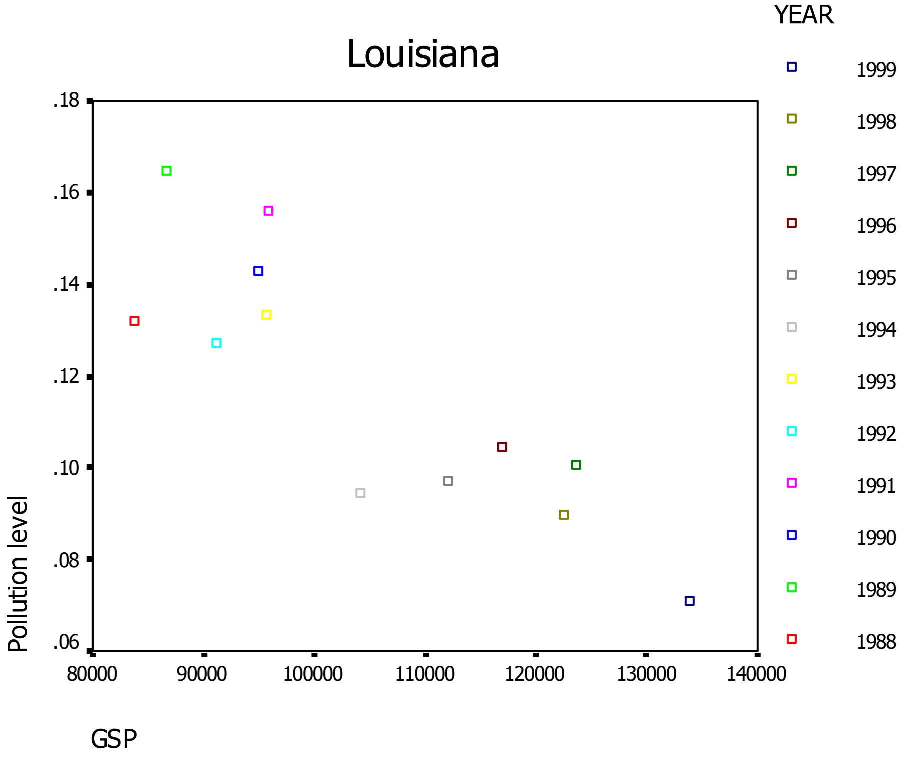
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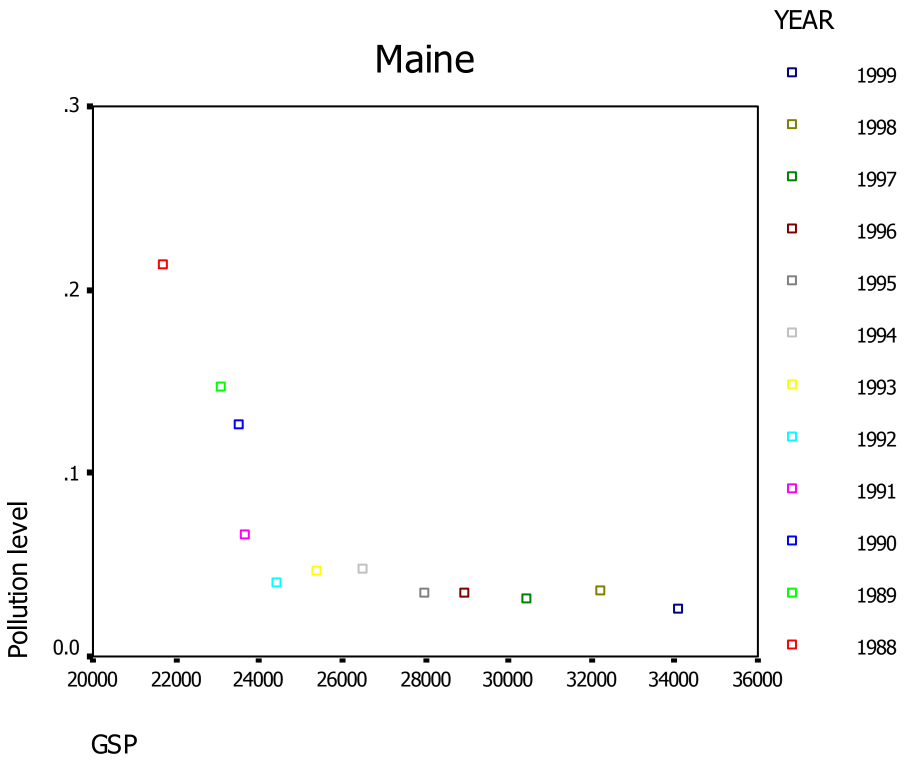
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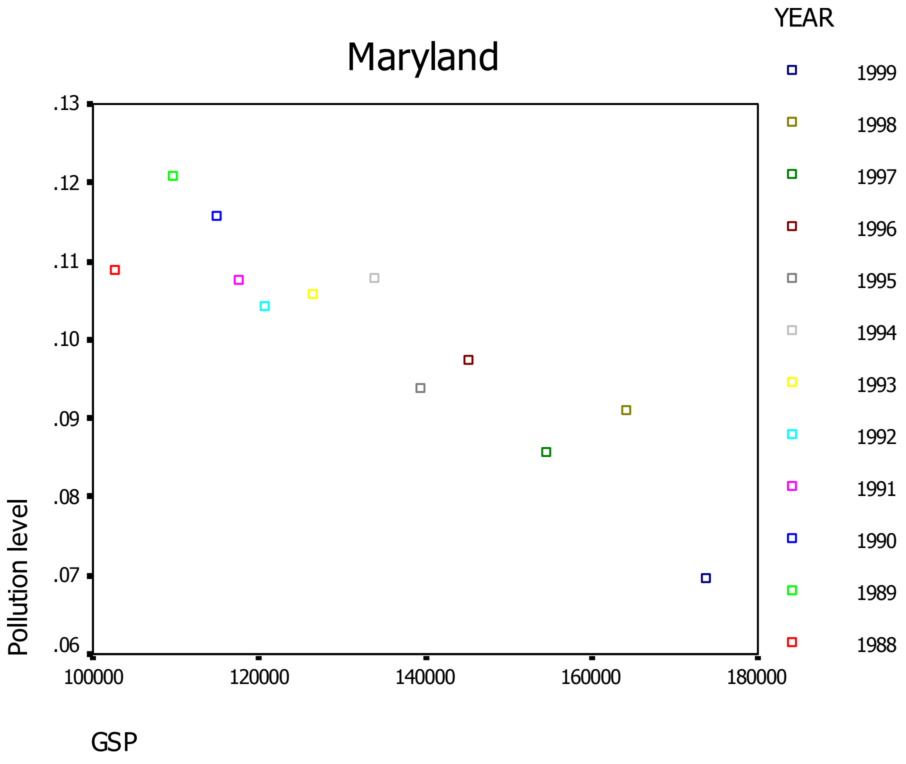
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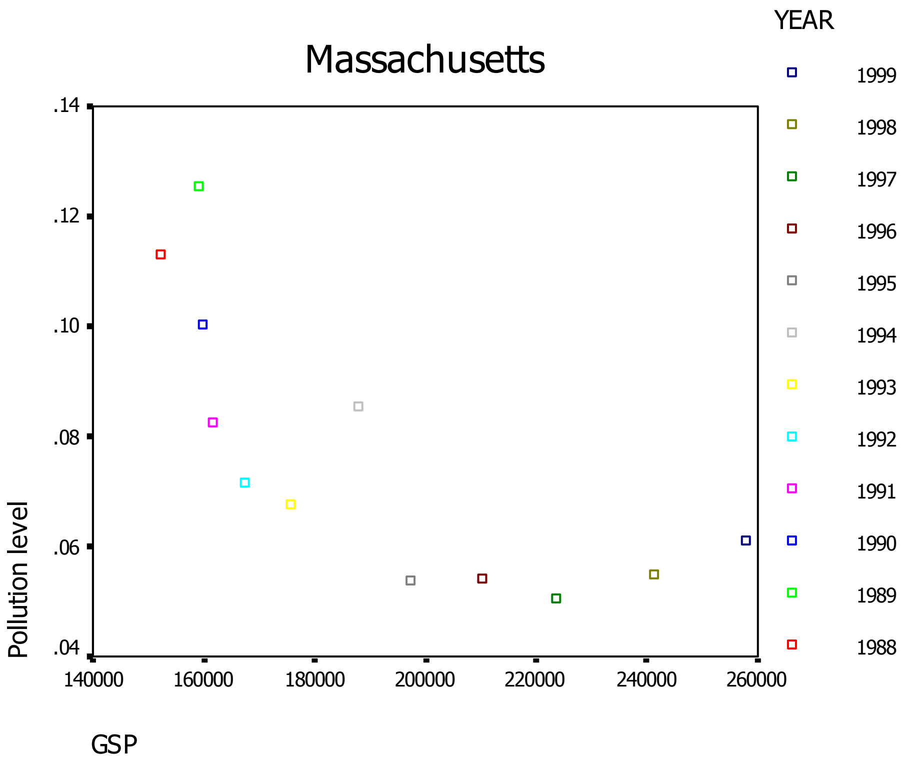
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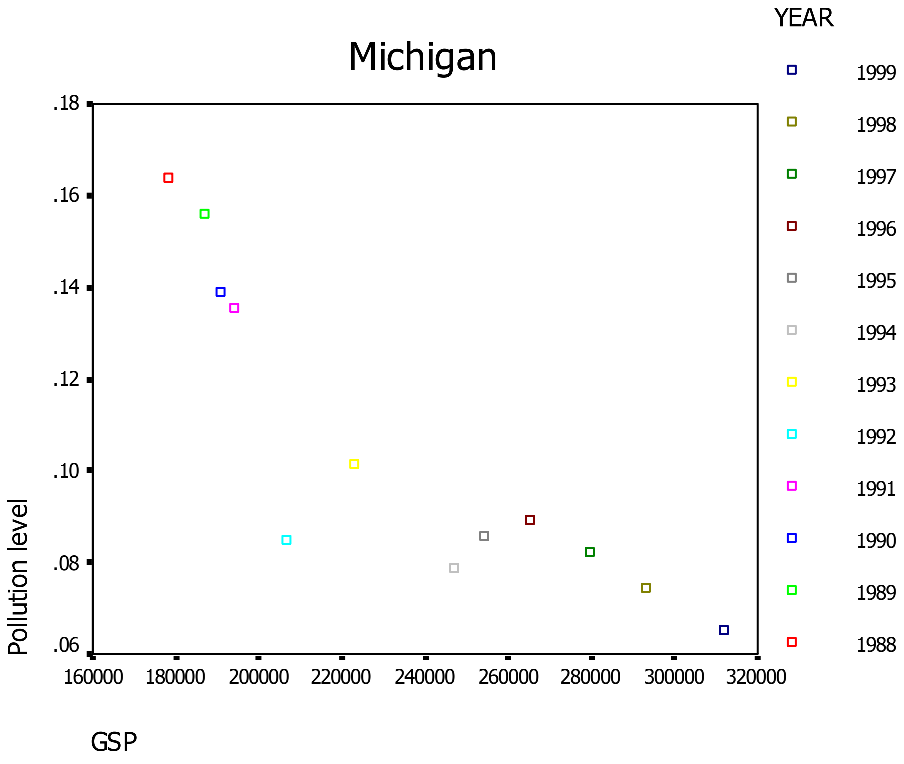
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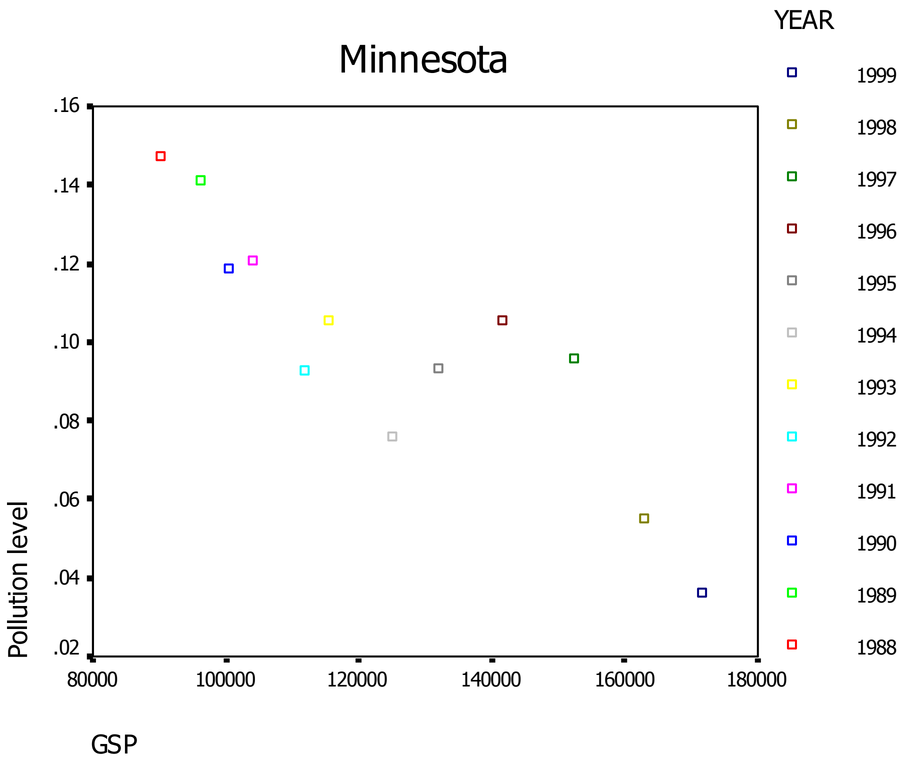
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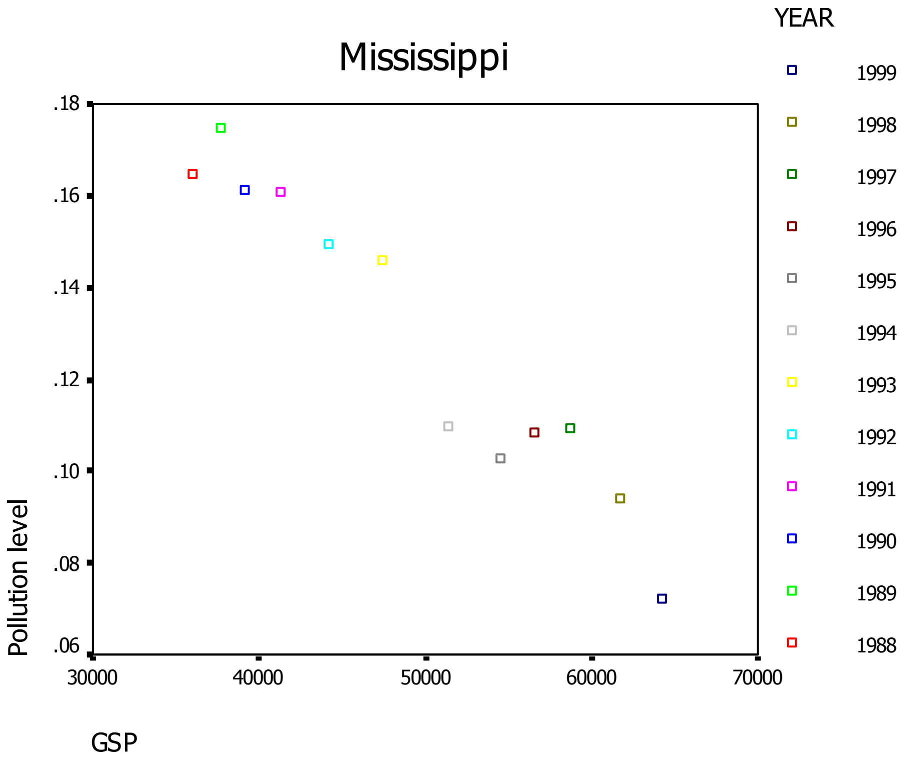
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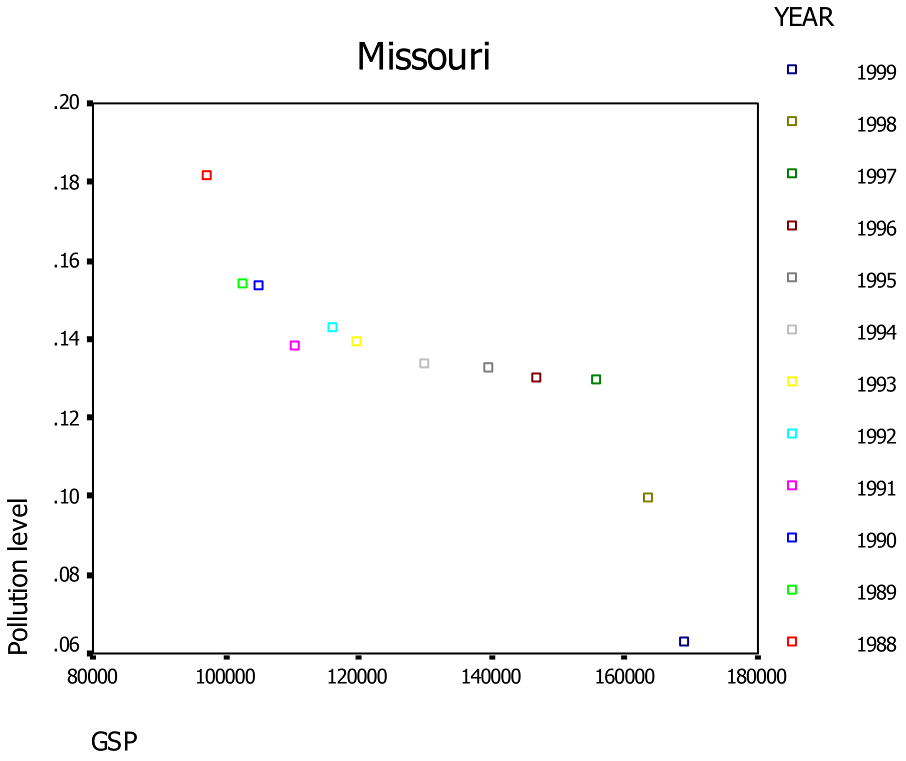
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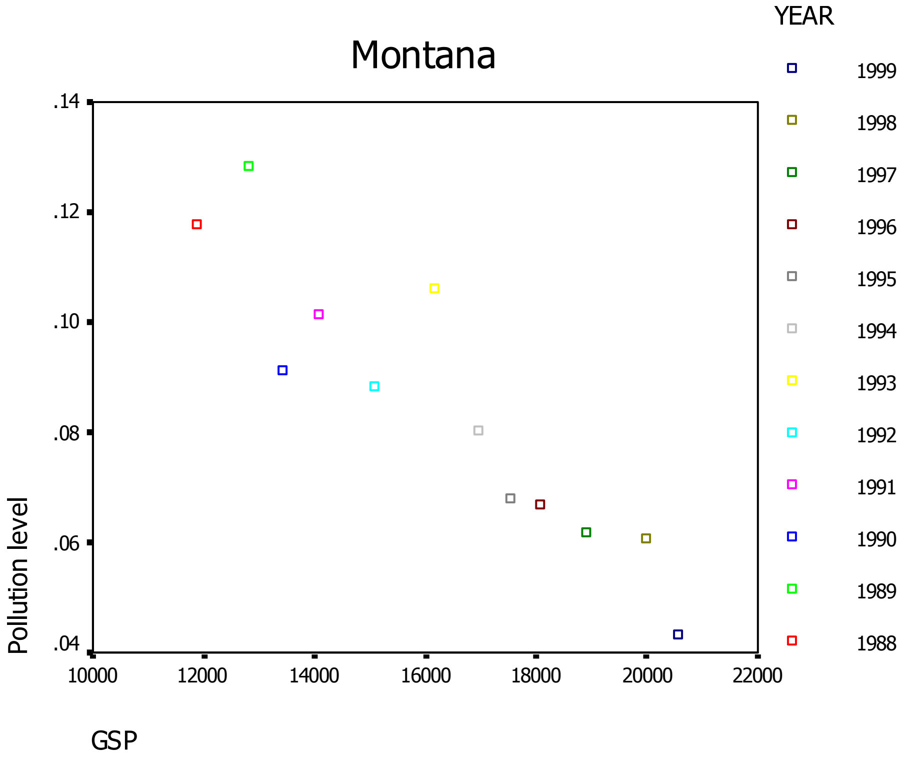
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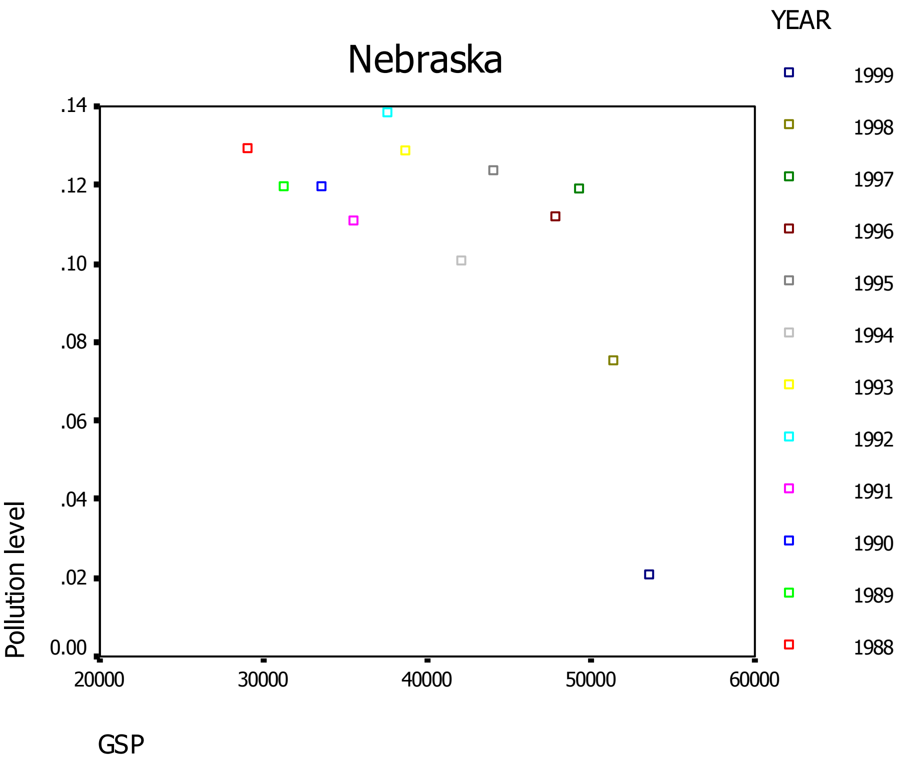
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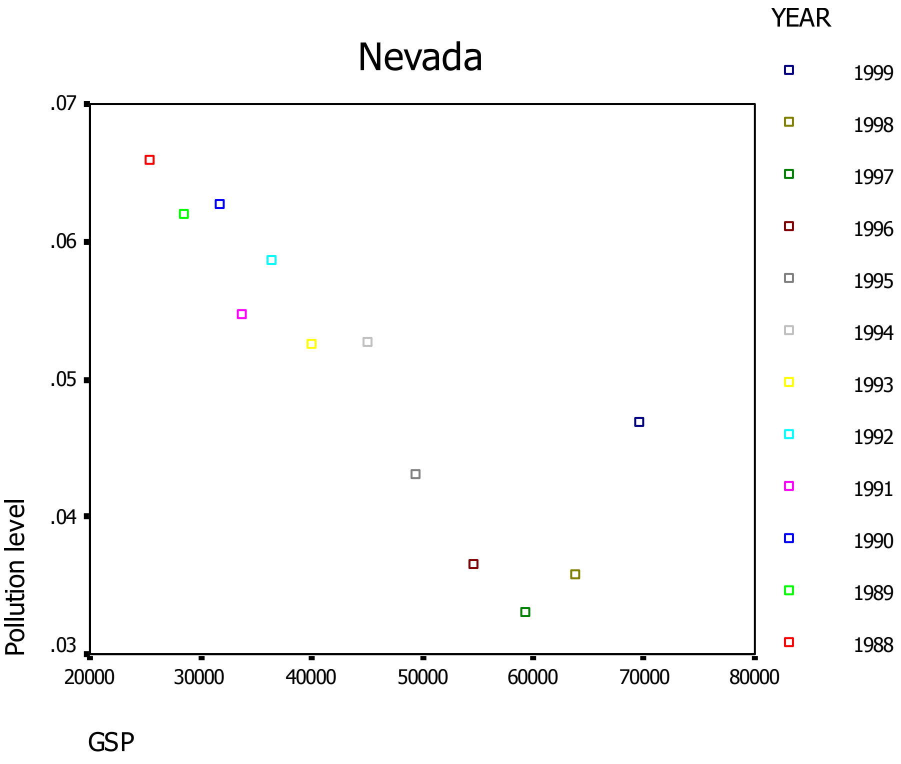
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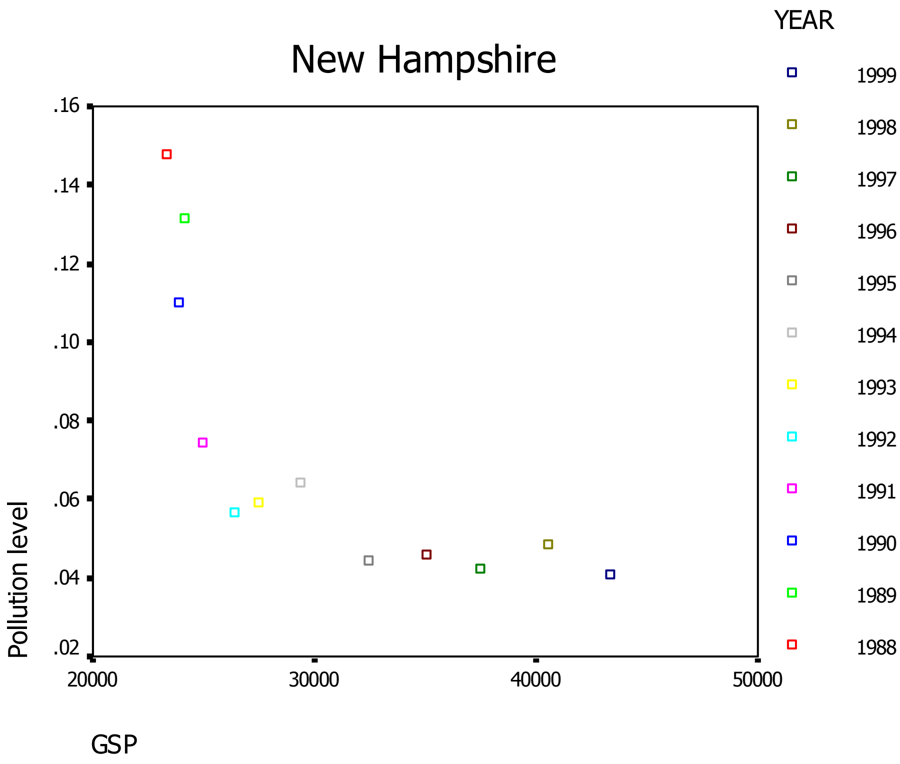
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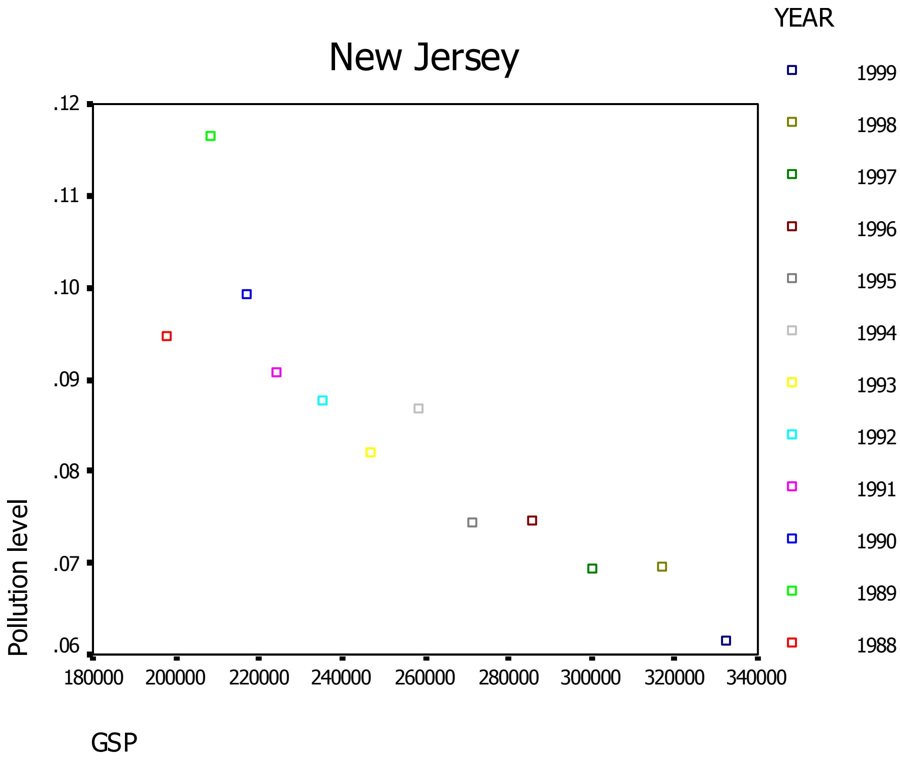
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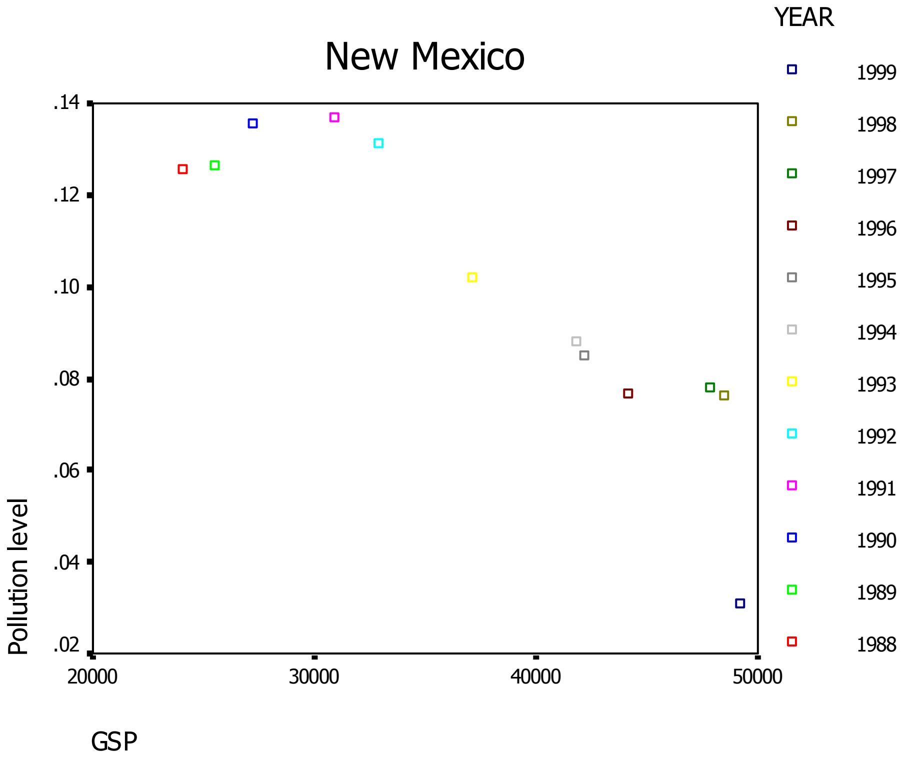
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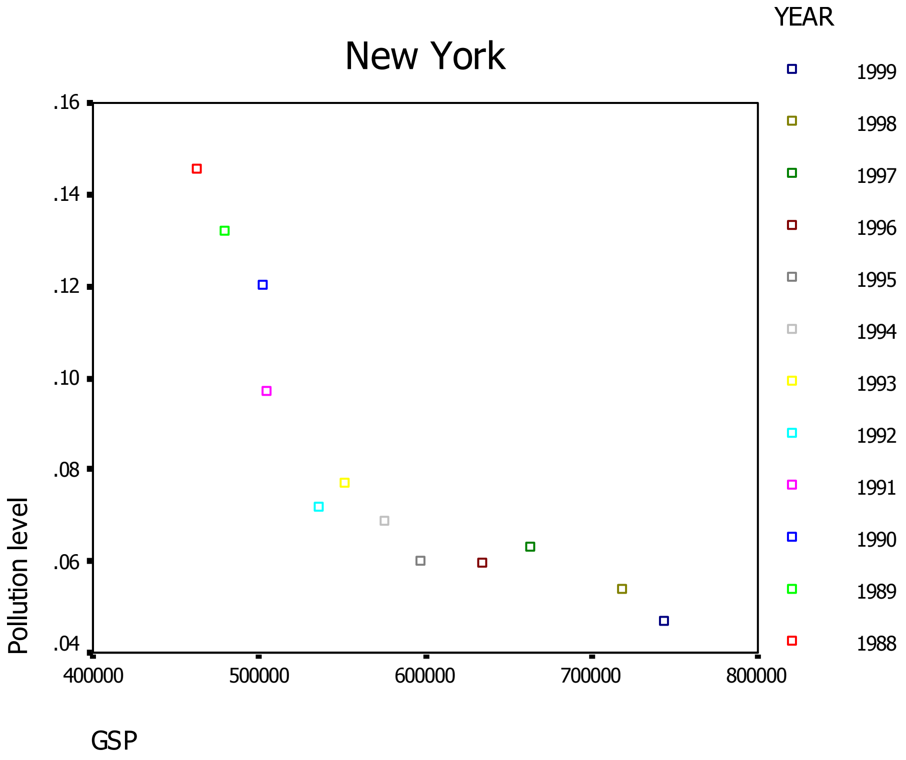
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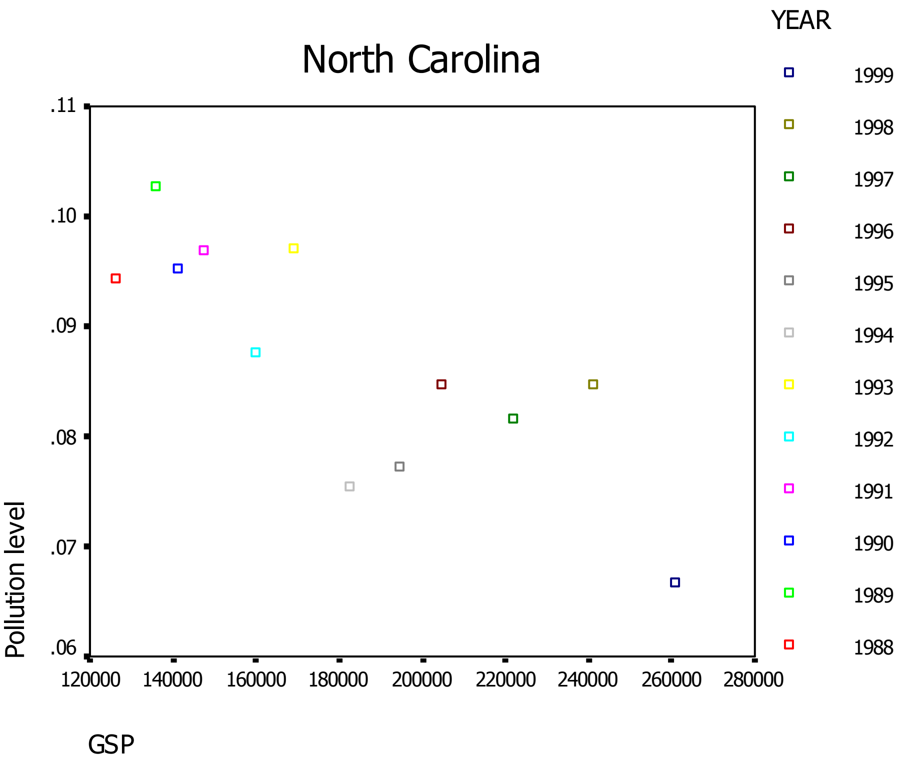
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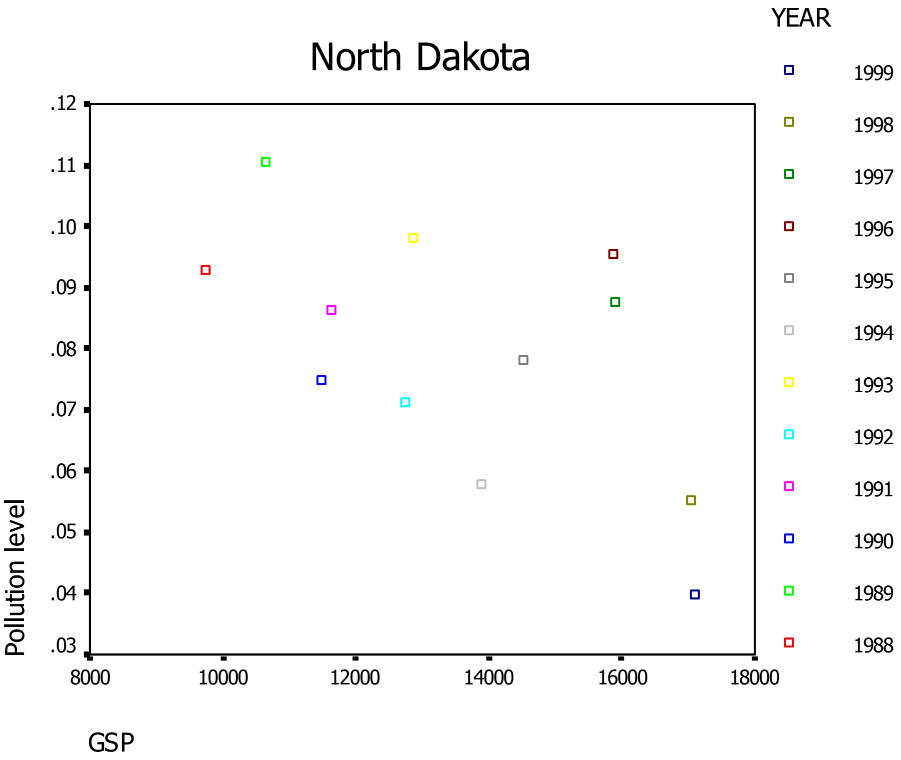
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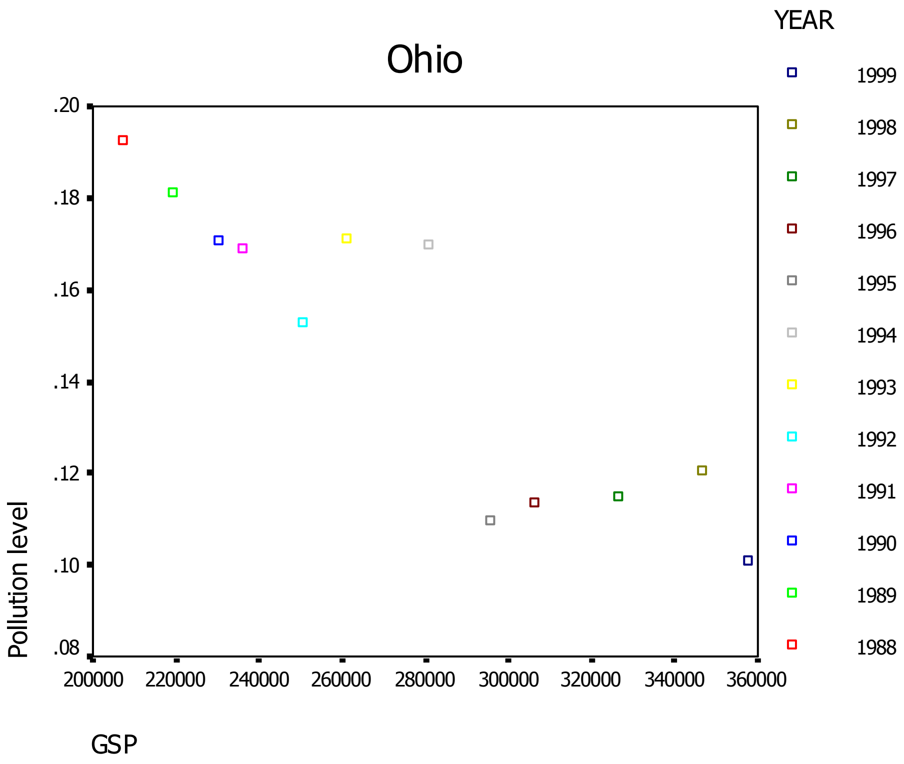
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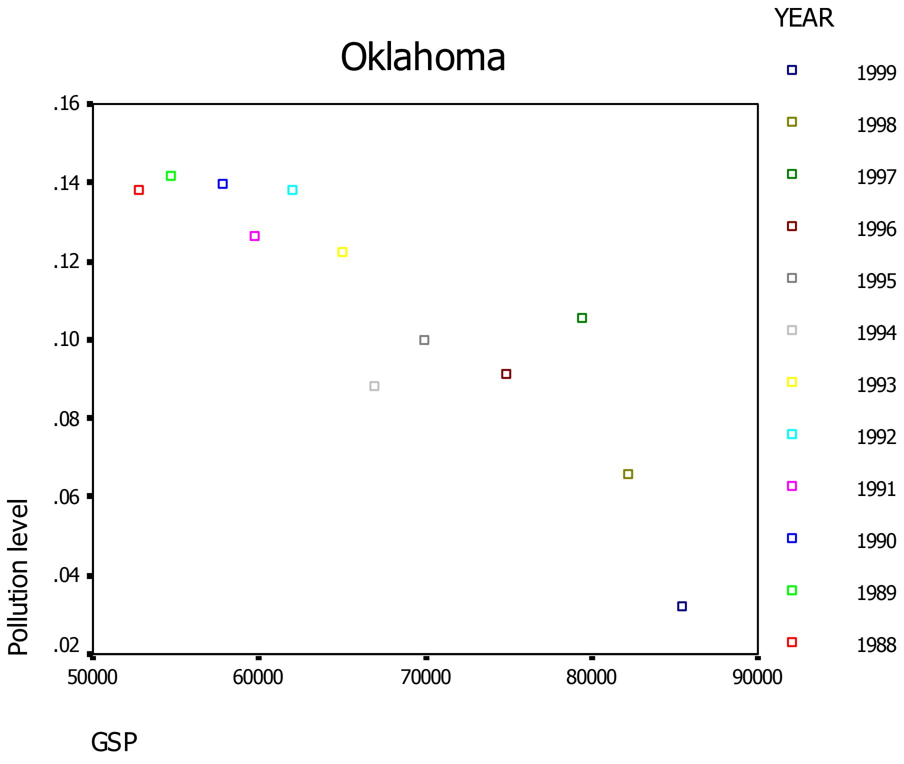
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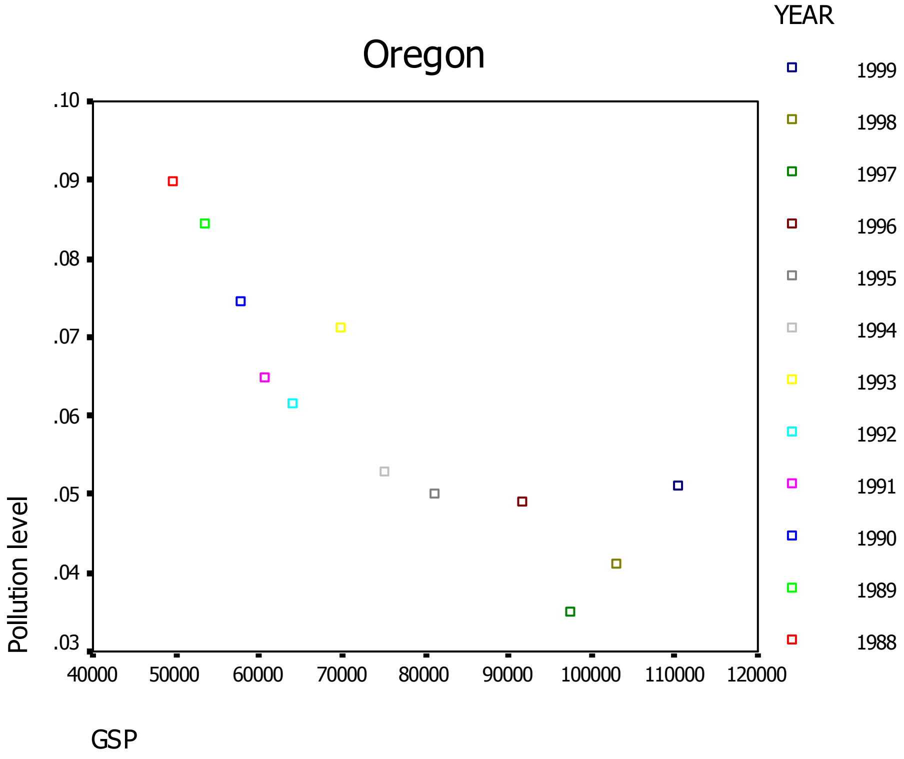
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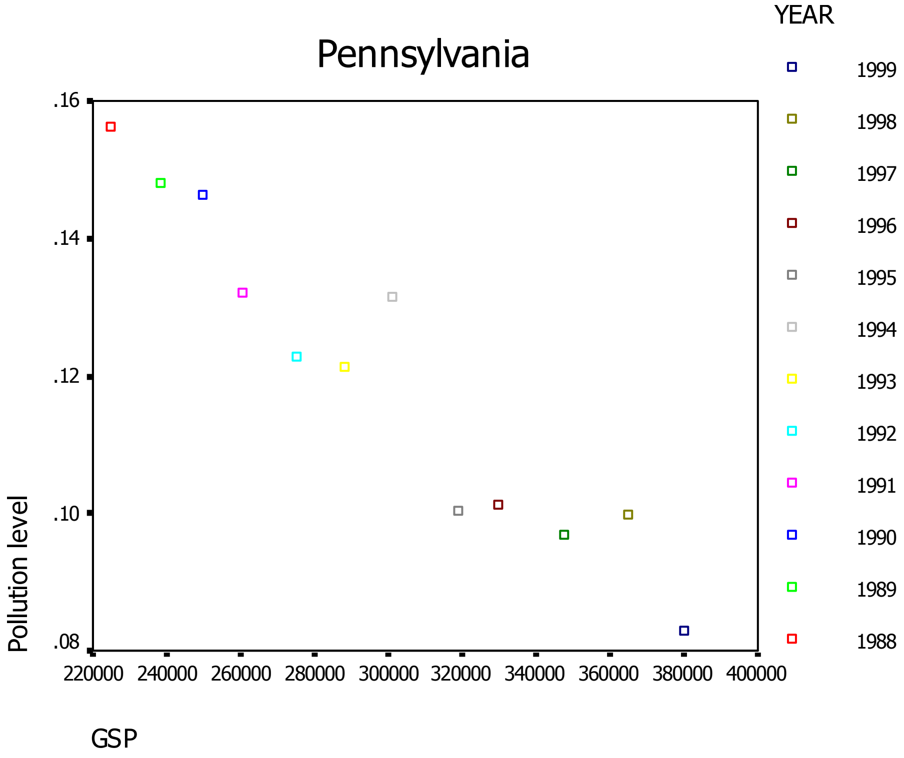
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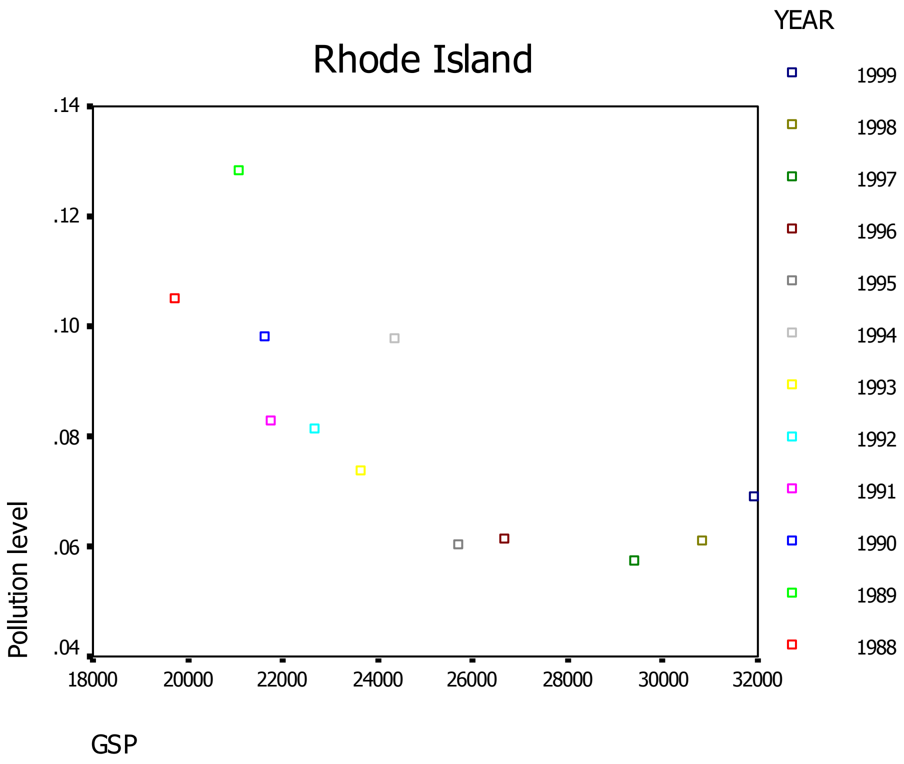
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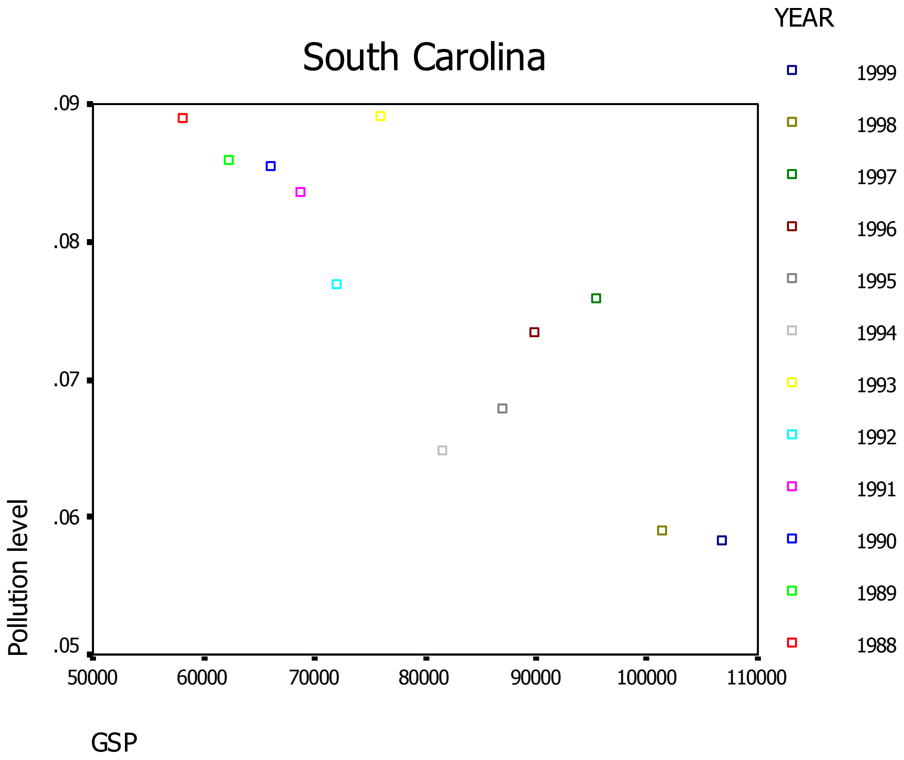
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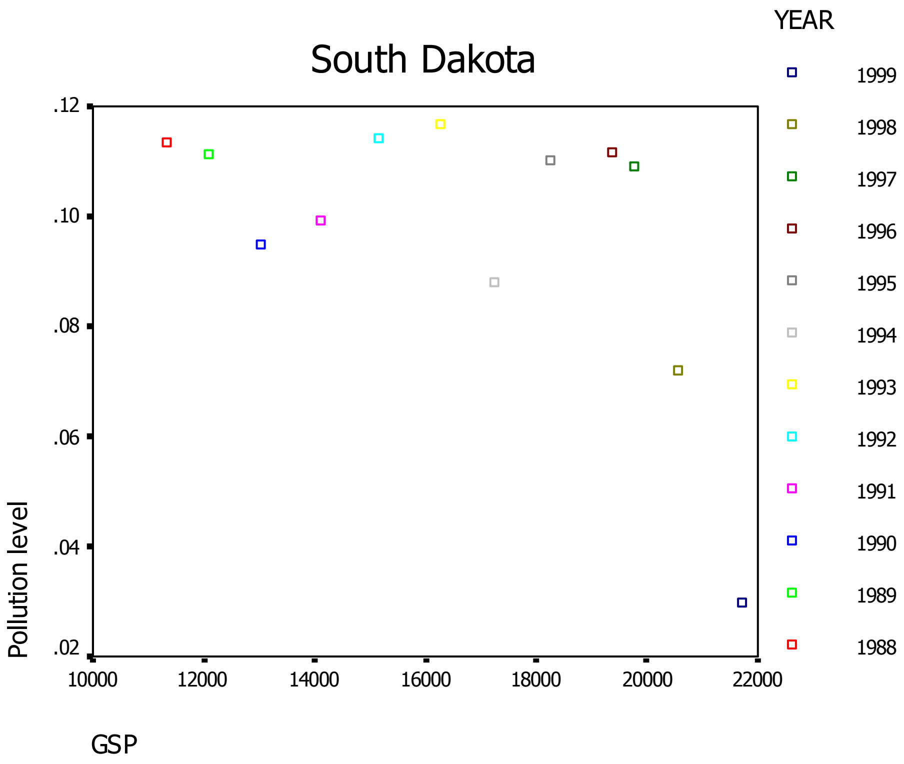
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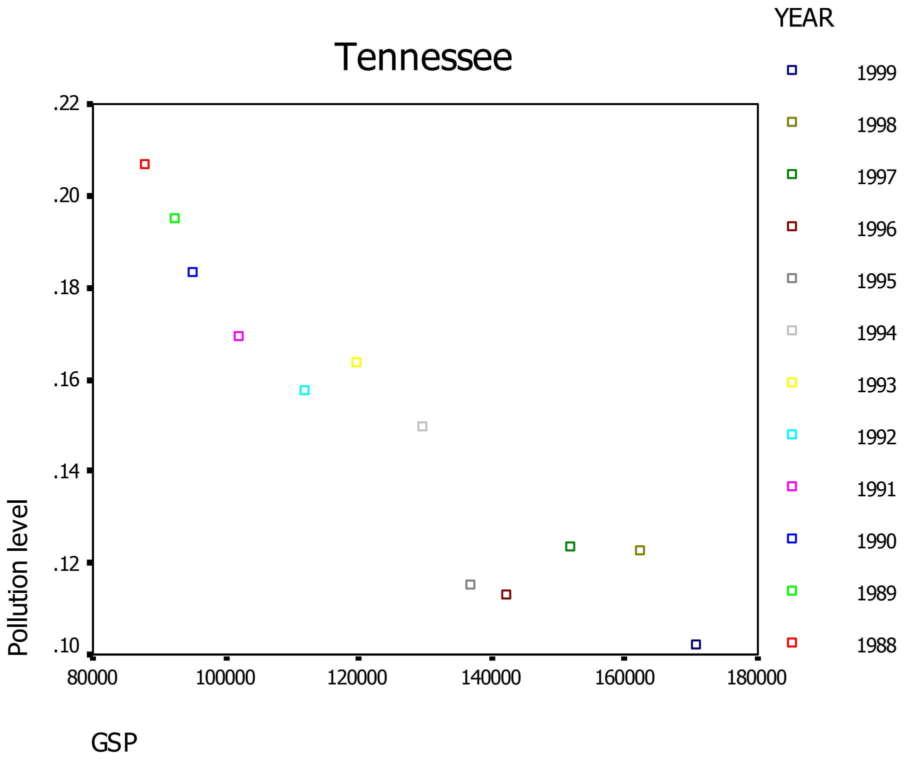
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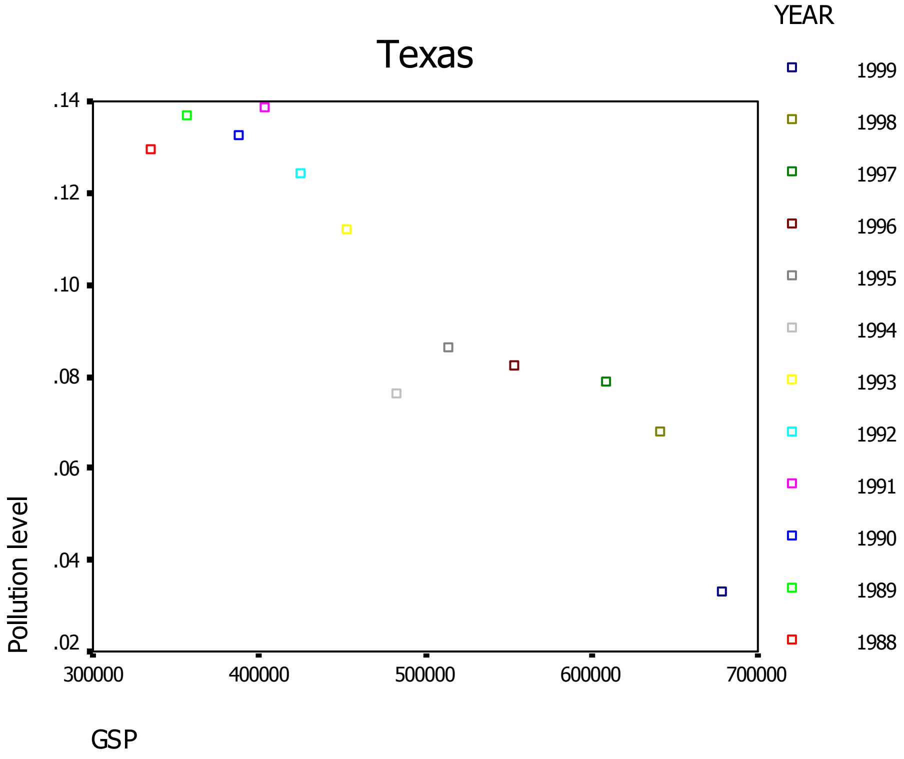
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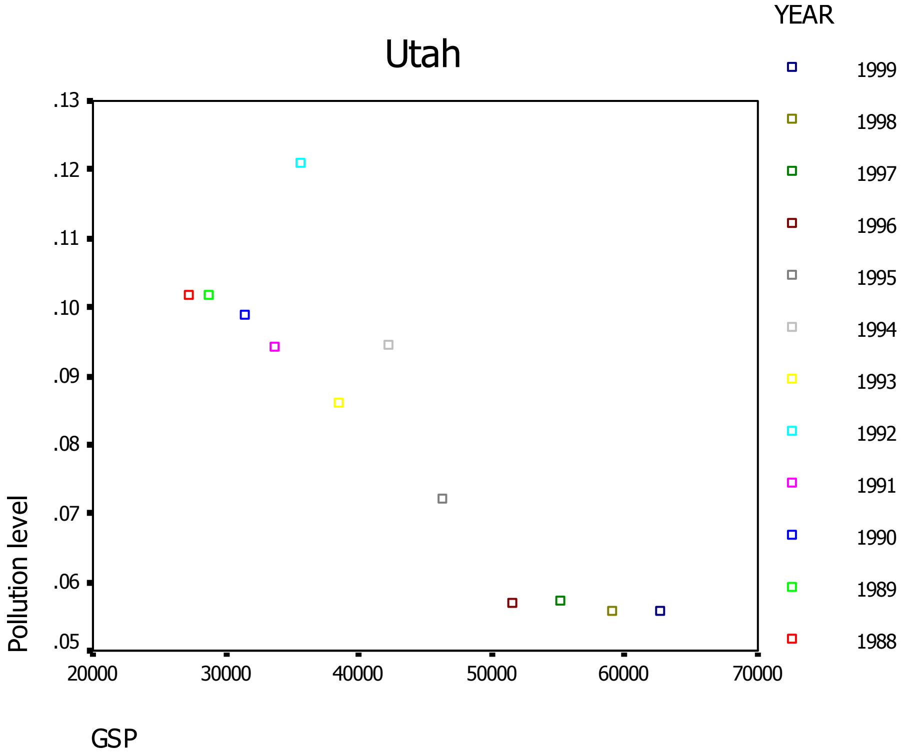
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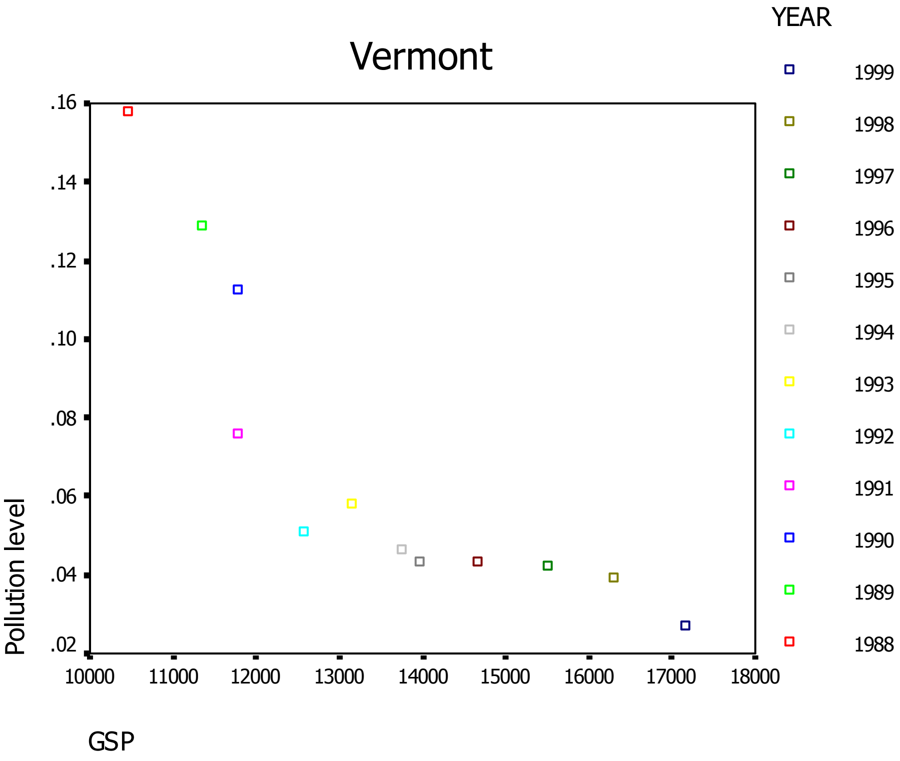
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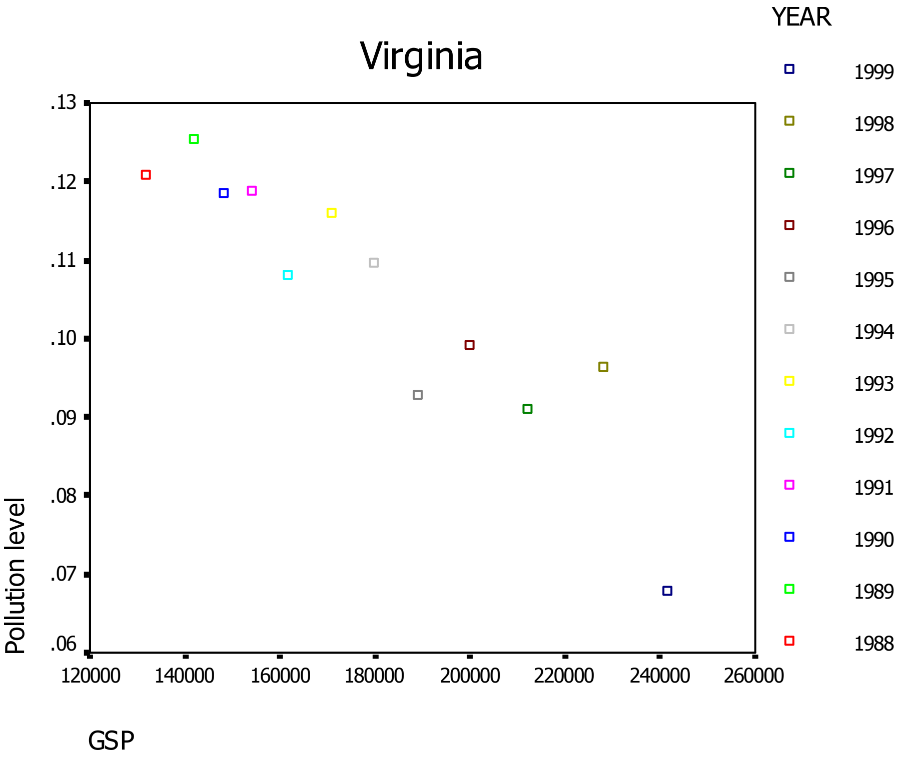
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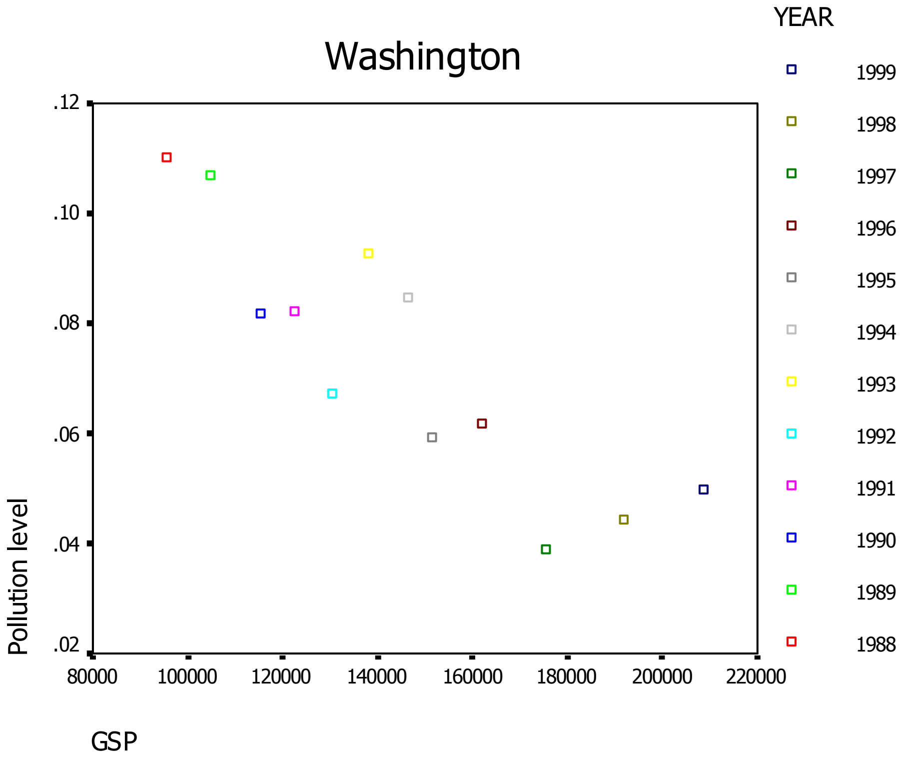
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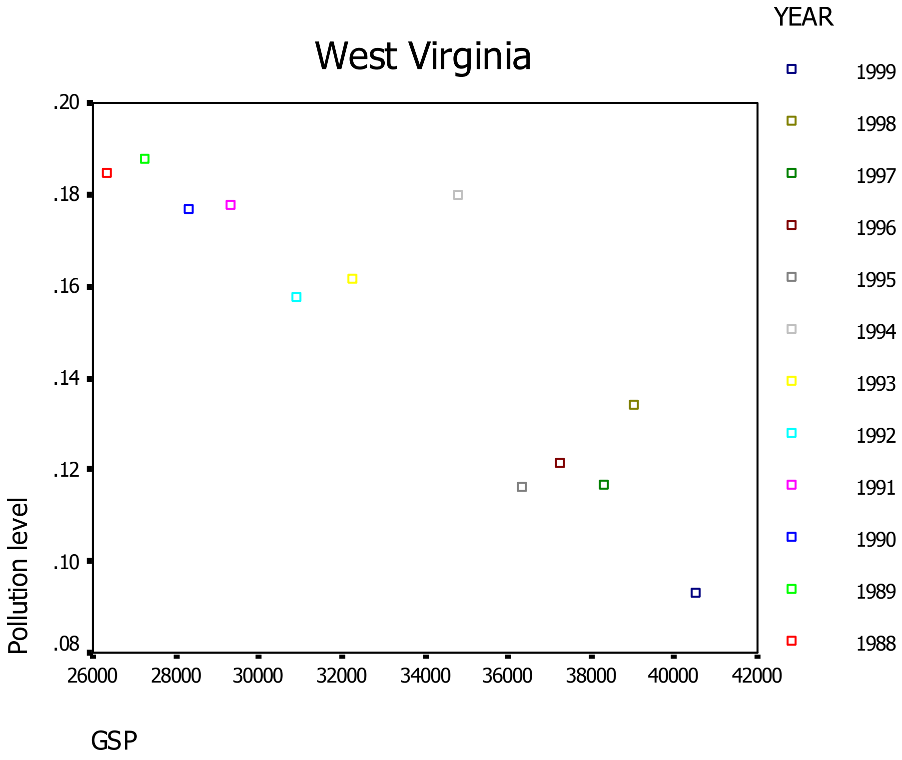
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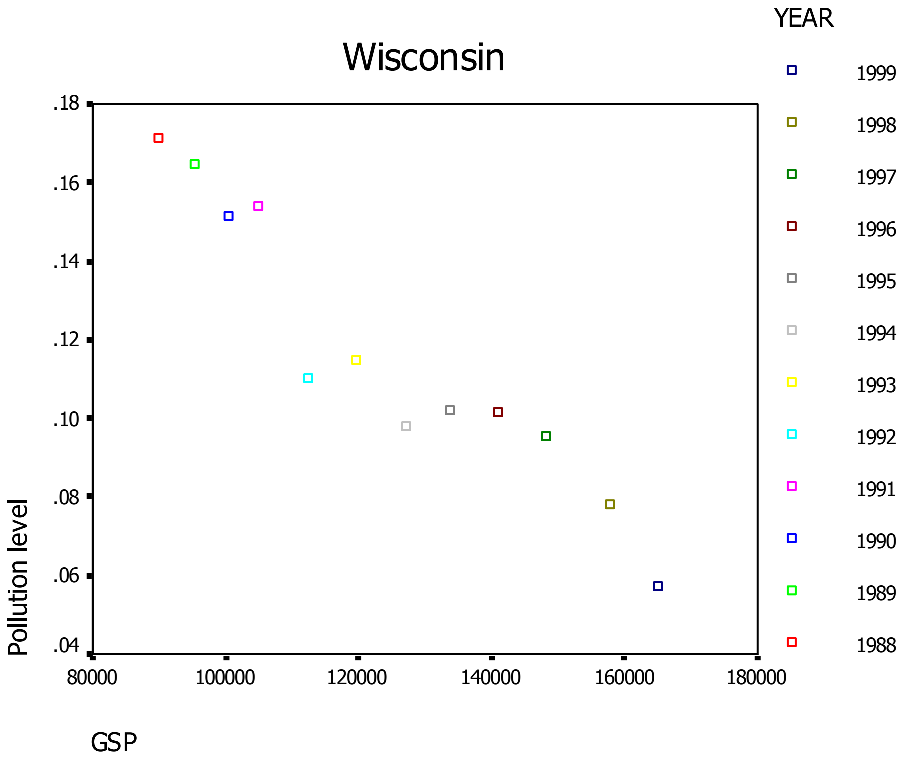
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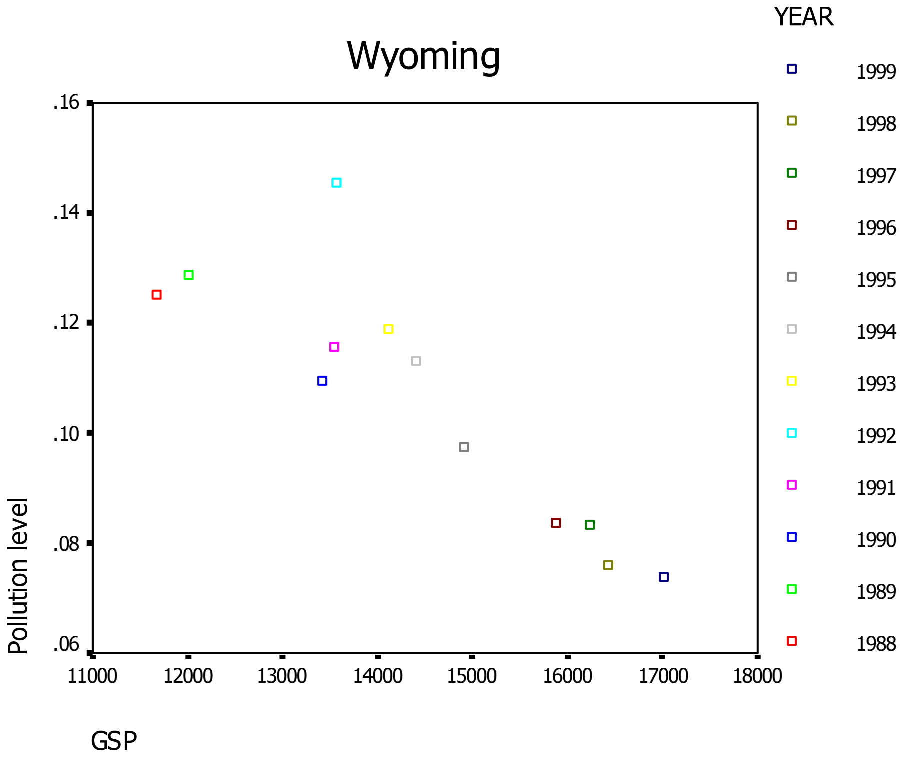
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