TO WHAT EXTENT DO ENVIRONMENTAL REGULATIONS CURB AIR POLLUTION AND ENHANCE PRODUCTION, PRODUCTIVITY, AND INNOVATION?

by

Emmanuel Wabi WANGI

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy

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APPROVED BY:

Michael Langlois, Committee Chair

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ABSTRACT

This study delves into the fascinating relationship between environmental regulations, air pollution reduction, and their subsequent impact on production, productivity, and innovation. By adopting Porter's hypothesis approach, the study aims to shed light on a crucial aspect overlooked in previous studies - the prerequisite of "well-designed environmental regulation," as Porter's hypothesis emphasizes. The study uses microeconomic principles, whose conclusions propose a novel framework for crafting effective policies that balance curbing air pollution and fostering economic growth. Specifically, the study advocates for a tax rate on pollution that aligns with the marginal cost of the polluter within the industry. This approach ensures that environmental regulations are not only effective in reducing pollution but also facilitate sustainable production practices.

Through a comprehensive analysis of industry-specific data and econometric modeling, we uncover the substantial potential of well-designed environmental regulations to enhance production and productivity. Moreover, our study highlights the transformative impact such regulations can have on innovation within industries, fostering the development of cleaner technologies and practices. By elucidating the profound interplay between environmental regulations, air pollution reduction, and economic outcomes, this study seeks to provide policymakers, industry leaders, and researchers with valuable insights into the importance of crafting meticulously designed environmental policies. Ultimately, this research contributes to the ongoing dialogue surrounding sustainable development, paving the way for a greener and more prosperous future.

Keywords**:** Environment regulation, Porter hypothesis, Air pollution, Economics activities, Competitiveness, Economics growth, Innovation.

Dedication

I dedicate this work to my whole family, mainly to my beloved wife Claudine Lepina, my children Wigita Wangi and Jamal Wangi, and all my offspring for their unconditional support and love necessary to realize this work. Love and support from my family have been an asset for me to realize this program. As we know, human work is easily accomplished if there is a support team. This work is also dedicated to the memory of my parents, Joseph Wabi and Julienne Bakohi, for having shaped us and taught us always to have courage. Let our sister Leontine Nkanga and our little brother Dieudonné Ntoti and their respective families find a model to follow from this thesis.

I also dedicate this work to Professor Mukoko Samba, my mentor, who gave me the taste and interest in this mental activity called research. Finally, I dedicate this thesis to all who, like me, have set goals. To them, I urge them always to dare to dream big while remaining optimistic with the courage to transform their dreams into productive and exploitable energy. Finally, to those who inspired and supported me throughout my academic journey, thank you for your guidance and encouragement. Your impact will forever be cherished.

Acknowledgments

The journey to complete this doctorate program was inspired and fueled by many elementary and high school professors through the University of Kinshasa, Johns Hopkins University, and Liberty University. My thanks go first to God, the Almighty, the Creator of all that exists, without whom the accomplishment of no work is possible. My deepest gratitude goes to my thesis committee, Dr. Michael Langlois, whose prayers, patience, constructive comments, and encouragement constantly nourish us at the right time. We sincerely thank Dr. Adriana Seagle for her quick responses, thorough reviews, constructive feedback, and insider insights into the new formatting. Thanks to Dr. Kabala Bolek and Dr. O'Brian for their tireless guidance and course instruction at Liberty University. I sincerely thank Dr. Fischer, Dr. Lidiya, Dr. Marcia, Dr. Amanda, Dr. Hughes, Bowen, and Dr. McDonald for their contributions to our training.

Thanks to Dr. Ahmad, my advisor at Johns Hopkins University, for his guidance and supervision. I would also like to thank Professors Bossonga Bofeki, Kamwitanko Miyamueni, Mukoko Samba, Kalonji Ntalaja, and Nvudi Matingu for their supervision during our bachelor's degree. May those who participated in our training and are no longer of this world also find our thanks, a sign that we will never forget them. My thoughts go to Professors Mukeni Lakuptier, Kitambo Mafuku, Luyinduladio Nzinga, and *Chef des Travaux* Daniel Luwa Kiyab. May our Baha'i brothers find here the expression of our gratitude. We sincerely think of Dr. Regina Harrington and Dr. Jody Petkovsek. We also thank the Brizuela's family, George Dannells, Mike, and Mahnaz Khalighi. Our thoughts to Ivy Murphy and Dr. Irene Mazer, who are no longer in this world.

This work would not have been possible without the contribution of a few people whom I would like to thank here. I thank Grand Michot Babwe, my tutor, whose assistance was decisive for our training. May my friends Martin Malenge Ekutsu, John Musengie, Franck Mosengo, and Willy Makengo each find our most sincere thanks. Those who directly or indirectly helped us and participated in the culmination of this thesis but have not been mentioned by name in this dissertation also find our most sincere thanks through this work.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AC: Average Cost

ATRI: American Transportation Research Institute

Cmx: Marginal Cost of Production

CO_2: Carbon Dioxide

Cq: Cost of Pollution

-Cq: Marginal Cost of abatement

C(x): Production Cost Function

Dmq: Marginal Damage

DOT: Department of Transportation

Dq: Damage caused by Pollution

ECY: Department of Ecology in Washington State

EOP: End-Of-Pipe Techniques (Technology)

EPA: Environmental Protection Agency

ER: Environmental Regulation

EViews: Econometric Views

FOC: First Order Conditions

FRED: Federal Reserve Economic Data

GHG: Green House Gas

H_{01}: First Null Hypothesis

H_{02}: Second Null Hypothesis

Ha_1: First alternative hypothesis

Ha_2: Second alternative hypothesis

IPCC: Intergovernmental Panel on Climate Change

ISO: Internal Organization for Standardization

MC: Marginal Cost

MR: Marginal Revenue

MSC: Marginal Social Cost

NAAQS: National Ambient Air Quality Standards

NGOs: Non-Governmental Organizations

NPTC: National Private Truck Council

OECD: Organization for Economic Co-operation and Development

R&D: Research and Development

REG: Regulation

SPSS: Statistical Package for Social Sciences

TC: Total Cost

TFP: Total Factor Productivity

TRI: Toxic Release Inventory

U(x): Utility Function

Um: Marginal Utility

USCAA: The United States Clean Air Act

VC: Variable Cost

CHAPTER ONE: INTRODUCTION

Overview

The literature on Porter's Hypothesis has grown steadily since its formulation in 1995. Porter and Claas van der Linde (1995) set forth this perspective constituted a revolution in understanding the relationship between environmental regulation and economic activity growth in general and competitiveness. According to the Hypothesis, more stringent and well-designed environmental policies could lead to better economic or financial performance and not necessarily increased costs. The argument is that environmental policies act as a catalyst for investment in innovation that would not have occurred without regulatory constraints. Several researchers have attempted to test the Hypothesis based on data collected from the companies involved, but the results are contradictory. Some attest to the validity of the Hypothesis, while others confirm the classic view that environmental regulation leads to an additional burden with a negative effect on competitiveness and profit. The discrepancy in the results is apparent. According to Porter's Hypothesis (PH), only strict, well-designed policies positively affect competitiveness and profit. How many studies have used strict and well-designed environmental regulations? What are these regulations? Many authors paid very little attention to the criteria of *strict and well-designed*. They only collected data from existing policies to see if there was a positive and significant relationship between the variable environmental regulations and growth or the financial situation of subject firms. This research is based on Porter's Hypothesis and examines theoretical and empirical literature using data on economic and environmental performance at the microeconomic level (companies or establishments). Much research has found a positive and statistically significant correlation between economic performance, measured by profitability indicators or stock market returns, and environmental performance, measured by polluting emissions or the adoption of environmental standards. According to EPA (2016), "*pollution emissions* is the term used to describe the gases and particles put into the air or emitted by various sources." According to Agriculture and *Vitae* (Agriculture and life: AGRIVI, 2022), citing the United States Environmental Protection Agency (EPA), considers *pollution emissions* as "any substance present in water, soil or air that degrades the natural quality of the environment; offends the senses; causes a health hazard, or alters the use of natural resources." Simply put, pollution is any substance that causes harm when it enters the environment (air, water, and soil).

These substances can reach concentrations in the air that cause undesirable health, economic, or aesthetic effects. In this study, pollution emissions are considered the leading cause of the deterioration of air quality. From there, environmental policies must be applied to solve the problem of air quality and climate change in general. Of all the literature reviewed, nothing regarding the essential concept of the Porter hypothesis, namely a "*strict and well-designed policy*," was found. In contrast, others have suggested that the relationship is neutral or negative. This research's main theoretical contributions and implications are that previous studies on Porter's Hypothesis have overlooked a crucial prerequisite of the hypothesis (well-designed regulation), leading to diverging results. Our research focuses on implementing well-designed environmental regulation, which involves efficient regulation based on production processes.

One of our study's main theoretical contributions is identifying the optimal tax rate for air pollution. Through microeconomic models, we have determined that this tax rate should be equal to the marginal cost of the polluter, denoted as **T*= Mc**. This approach aims to prevent pollution at its source rather than simply taxing the adverse effects of pollution on the environment.

In the case of the transportation industry, this study found the relationship between environmental regulation and innovation to be positive. If a tax of $67 per metric ton of pollution were applied, environmental regulation would explain 85% of the transportation industry's research and development level. A 1% increase in environmental regulations would increase research and development by 4.49%. On the other hand, the same environmental regulations also evolved in the same direction as the productivity captured here by Total Factor Productivity (TFP). Environmental regulations explain 24% of productivity, and a 1% increase in regulations would increase productivity by 0.63%. This chapter presents in the first section the dissertation background, then the problem statement, and then the purpose statement, followed by study significance and research questions.

Background

The debate over environmental regulation and economic growth is decades old. In the United States, "***environmental regulation***," which, according to the US EPA, means all Laws and Regulations concerning Hazardous Materials, including the Comprehensive Environmental Response, Compensation, and Liability Act, has been blamed for harmful (undesirable) economic consequences. The belief that environmental regulation hurts the American economy is widespread. It has been at the heart of a question in recent years of all the gains that have produced considerable improvements in air quality. The idea that environmental regulation harms the economy is simply a myth. The environmental regulation's benefit far outweighs its expenses. Moreover, well-designed regulations can positively impact economic growth and competitiveness and promote job creation. This idea is widely regarded as a revolutionary statement, first made by Michael Porter, famous for his economics theories, business strategy, and commitment to social causes.

Economic growth has been considered an obstacle to environmental protection for a long time. Several public policies have been initiated to discourage growth and protect the environment.

Recent studies, however, have shown that growth is not incompatible with environmental health. The key is finding an environmental policy that promotes economic growth and protects the environment. The goods and services production analysis process responsible for air pollution provides an environmental policy that would promote growth and protect the environment for the benefit of all. According to the United States Environmental Protection Agency (USEPA, 2022), Air pollution is a mixture of solid particles and gases.

On the other hand, the World Health Organization (WHO, 2022) defines *air pollution* as "contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere." This study uses microeconomic analysis to find the elements supporting effective environmental regulation. This process analysis aims to identify the conditions under which goods can be produced at the lowest possible unit cost. Based on the notion of *marginal calculation* and *production efficiency*, a state where a system can no longer produce more goods or services without sacrificing another related product, there is already a basis for this in economics theory. To achieve production efficiency, one must use resources and minimize waste, resulting in higher incomes.

As for *production efficiency*, which implies efficient allocation, Farrell (1957) distinguishes two components of allocative efficiency in economics: technical efficiency, which reflects the firm's ability to obtain maximum output with a given level of inputs, and allocative efficiency, which reflects the ability of the company to use its inputs in optimal proportions, given their respective prices—comparing the observed values and the optimal values of inputs and outputs with the optimum defined in terms of production possibility gives technical efficiency.

Regarding *marginal calculation*, Sarah Sagal (2022) argues that Marginal analysis examines the incremental value or benefits derived from a particular activity against the costs of that same activity. The definition of marginal analysis emphasizes that the analysis examines the costs and benefits of purchasing one additional unit of a good or service, as the term marginal denotes. It also analyzes the costs and benefits of adding additional business activity to production. This extra unit of something is often called a control variable, the input or output those changes by one unit. It helps business strategists determine whether the potential benefits of the additional business activity are sufficient to offset the cost of the additional activity and hopefully produce a profit. Using marginal analysis in a business context is essential to allocate resources and invest in the most profit-maximizing inputs properly. The marginal analysis calculates the net benefits of an additional unit of a good, service, or business activity. If the net profits are positive, it is in favor of the business or individual to purchase that additional unit. The business or individual should not purchase that additional unit if it is negative. This study uses marginal analysis to achieve the expected results.

Regulating pollution through strict measures, far from being a bad thing, is beneficial for businesses and air pollution control alike. In 1991, Porter proposed various mechanisms by which environmental regulations could improve competitiveness by reducing toxic and expensive inputs or waste disposal costs. The traditional view of environmental regulation, shared by many economists up to that time, was that forcing companies to reduce pollution limited their options and negatively impacted their profits. Porter thinks that companies that maximize their profits will benefit if there are opportunities to reduce pollution through strict regulation.

Porter’s Hypothesis (Porter, 1991; Porter & van der Linde, 1995) asserts that firms can benefit from environmental regulations. They argue that well-designed environmental regulations stimulate innovation, which, by improving productivity, increases the personal benefits of firms. The concept is that government-imposed environmental regulations incentivize firms to identify cost-saving innovations that they would not have known existed. Therefore, environmental regulations would be good not only for society but also for business. The Porter Hypothesis authors think that polluting firms can benefit from environmental policies, arguing that well-designed and stringent environmental regulation can spur innovations, increasing firm productivity or product value for consumers (Porter 1991, Porter, and Van der Linde 1995). This study is based on Porter's Hypothesis and starts from this concept to propose an environmental regulation that draws roots from this notion and is structured on microeconomics principles.

By expressing that environmental regulations positively impact innovation and productivity, Porter (1991) somehow aligns the two positions for and against environmental regulation. According to the U.S. Bureau of Labor Statistics (U.S. BLS, 2017), "*Productivity* is a measure of economic performance that compares the number of goods and services produced (output) with the number of inputs used to produce those goods and services." The productivity concept directly implies that of efficiency. Abstractly, efficiency describes a situation in which limited resources are used to achieve desired goals without waste. Productivity measures economic efficiency, which shows how effectively economic inputs are converted into output. This study considers productivity as one of the independent variables that the dependent variable, environmental regulation, will explain.

Indeed, it is exciting for environmentalists wishing to implement binding regulatory policies vis-à-vis polluting industries and supporters of technological progress who see increased innovations in polluting industries and profit companies using their resources more efficiently. It is beneficial to examine where air pollution originates and reduce it significantly. This study focuses first on understanding what Porter means by a "Well-designed Policy" and then proposes a market-based approach to regulation.

Problem Statement

This problem statement discusses how studies related to Porter's Hypothesis literature may not have thoroughly addressed the relationship between environmental regulation and economic activities. This situation is noticeable in the controversy surrounding the mixed results of many studies in the sectors or industries examined and the absence of a new analytical approach. This study tries to convince readers that more than the available research is needed to solve the problem. The problem statement of this research finds its roots in other studies and expands on their recommendations for future research. This study aims to link the sources of air pollution and pollution regulation to propose a regulation that respects the criteria of Porter's Hypothesis to reconcile environmental regulation and economic activities, two objectives long considered antagonists. The research focuses on how environmental control affects economic performance or how economic growth affects environmental quality. Previous studies have verified Porter's (1995) hypothesis, which states that "well-designed environmental regulation can benefit businesses by encouraging innovation and boosting their competitiveness, which can partially or entirely offset the costs associated with regulatory compliance." These various studies were carried out without being able to consider the necessary condition, which is that of "a well-designed environmental policy." Missing to consider this condition stated by the authors of the hypothesis has led several authors to ignore the relevance of this hypothesis.

In economics, "a well-designed policy" is understood as "an efficient policy." From this perspective, this research first focuses on and uses microeconomic analysis instruments to understand this notion of "well-designed policy." Then, it proposes a regulation resulting from the microeconomic analysis of "efficiency," capable of controlling air quality and increasing economic production. Considering Porter's hypothesis perspective and applying its requirement (well-designed policy), environmental regulation will no longer be a burden for the firms and industries subject to it. However, it will be considered a stimulus to innovation and productivity. So far, it can be considered that Porter's hypothesis has not been fully explored, nor has the "*sine qua non"* condition been incorporated into different studies. Were the environmental policies used to test Porter's hypothesis "well designed?" On what criteria were the authors of the various verifications of this hypothesis based? These are the few questions to prove that previous studies have ignored the essential criterion of this hypothesis, and the results could only be divergent. In this study, a coherent analytical approach emerges to solve the problem and illustrate the environmental policy resulting from this approach.

Purpose Statement

Environmental economics is founded upon an economic concept known as *"external effect.*" According to the Corporate Finance Institute (CFI, 2022), an externality is a cost or benefit of an economic activity incurred by a third party. Externality exists when one person's actions affect other people, who neither receive compensation for harm done nor pay for benefit gained (Hanley, Shogren, and White,2007). In the externality situation, the external cost or benefit does not appear in the final cost or benefit of the good or the service. Therefore, economists view externalities as a severe problem that renders markets inefficient, resulting in market failures (Greenlaw & Shapiro, 2011, pp. 276-278). *Externalities* are the main catalysts leading to the tragedy of the commons. The main cause of externalities is poorly defined property rights. Ambiguous ownership of some things can create a situation where some market agents start consuming or producing more. At the same time, part of the cost or benefit is inherited or received by an unrelated party. Environmental elements, including air, water, and wildlife, are the most common examples of things with ill-defined property rights. Externalities are of two types:

negative or positive. This study considers externality as a source of market failure that causes the implementation of environmental policies.

The nuisance caused by pollution, or the degradation of natural capital, and the resulting welfare loss are, for economic theory, assimilated to a loss of utility or satisfaction for economic agents. When the market regulation does not include such a loss (market failure situation) or does not allow its compensation, then the "environmental problem" arises or, more generally, the "natural capital management problem" occurs. By establishing a link between economic activities considered as the principal source of air pollution and the pollution control policy, this research aims to build a regulation capable of allowing air quality improvements and, at the same time, supporting economic growth, two realities considered for a long time to be antagonistic. The study focuses first on understanding what Porter and van der Linde (1995) mean by a "strict and well-designed policy" and then proposes a market-based approach to regulation.

The proposed policy, which refers to Porter's prerequisite (strict, well-designed, and flexible environmental regulation), leads and guarantees a win-win situation regarding social welfare and private net profits of companies operating under such regulations. The objective is to apply this new policy to polluting emissions data to test the statistically significant relationship between environmental regulation and innovation and between environmental regulation and productivity. The study focuses on how environmental control affects economic performance or how economic growth affects environmental quality. Since Neoclassicals believe that stakes around environmental regulation and economic activities have always been a constraint that would increase costs (negative externality), Porter's Hypothesis (1995) opened a new perspective considering environmental regulation as an incentive for product innovation and competitiveness. Jaffe, Newell, and Stavins (2003) dissect the propositions Porter and van der Linde made concerning environmental regulations' impact. Among these propositions, the study retains two: 1) regulation signals to companies that resource usage is inefficient and technological improvements are possible. 2) The pressure on polluting companies pushes them to review their production processes. From a dynamic perspective, these additional costs will push companies to review their production process and innovate. Thus, these innovative efforts will reduce pollution control costs and increase the company's productivity. This increase in productivity results from an improvement in the quality of the product offered (increase in the product's value) or better use of inputs (reduction of production costs).

Numerous empirical studies on the environment and productivity produce contradictory results. Some studies support Porter's Hypothesis, while others confirm the classic economic model, which considers pollution a negative externality. Many studies (Lipsey, Purvis, and Steiner, 1993; Pillet, 1993; Prudhomme, 1980) found that pollution control entails excess costs for the company and, in return, negative externalities (damage to the environment, the health effects, deterioration of the ecosystem) tend to decrease when the expenditure due to the cost of pollution increases. There is an optimal level of pollution to balance the costs borne by the company and the damage suffered by the community, affirms Fridhi Bechir (2020). Other empirical analyses have shown that many environmental policies (regulations) hurt business growth. Among these studies are Denison (1978), Gollop and Roberts (1983), Dufour, Lanoie, Patry (1992), and Christiansen and Haveman (1981). Few studies have sought to link the production process activities and environmental regulation. This research brings its modest contribution to the literature on environmental economics and public policy decision-making by proposing the guiding principles of an environmental regulation based on microeconomic analysis (market-like). These principles refer to Porter's vision of a "strict and well-designed" environmental policy to promote air pollution control and economic growth.

As far as microeconomic theory is concerned, this research project draws its theoretical basis from the producer's behavior facing a Pigouvian tax on his productive activities, which emit pollution. The general question addressed is about the effectiveness, within Porter's hypothesis, of defining a strict and well-designed regulation to influence polluters' behavior to ensure better protection of the environment and to preserve economic growth, two long-term objectives considered contradictory. The research combines theory and empirical facts.

Gregory N. Mankiw (2015), Douglas Curtis and Ian Irvine (2017), and Libby Rittenberg and Timothy Tregarthen (2015) all agree that *microeconomics* is the study of the behavior of individuals, households and firms in decision-making and resource allocation. It generally applies to contracts for goods and services and deals with individual and economic matters. This branch of economics focuses on the choices people make, the factors that influence their choices, and how their decisions affect the markets for goods by affecting price, supply, and demand. Microeconomics determines how households and individuals spend their budget and is interested in knowing what combination of goods and services will best meet their needs and wants, given the budget they must spend. Greenlawn and Shapiro (2011) affirm that microeconomics tries to understand what determines the products and how much a firm will produce and sell. It determines the prices a company will charge and how it will manufacture its products. The microeconomic part is the theory of consumer behavior, the theory of the firm, the functioning of labor markets and other resources, and how markets sometimes fail to function correctly. Unlike macroeconomics, the study of nationwide phenomena such as growth, inflation, and unemployment. Microeconomics considers how households make decisions about consumption and savings, how firms set prices for their output, and how investors decide to invest. Microeconomics is also interested in the market situation. How do the goods and services market and the employment market work? In this study, the logic of the analysis is microeconomic based on the producer's behavior.

Significance of the Study

Reviewing the existing literature on the Porter hypothesis, none of these studies is interested in the ripple effects of environmental regulations on the economic activities of companies and industries that would condition the implementation of strict and well-designed environmental regulations likely to stimulate economic growth and control Pollution. This study's findings will help promote economic activity growth and ensure air quality; two concepts long considered antagonistic. This analytical approach will also help those conducting studies verify Porter's hypothesis to understand the meaning of the term "Strict and well-designed policies," leading to convergent results without contradiction. *An environmental regulation with a rate equal to the polluting firm or industry's production marginal cost is the solution to combat air pollution and promote the growth of economic activities.*

Without well-designed public policy, increased economic activity will likely significantly increase air pollutant emissions. According to economic theory, these emissions produce negative externalities, unintended consequences of the action of the economic agent on others without a monetary transaction. In a failing market with externalities, the public authorities have every right to intervene and correct the situation by reducing externality (pollution).

This study aims to highlight the significance of well-designed environmental policies in combating air pollution while simultaneously fostering economic activity growth. A novel policy proposal framework, T=Mc (Tax rate equals the marginal cost of the industry), to address this pressing issue. For the Significance of a Well-Designed Environmental Policy on Environmental Protection: Air pollution significantly threatens human health and the environment. Implementing well-designed environmental policies can effectively mitigate pollution levels, ensuring cleaner air and protecting the ecosystem. This leads to improved public health, reduced healthcare costs, and enhanced quality of life while economic activities increase.

Regarding Economic Growth: Contrary to the perception that environmental regulations hinder economic growth, studies have shown that well-designed policies can stimulate sustainable economic activity. Environmental policies encourage innovative solutions, such as clean technologies and renewable energy, creating new job opportunities and fostering sustainable industries. This leads to long-term economic growth, increased competitiveness, and enhanced resource efficiency.

Speaking of Resource Conservation: Environmental policies promote the efficient use of resources, reducing waste and improving resource management. By implementing measures such as pollution taxes or cap-and-trade systems, these policies incentivize industries to adopt cleaner technologies and practices. This reduces pollution and conserves valuable resources, ensuring their availability for future generations.

Policy Proposal: T=Mc is efficient to effectively address air pollution and promote economic growth; we propose the policy framework of T=Mc. This framework integrates three key elements—targeted regulation and tailored environmental regulations considering different industries and regions' unique characteristics and challenges. By setting realistic and measurable targets for pollution reduction, this policy ensures that industries are held accountable while allowing flexibility for innovation and growth.

Well-designed environmental policies are crucial in effectively controlling air pollution while fostering economic activity growth. By implementing targeted regulations market-based mechanisms, and promoting collaboration and technological innovation, the proposed T=Mc policy framework offers a comprehensive approach to address these challenges. This holistic approach ensures a cleaner environment, improved public health, sustainable economic growth, and a pathway toward a more resilient and prosperous future.

Research Question(s)

From Malthus, Ricardo, and Mill to economists like Galbraith, Mishan, Boulding, Nordhaus, and many more, they have all agreed on the harmful effects of economic growth on the environment. Their point is that economic growth always produces pollution, which constitutes a nuisance and causes a loss of well-being in terms of decreased utility or people's loss of satisfaction. Among the adverse effects, it is easy to cite *air pollution*, which is the presence in the atmosphere of toxic substances produced by economic activity. *Economic activity* is a process that goes from inputs to manufacturing a good or providing a service. Economic activities involve producing, distributing, and consuming goods and services at all levels of society (Wood, 2015). The nomenclature of activities divides the economic activities into categories that make it possible to define the sectors of activity (Agriculture, Industry, Construction, Trade). These gases and chemicals generate many phenomena and consequences for ecosystems and humans. It is accepted that strong economic growth is a crucial way to increase the standard of living and social protection. It is a qualitative aspect of development. Economic growth reduces unemployment and other forms of exclusion. The increase in wealth production leads to a country's development. To this end, economic growth creates jobs since it requires a workforce.

Moreover, when growth plays an essential role in the economy, it strengthens the country's development. Like the environment, economic growth is vital, and one cannot live without producing and accumulating wealth. It is crucial to have balanced environmental regulations for better environmental quality and economic growth. Policymakers should provide regulations that promote both economic growth and environmental protection.

This study revolves around a central question supported by a few other subsidiaries. This research focuses on knowing *what type of environmental regulations meet Porter's Hypothesis criteria, ensuring environmental protection, and promoting competitiveness and the growth of economic activities.*

Among the subsidiary questions, there are three questions that this research will cover.

(1) What effect does the environmental public policy have to promote a transition to a green economy?

(2) How should economic theories address the relationship between economic growth and environmental quality? The answer to this question refers to previous studies and existing theoretical frameworks that can help explain the relationship.

(3) What role does imperfect information play regarding the signals sent to corporations and their ability to accurately understand and act on those signals?

Summary

The introductory chapter has just presented the constituent elements of this research. These elements relating to research background, problem statement, study purpose, study significance, and research question are the foundation of all research and mark the way for a good understanding of research. The reader will find in this first chapter the importance and the relevance of the research, which allows him to have a clear idea of what is to be discussed in the body of this dissertation. This study focuses on finding environmental regulations that can help control air quality and promote economic activities simultaneously. Porter's Hypothesis proposes such an idea, but the authors did not suggest any regulation to support their hypothesis. This study tries to make a regulation proposal based on Porter's hypothesis prerequisite.

Reviewing the existing literature on Porter's Hypothesis, none of these previous studies focused on the knock-on effects of environmental regulations on the economic activities of firms and industries that would condition the implementation of strict environmental regulations and well-designed, likely to stimulate economic growth and control Pollution. This study's results will help promote economic activity growth and guarantee air quality, two concepts long considered antagonistic.

CHAPTER TWO: LITERATURE REVIEW

Overview

This literature review covers both theoretical and empirical aspects of the Porter hypothesis. The theoretical side examines classical theory on environmental regulation and the revolution in environmental regulation brought about by Porter's Hypothesis. On the practical side, it goes through the literature on the positive aspects of environmental regulation on pollution on the one hand and the adverse effects of this same regulation on pollution on the other hand. Porter and Van der Linde propose a "win-win" approach to applying the hypothesis. The literature review for this research tries to cover the most relevant elements and arguments regarding Porter's Hypothesis. The aim here is to cover the theory and empirical data most relevant to the main objective of this research.

The impact of environmental regulation on economic activities and competitiveness has always been the subject of endless debate, as Palmer, Oates, and Portney (1995), on the one hand, and Porter and van der Linde, 1995) attest. Porter's Hypothesis asserts that strict and well-designed environmental regulations improve competitiveness. Empirical studies have confirmed this relationship mainly. Palmer, Oates, and Portney, 1995 testified that mainstream economics postulates that forcing firms to internalize pollution externalities would increase costs and reduce profits. Porter and van der Linde, 1995 argued that well-designed environmental regulations could create an incentive to innovate in resource efficiency and emission reduction and possibly improve the competitiveness of firms. For their part, Jaffe, and Palmer (1997), from the Porter Hypothesis, have proposed three versions of Porter's Hypothesis (Agostino, 2015). The weak version claims that environmental regulation induces innovation, and the robust version postulates that environmental regulation affects overall competitive advantage;

furthermore, a narrow version proposes that only specific policies stimulate innovation (Agostino, 2015). The available empirical evidence for Porter's Hypothesis has provided mixed results more than twenty-five years later. Empirical evidence exists on the link between environmental regulation and innovation (the weak version of Porter's Hypothesis), as attested by Brunnermeier and Cohen (2003), while oscillatory effects characterize the link between environmental regulations and competitiveness (the robust version of Porter's Hypothesis) attested by Lanoie et al. (2011). According to Iraldo et al. (2011), the support of Porter's Hypothesis depends on the level of observation, the type of regulation, innovation, and competitiveness indices. Recent research contributions have shown a more systematic investigation of the conditions under which such positive links emerge (Wagner, 2007) and - particularly at the industry level - how innovation resulting from environmental regulations spreads across industries and countries (Corradini et al., 2014).

Theoretical and Conceptual Framework

Classical point of views on Environmental Regulations effects

The public authority is developing environmental regulations to counteract and encourage companies to reduce pollution emissions, negatively impacting humans, and the environment. The economic theory sees regulations for environmental protection as an additional cost to businesses, although environmental protection will benefit society as a whole and be preferred by all. Given that an additional cost to the entrepreneur has always impacted profit, the classic view of environmental regulation goes against the corporate view of profit maximization. As a result, environmental regulations appear to work against the businesses subject to them. Ambec and Lanoie (2009) assert that environmental protection requires changing technology or modifying production factors such as fewer polluting products or additional resources to treat the waste, consequently reducing the profit. Therefore, improving environmental performance by imposing regulations on companies is believed to work against their economic performance.

For some authors like Jaffe and Palmer (1997), the conventional view on the effects of environmental regulation on the economy imposes costs on companies, thus reducing their profits and slowing their productivity growth. From the neoclassical point of view, stricter environmental standards increase the production costs of polluting companies, weakening the position of American companies, and raising the prices consumers face, according to companies in international markets. According to Greenstone, List, and Syverson (2012), the decline in manufacturing employment in the United States from 18 million (25.3% of total employment in the United States) in 1970 to 12 million (9.0% of total employment) in 2012 reflects the introduction and expansion of U.S. environmental policy. Considering this reality, the three authors argue that several lawmakers claim that environmental regulations reduce employment opportunities.

At the level of industry and the economy at the national level, environmental regulation could hurt international competitiveness, thus causing a drop in exports and an increase in imports. In addition, the effects of environmental regulation can cause investment and manufacturing capacity to shift to countries with less stringent regulations (Jaffe et al., 1995). Environmental regulations can take either command and control or market-based approaches (Jaffe, Newell & Stavins, 2002). Command and control environmental regulations generally set technological standards or are performance-based, such as *end-of-pipe* pollution control. According to an environmental services company that offers thermal oxidation systems and air pollution control solutions, NESTEC (2018), *"end-of-pipe"* technology describes a pollution control approach that corrects contaminated air streams before effluent enters the environment. End-of-pipe technologies are a series of measures to either reduce or eliminate emissions of toxic substances into the atmosphere capable of harming human health or the environment. These technologies were first deployed when the Clean Air Act was introduced in the 1960s. Over the following decades, they were continually updated to keep pace with increasingly stringent environmental regulations, such as those imposed by the Clean Air Act's BACT standard (Best Available Control Technology). The BACT requires that producers of air emissions take all practical measures to prevent the release of pollutants, considering energy consumption, environmental impacts, and economic costs. GreenFact.org (2022) considers it a method to remove already formed contaminants from a stream of air, water, waste, product, or similar. They are typically implemented as the last process stage before the stream is disposed of or delivered. Technologies such as scrubbers on smokestacks and catalytic converters on automobile tailpipes reduce emissions of pollutants after they have formed. (US EPA Terms of Environment Glossary).

The theory of negative externalities and abatement costs constitutes the economic counterpart of the classical point of view. According to this perspective, the environmental nuisances caused by industrial activity result in costs that are neither borne by the company nor included in the price of its products: health problems, acceleration of corrosion, loss of harvests, deterioration of a recreational or tourist site, and depletion of natural resources. These costs are externalized and transferred to the community. Environmental pressures and regulatory standards will lead companies to internalize these costs through actions to reduce the impact on the natural environment. These abatement actions will thus result in costs related to acquiring environmental equipment and operating expenses.

The direct relationship between pollution abatement and the increase in the costs borne by the company leads to an "optimal level of pollution" calculation. Lipsey, Purvis, and Steiner

(1993), Pillet (1993), and Prud'homme (1980) defined this optimal level of pollution as the level from which the marginal costs of reducing the impact on the environment outweigh the reduction of costs associated with environmental damage. This model considers that pollution abatement actions entail additional costs for the company. On the other hand, negative externalities such as environmental damage, health risks, and property degradation tend to decrease when pollution abatement expenditure increases. Therefore, there is a so-called "optimal" level of discharge that balances the costs borne by the company and the damage suffered by the community. However, the "cost-benefit" analysis, which environmentalists generally criticize, assumes it is possible to price nature. However, as Passet (1979) and Cairncross (1992) argued, ecosystems and life generally do not have a price since they escape economic rationality based on the exchange value of goods.

Other, more empirical economic analyses have endeavored to model the relationships between environmental investments and the economic situation of companies based on global statistical data. Thus, many studies have shown, following the classic model of pollution abatement costs, that the environmental regulations implementation and the investments made to meet them tend to harm the productivity of companies (Denison, 1978; Christiansen and Haveman, 1981; Guollop and Roberts, 1983; Dufour, Lanoie and Patry, 1992). According to Walley and Whitehead (1994), the predominance of "win-win" rhetoric in recent studies on environmental management is unrealistic and risks leading to costly choices that can seriously jeopardize the competitiveness of companies. The acquisition of environmental equipment generally involves hefty investments, which is low. For example, environmental standards imposed by the U.S. Clean Air Act would increase additional annual costs of $4-5 billion to control sulfur dioxide emissions at U.S. power plants and investments of more than $37 billion for oil refineries (Cairncross, 1992; Walley and

Whitehead, 1994). This "win-lose" economic assumption has environmental and political implications that go well beyond the organizations and its strategy's boundaries.

Other Commons Management Approaches

Elinor Ostrom's point of view

Elinor Ostrom's (1990 and 2010) view of the "tragedy of the commons" demonstrates through theoretical and empirical research that commons resources can be managed collectively and effectively – without government or private control. Her contributions made her the first female Nobel Prize in Economics winner in 2009. Ostrom's work and her peers like Roberta Herzberg (2020) live on, laying the foundation for many branches of cooperative economics that dominate popular thought today.

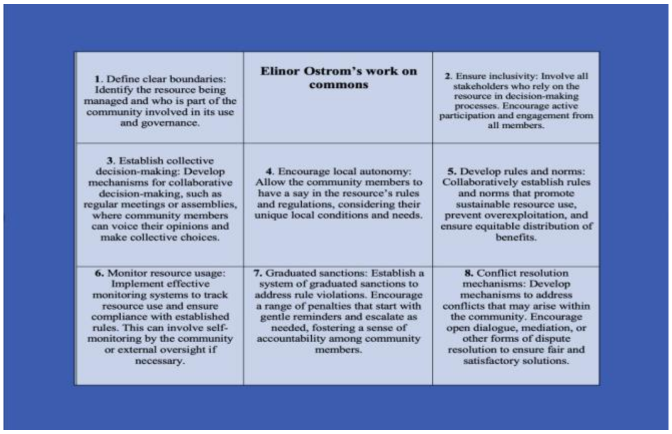
For Elinor Ostrom, in simple terms, the commons are scarce resources that provide users with tangible benefits that do not belong to anyone. So, the ocean, an open pasture, or a community garden could all be considered part of the commons. When using shared resources, the practice of "optimizing for a person's self in the short term is not optimal for anyone in the long term." On the contrary, it is better for everyone to adopt the mindset that "what is good for all of us is good for each of us." The tragic assumption here is that, given the possibility and unregulated access, most people would adopt a mindset closer to the former.

Ostrom says there is no panacea for solving Commons' problems. The complex problems arising from using shared resources will naturally require complex solutions. From this, she developed eight fundamental principles for managing a common good that could be used as an excellent starting point. According to Greg Bloom, Dr. Angie Raymond, Willa Tavernier, Divya Siddarth, Gary Motz, Melanie Dulong de Rosnay, and Anouk Ruhaak (2021), the figure shows that in the first phase (1) of clearly defined boundaries: People who have rights to the appropriate resources should be clearly defined, as should the boundaries of the resource itself. The second phase (2) of appropriate rules recommends that rules be appropriately linked to local conditions, including the appropriation of shared resources - restricting time, place, technology, quantity, and the rules related to the provision of resources - requiring labor, materials, and money. The third step (3) of the rule-making process is establishing collective choice agreements that allow most resource users to be part of the decision-making process. Those affected by the decisions and rules that govern the resource or the community should have a way to influence those decisions.

Stage four (4) monitoring will require adequate monitoring by monitors who are part of, or accountable to, ownership managers. This means that compliance with established rules is monitored, and users of the commons have an active role in monitoring compliance. Step five (5) of Sanctions proposes a graduated scale of sanctions for resource users who violate community rules. The principles refer to all accountability measures that must be implemented to guarantee the rules' application. Step six (6) of the dispute resolution mechanisms establishes that landlords and their agents have quick access to low-cost local arenas to resolve disputes between landlords, landlords, and officials. Stage seven (7), the right to self-government, dictates that the right of a community to design and manage outside authorities recognize its institutions. Finally, the Nesting/Interoperability step (8) states that ownership, provisioning, monitoring, enforcement, conflict resolution, and governance activities are organized into multiple layers of nested enterprises. The eight principles are put in a summary table as follows:

Figure 1:

The eight "design principles" to Self- Govern



1. Define clear boundaries: Identify the resource being managed and who is part of the community involved in its use and governance.	**Elinor Ostrom's work on commons**	**2**. Ensure inclusivity: Involve all stakeholders who rely on the resource in decision-making processes. Encourage active participation and engagement from all members.
3. Establish collective decision-making: Develop mechanisms for collaborative decision-making, such as regular meetings or assemblies, where community members can voice their opinions and make collective choices.	**4**. Encourage local autonomy: Allow the community members to have a say in the resource's rules and regulations, considering their unique local conditions and needs.	**5.** Develop rules and norms: Collaboratively establish rules and norms that promote sustainable resource use, prevent overexploitation, and ensure equitable distribution of benefits.
6. Monitor resource usage: Implement effective monitoring systems to track resource use and ensure compliance with established rules. This can involve self-monitoring by the community or external oversight if necessary.	**7.** Graduated sanctions: Establish a system of graduated sanctions to address rule violations. Encourage a range of penalties that start with gentle reminders and escalate as needed, fostering a sense of accountability among community members.	**8.** Conflict resolution mechanisms: Develop mechanisms to address conflicts that may arise within the community. Encourage open dialogue, mediation, or other forms of dispute resolution to ensure fair and satisfactory solutions.

Note: Elinor Ostrom: Debate Graph on eight (8) rules for managing the commons

To put this into practice, it turns out that long before the modern debate, local communities have been shaping sustainable, self-sustaining commons for centuries. Today, these modes of operation are studied, reproduced, and exploited to create equitable systems whose role is to solve modern problems such as food scarcity, access to energy, and inequalities in the ownership of platforms: digital media and even money, elements considered as externalities and likely to cause market failure.

For their part, Bimber, Flanagin, and Stohl (2006) evoke the theory of collective action. For them, this theory is widely applied to explain human phenomena in which public goods are at stake and is traditionally based on at least two fundamental principles:

1. Individuals are faced with discrete decisions about parasitism.

2. Formal organization is essential for parasitism to contact potential participants in collective action by motivating them and coordinating their actions. In some cases, the current uses of information and communication technologies for collective action seem to violate these two principles. To explain them, they reconceptualize collective action as a phenomenon of the border

crossing between the private domain and the public domain. They show how a reconceptualized theory of collective action can better explain certain contemporary phenomena, and they situate the traditional theory of collective action as a particular case of our extended theory.

Tradable Polluting Permit

The first flexibility tools attached to the concept of exchange in the service of environmental protection date back to the mid-1970s. The idea begins with the Kyoto Protocol (1997) to the Framework Convention on Climate Change (1992), which established national emission caps in major industrial countries for six greenhouse gases. It is in the United States that the experience is the oldest and the widest. It is helpful to consider this experience to shed light on specific problems of implementing tradable permits that could be encountered in the context of the Kyoto Protocol.

Historically, Berta (2010) affirms that the first theoretical reference in favor of a market negotiation of rights to pollute comes from Dales in his seminal work Pollution, Property, and Prices (1968). Dales was concerned about the water pollution problems of Canadian lakes, and it seems that he was the first to advocate the creation of rights to emit specific quantities of pollutants per year, to “date” these permits, and to associate them with various maturities, allowing forward purchases and sales. The main argument cited in favor of the market is that of the cost savings generated compared to an administered solution or a tax system: “The market automatically ensures that the desired reduction in polluting waste will be achieved at the lowest cost for society” (Dales, 1968, p.107).

The principle of negotiable permits is simple. An overall emissions threshold, resulting from a political compromise between polluting companies, is determined. An equivalent number of permits is allocated – or sold – to polluters. These must then cover each emission with a permit or quota by acting either on the level of their emissions (abatement) or the level of permits held (exchange). Each strategy always assumes a trade-off between permit price and marginal abatement cost.

Finally, public authorities set up “greenhouse gas emission quota markets” to reduce pollution using market mechanisms. “Pollution permits” in limited quantities (quotas) are allocated to companies that pollute according to their characteristics. If a company manages to pollute less, it can then resell the “unused” quantities on the market; if the company pollutes more than the prescribed quantity, it will then have to buy additional permits: the confrontation of supply and demand for permits results in the fixing of a market price. A company will only be encouraged to emit less GHG if the cost of investments related to abatement is lower than the price at which it could buy new permits. The incentive to change behavior is then based on the level of the price set on the market. This type of market is, in theory, an incentive measure equivalent to a carbon tax; it leads to the same result of reducing emissions. However, it can be more effective if the State does not know the cost of reducing emissions for companies because it will allow each company to manage pollution most effectively, either by trading quotas or reducing it.

Such a market has existed since 2005 at the European level for CO2 emissions, the Emissions Trading Scheme or ETS, but its effectiveness has remained limited until today. This European carbon market has indeed suffered from flaws since its creation. It has failed to encourage companies to reduce their emissions, mainly because the market price of CO2 is too low to fulfill its mission. Two main reasons can explain this lack of price. The first is that when the market was set up, the quotas allocated to companies were too "generous" compared to the actual quantities of CO2 emitted. The companies, making little effort to achieve this objective, did not significantly fuel the demand for permits on the market, which contributed to keeping the price too low. The second reason is that the 2009 economic crisis, later resulting in the reduction of the production of many polluting companies, has further reinforced this trend. To correct these dysfunctions, the European Union implemented a policy of reducing quotas in 2018, hoping that the price would rise above 30 euros, the minimum price theoretically to be enough of an incentive (Eloi, 2018).

From a logical point of view, regulation by the trading permit has shown its inefficiency. Public authorities cannot make regulations for protecting the environment while giving the possibility of polluting through the purchase of pollution permits. On a practical level, the fixing of prices and the transferability of permits remains a problem. Finally, like all trading markets, the possibility of speculation is high, which could lead to a disturbance that would cause greenhouse gas emissions to go uncontrollably. A good environmental policy to control emissions and promote economic growth would be the best option to explore.

Porter's Hypothesis Theory

By introducing their hypothesis, Porter and Claas Van der Linde (1995, 97) argue that the relationship between environmental objectives, competitiveness, and innovation is generally conceived as a trade-off situation with social benefits and private costs. In such a situation, the main concern is to find a balance between society's desire to protect the environment and the economic burden on industry. The regulatory authority, pushed by people's pressure, wants stricter regulations, while corporate polluters on the other side try to push back against those regulations. From this perspective, the environmental policy for improving environmental quality becomes a burden for polluting firms.

The authors believe that this environment-competitiveness and innovation debate has been formulated incorrectly. For them, this supposedly inevitable struggle between environmental regulation and economics is due to a static view of environmental regulation, in which technology, products, processes, and customer needs are all fixed. They defend that the paradigm defining competitiveness is no longer conceived as a static model. In a static vision, companies have already made their cost-reduction choices. Environmental regulations inevitably increase costs and reduce national companies' global market share. The new paradigm of international competitiveness is dynamic and based on innovation.

Porter and van der Linde (1995) have criticized the traditional approach in environmental economics, which considers that bringing companies into compliance will only produce additional private costs. The essence of their argument is that a well-designed environmental regulation will have the effect of inducing, in most cases, innovation on the part of companies. These innovations will eventually generate income to cover compliance costs and, eventually, will even be a source of additional profit opportunities. Porter and van der Linde take up the usual reasoning on the effects of innovation, which makes it possible to develop new products or processes, new modes of organization, or even to open new markets. The authors thus seek to have the role of regulation recognized as an incentive factor for development and innovation.

Theoretical and Empirical Studies on the Porter Hypothesis

Ambec et al. (2011) present some summary tables on the theoretical and empirical approaches applied to the hypothesis to get an idea of the different significant works conducted on Porter's hypothesis. This research uses these tables to illustrate the divergences in results and the different methodologies used to demonstrate the lack of consideration in these works of Porter's hypothesis primary condition, which is a "well-designed" policy.

Table 1.

Theoretical Studies on the Porter Hypothesis

Study	Market or Organizational Failure	Main Argument
Ambec and Barla (2002)	Asymmetric information within firm: managers have private information about the cost of new technologies.	By helping firms commit on pollution reductions, the regulator reduces the informational rent extracted by managers.
André et al. (2009)	Market power with vertically differentiated products on environmental quality.	Environmental regulations help firms coordinate on a Pareto superior equilibrium choice of environmental quality.
Greaker (2003)	Technological spillovers in the upstream pollution abatement industry.	Environmental regulations mitigate the underinvestment problem to the benefit of the downstream firm.
Mohr (2002)	Learning-by-doing technological spillovers.	Environmental regulations mitigate the underinvestment problem to the benefit of all firms.
Simpson and Bradford (1996)	Market power in an international trade model .	Firms facing more stringent environmental regulations exploit a “first-mover advantage” on international markets.

Study	Behavioral Assumption	Main Argument
Aghion et al. (1997) Ambec and Barla (2007)	Conservative managers who minimize innovation efforts under the constraint that the firm survive tend to postpone profitable technological adoption.	Environmental regulations force managers to adopt profitable technologies earlier.
Ambec and Barla (2006)	Managers with present-biased preferences tend to procrastinate profitable R&D investments.	Environmental regulations help managers solve their self-control problem.
Gabel and Sinclair-Desgagné (1998)	Manager focuses on routines and habits, which keeps the firm away from the global optimum.	Environmental regulations force managers to reconsider their decisions.
Kennedy (1994)	Risk-averse managers underinvest in risky R&D projects.	By increasing the return on R&D investments, environmental regulations bring managers closer to the optimal investment decision.

Note: Ambec et al. (2011), inventory on Porter’s Hypothesis theoretical and empirical Studies.

This summary table of studies on Porter's hypothesis highlights market failure, the behavior of firm managers, and their arguments. Ambec et al. (2011) find that environmental regulation helps firms to regulate a superior equilibrium choice of environmental quality. In addition, environmental regulation helps managers to adopt promising technologies and to solve their self-control problems.

Table 2.

Empirical Studies on the Porter Hypothesis

1. Impact of Environmental Regulations (ERs) on Innovation and Technology

Study	Data	Methodology	Main Results
Jaffe and Palmer (1997)	Panel of U.S. manufacturing industries, 1973–1991	Reduced form model. Innovation proxy: R&D investments and number of successful patent applications. ERs proxy: pollution control capital costs	R&D significantly increases with ERs (elasticity: +0.15). No significant impact of ERs on the number of patents.
Brunnermeier and Cohen (2003)	Panel of 146 U.S. manufacturing industries, 1983–1992	Reduced form model. Innovation proxy: number of environmentally related successful patent applications. ERs: pollution control operating costs and number of air and water pollution control inspections.	Small but significant impact of pollution operating cost on number of patents. No impact of inspections.
Nelson et al. (1993)	44 U.S. electric utilities, 1969– 1983	Three-equation model: (1) age of capital; (2) emissions; and (3) regulatory expenditures. Model includes two ER proxies: air pollution cost and total pollution control costs per KW capacity.	ERs significantly increase the age of capital (elasticity: +0.15). Age of capital has no statistically significant impact on emissions. Regulation has affected emissions levels.
Arimura et al. (2007)	Survey of 4,000 manufacturing facilities in 7 OECD countries	Bivariate probit model with (1) environmental R&D dummy regressed on various measures of environmental policy (perceived stringency, standards, taxes), an environmental accounting dummy, and other management practices control variables; and (2) environmental accounting dummy regressed on same variables.	The perceived ER stringency has a positive and significant impact on the probability of running an environmental R&D program. The type of ER (standard or tax) has no significant effects on environmental R&D.
Popp (2003)	Patent data and performance measures of flue gas desulfurization units ("scrubbers") of 186 plants in U.S., 1972–1997	SO_2 removal efficiency of new scrubbers regressed on the flow of knowledge (measured by patents) and policy variables. Operating and maintenance cost of scrubbers regressed on same variables.	The new SO_2 emissions permit regulation introduced in 1990 increased SO_2 removal efficiency and lowered operating and removal costs.
Popp (2006)	Patent data from the U.S., Japan, and Germany, 1967– 2001	Impact of SO_2 (U.S.) and NO_X (Germany and Japan) ERs on patenting and patent citations. ERs: timing of the introduction of new ERs. Estimate the cross-country spillovers using patent citation origins.	ERs followed by an increase of patenting from domestic firms but not from foreign firms. Earlier ERs for NO_X in Germany and Japan are important components of U.S. patents for pollution control technologies to reduce NO_X emissions.

Note: Tables from Ambec et al. (2011) inventory on Porter's Hypothesis Studies.

Table 3.

2. Impact of ERs on Productivity

Study	Data	Methodology	Main Results
Gollop and Roberts (1983)	56 U.S. electric utilities, 1973–1979.	Productivity measure: derived from the estimation of a cost function that includes the ERs proxy. ERs: the intensity of SO_2 regulations based on actual emissions, state standard, and the utility estimated unconstrained emissions levels.	ERs reduce productivity growth by 43%.
Smith and Sims (1985)	4 Canadian beer breweries, 1971–1980.	Productivity measure: derived from the estimation of a cost function. Two breweries were submitted to an effluent surcharge and two breweries were not.	Average productivity growth regulated breweries –0.08% compared to +1.6% for the unregulated plants.
Gray (1987)	50 U.S. manufacturing industries, 1958–1978	Change in average annual total factor productivity growth between the 1959–1969 period and the 1973–1978 period regresses on pollution control operating costs.	30% of the decline in productivity growth in the 1970s due to ERs.
Barbera and Mc Connell (1990)	5 U.S. pollution- intensive industries (paper, chemical, stone- clay-glass, iron- steel, nonferrous metals), 1960–1980	Derive the direct (abatement cost growth) and indirect (changes in other inputs and production process) effects of pollution control capital using a cost function approach	Overall, abatement capital requirements reduce productivity growth by 10% to 30%. Indirect effect sometimes positive
Dufour et al. (1998)	19 Quebec manufacturing industries, 1985- 1988.	Total productivity growth regressed on changes in the ratio of the value of investment in pollution control equipment to total cost.	ERs have a significantly negative impact on productivity growth rate.
Berman and Bui (2001)	U.S. petroleum refining industry, 1987– 1995	Comparison of total factor productivity of California South Coast refineries (submitted to stricter air pollution regulations) with other U.S. refineries. ERs severity is measured by the number of environmental regulations each refinery is submitted to	Stricter regulations imply higher abatement costs; however, these investments appear to increase productivity.
Lanoie et al. (2008)	17 Quebec manufacturing industries, 1985–1994	Total productivity growth regressed on lagged changes in the ratio of the value of investment in pollution control equipment to total cost.	ERs have a significantly positive impact on productivity growth rate, using lagged results, especially in the sectors highly exposed to outside competition.
Alpay et al. (2002)	Mexican and U.S. processed food sectors, 1962–1994	Productivity measure obtained through the estimation of a profit function that includes pollution abatement expenditures (US) and inspection frequency (Mexico) as proxies for ERs.	US: negligible effect of ERs on both profit and productivity. Mexico: ERs have a negative impact on profits but a positive impact on productivity.
Gray and Shadbegian (2003)	116 U.S. paper mills, 1979–1990	Regression of total factor productivity on pollution abatement operating costs, technology and vintage dummies and interaction terms between the dummies and the abatement variable. Estimation of a production function that includes input prices, pollution abatement costs and other control variables.	Significant reduction in productivity associated with abatement efforts particularly in integrated paper mills.
Managi (2004)	U.S. state-level data, 1973–1996, agricultural sector	Regression analysis of Luenberger productivity indexes.	Mixed results.
Crotty and Smith (2008)	37 firms in the UK automotive sector	Qualitative questionnaire to verify the strategic response to a new regulation	No support for Porter hypothesis.
Rassier and Earnhart (2010)	73 U.S. chemical firms, 1995–2001	Regression of returns on sales on permitted wastewater discharge limits.	Tighter regulations meaningfully lower profitability.
Lanoie et al. (2010)	4,200 manufacturing facilities in 7 OECD countries, 2003	Mail survey. Three equations estimated with dependent variables: (1) presence of environmental R&D, (2) environmental performance, (3) business performance Key independent variables include perceived regulatory stringency and policy mechanisms.	Tighter ER increases R&D, which improves business performance; however, direct effect of ER is negative, and combined impact is negative (innovation offsets do not offset cost of ER).

Note: Tables from Ambec et al. (2011) inventory on Porter's Hypothesis Studies.

These tables above show that Ambec et al. (2011) have provided an overview of the primary theoretical and empirical knowledge on PH. First, on the theoretical level, it turns out that the theoretical arguments that could justify Porter's Hypothesis are more potent than they initially appeared in the heated debate of the 1990s in the Journal of Economic Perspectives (Palmer et al., 1995). Empirically, the evidence for the diversity of results is clear. This study assumes that failure to incorporate "well-designed policy" into the analysis leads to these non-uniform results. These mixed results suggest that something is missing in understanding the necessary condition of Porter's e hypothesis.

Previously used methods, data, and research designs

Regarding the justification of the research methods and approach, a few articles discuss previously used methods, data, and research designs to build justification and support for the study. Tomasz Koźluk and Vera Zipperer (2015) state that finding significant effects of environmental policy changes seems complicated because environmental compliance costs generally represent only a tiny percentage of total costs (Gray and Shadbegian, 2003). The magnitude of the effects observed in the different studies reviewed is challenging to compare, mainly due to the coarseness of the environmental policy proxy variable. Studies of differences at different firm levels are methodologically the most effective approach. These studies make it possible to identify the economic effects of environmental policies, which helps to understand the forces at play at the microeconomic level. However, the same argument implies that these studies suffer from a lack of generality.

Gollop and Roberts (1983) examined the effects of the ratio of legal emission targets on American electric power from 1973 to 1979 and compared the estimated contributions to productivity and growth between regulated and unregulated power plants. The results showed that productivity was reduced for the taxed plants by 0.5 percentage points per year on average and evidenced increased costs due to the restriction of sulfur dioxide emissions. In other dimensions, Gray and Shadbegian (2003) measured the operating cost effects of pollution abatement on the total factor productivity of pulp and paper mills in the United States from 1979 to 1990. They used the fixed effect and estimated GMM (generalized method of moments) of TFP and pollution. A regression was directly used on the production function, which includes Abatement Operating Cost (PAC). Their results showed that integrated factories negatively affect productivity levels; the effect for non-integrated plants is negligible. Greenstone et al. (2012) estimated the effects of the achievement/non-achievement dummy variable of air pollution regulations on total factor productivity using U.S. manufacturing data from 1972 to 1993. Their methodology included two lags and a fixed effect estimate regressing TFP on environmental policy variables. The results showed an overall negative effect on MFP. Next, ozone regulations have the most substantial contemporaneous negative effect, and PM and SO2 regulations have the most potent cumulative effect. After that, an overall negative cumulative effect is more significant than the contemporaneous effect.

Broberg et al. (2013) tested the effects of environmental protection investments (distinguished between pollution prevention and pollution control) on labor productivity using data from four Swedish manufacturing industries from 1999 to 2004. They used the efficiency measure using the translog stochastic production frontier model and modeled efficiency depending on the regulatory proxy, including up to two offsets. The results showed no support for Porter’s hypothesis in manufacturing, with a negative effect in the pulp and paper industry, mainly due to the negative effect of lagged variables. The effect of environmental protection expenditure on industrial research and development expenditure Total R&D activity was estimated by Kneller and

Manderson (2012). Using U.K. manufacturing from 2000 to 2006 with a GMM estimate including two lags, the results showed a positive effect on environmental R&D and investment in environmental capital, with no effect on overall R&D or total accumulation capital. Environmental R&D can crowd out non-environmental R&D, and there is no evidence of environmental capital crowding out effect.

Porter's Hypothesis Criticism

Among so many criticisms that Porter's Hypothesis faces on the theoretical or empirical level, we retain one made by Amber and Lanoie within the Hypothesis framework. Ambec and Lanoie (2008) list a few empirical studies in the synthesis of their work, showing that only one study tests the entire relationship between environmental innovation and environmental Regulation (Lanoie et al., 2007). However, all these studies find a very slight impact of regulation on the ultimate productivity of the company. Regulation has a direct and positive influence on innovation and a negative indirect consequence on performance. Some results even attest to a deterioration in environmental performance for companies undertaking ISO 14001 environmental certification procedures. The negative effect wins out, leading the authors to say that Porter's Hypothesis is more the exception than the rule (Gallaud et al., 2012).

From a theoretical side, the relationship between Regulation and Environmental Innovation brings criticism on two points: first, the systematic existence of the relationship between regulation and innovation, and second, the failure to take strategic behavior into account in enterprises. Thus, like the empirical tests (Ambec, Lanoie, 2009), Porter's Hypothesis assumes that once a regulation exists, companies must apply it and become compliant, leading to innovations. However, regulations are only effective if the regulator can monitor companies' compliance and sanction them effectively in the event of fraud (Bontemps, Rotillon, 2003).

Companies could have a meager interest in innovating in industries where the cost of control will be high and the penalties low. A second criticism stems from the fact that Porter and van der Linde (1995) do not consider the possibility of strategic behavior. Indeed, they see regulation as exogenous to businesses. Companies must follow regulations defined by an independent administration. However, this conception ignores that companies may try to manipulate regulations for their benefit through lobbying actions (Galleaud et al., 2004).

As a corollary, the strategies of companies are not very detailed in Porter's Hypothesis. The type of Environmental Innovations developed, or the structural characteristics of the companies (sector, size, membership of a group) are absent. The literature recognizes the preponderant role of R&D and that it is an occasional or continuous basis in developing technological innovations (Tether, 2002). Group membership and firm size are also known determinants of this type of innovation, the latter two factors also influencing recourse to cooperation. On the other hand, intangible innovation's determinants differ from technical innovation, as Research and Development do not influence this type of innovation. Advertising spending will play a role in determining marketing innovation.

Porter's Hypothesis centers on achieving technical process innovations (the lower costs underlying the hypothesis). Organizational innovation exists, but only as a complement to technological innovation. One of the specificities in specific industries is autonomous intangible innovation (Martin, Tanguy, 2011). It also happens that this strategy also exists for environmental innovation. One objective is to test these variables to consider better the variety of companies' strategies for introducing Environmental Innovation. Analytically speaking, Porter's Hypothesis is mainly critical because it assumes the presence of profit opportunities that would spontaneously remain unexploited. Critics of Porter's Hypothesis argue that if it is possible to increase corporate profits by enforcing environmental regulation, then this means that the firm always ignores profit opportunities in the absence of regulation (Palmer and Alii, 1995). Porter's Hypothesis is conceivable in the analytical framework of a market economy only in the presence of at least one market imperfection (market failure) and the externality linked to environmental degradation. André and Alii's (2009) model show that market imperfection comes from the absence of free entry for companies. Another market imperfection appears in technological innovation, which helps to justify Porter's Hypothesis.

This analytical framework is more faithful to Porter's vision since it considers companies to gain a competitive advantage by improving their technology. The innovation strategy, particularly the investment in research and development (R&D), is a choice variable of the company that uncertainly conditions the future production function. The market failure considered is the imperfect appropriation of the company's results of the R&D process due to spillover effects. It assumes that a company's R&D process generates information that benefits competitors. This information on technological advances is a public good because a company can hardly exclude its competitors from its use. Part of the profits from its investment in R&D then escapes the company. Since the firm does not capture all the benefits of its investment, it will tend to invest less in R&D compared to a Pareto optimal situation (in which technical information is a private good). According to Aspermont and Jacquemin (1988), environmental regulations encouraging companies to invest more in R&D would benefit them in this framework for analyzing innovation with spillover effects. It would reduce the problem of underinvestment in R&D for the benefit of all.

Related Literature to Porter Hypothesis

This literature review applying Porter's Hypothesis provides a new perspective, mainly applied to the link between competitiveness and environmental regulations. From a microeconomic point of view, this interpretation originated from two types of mechanisms for improving competitiveness:

1. *product improvement and therefore more excellent product value.*

As a producer, offering a product with high added value is advantageous. All the producer's actions must go in this direction to offer the best product and service at an appropriate price. In a competitive market, offering something different to stand out is imperative. Adopting a continuous improvement approach within a company means activating levers daily to improve performance and achieve objectives. In the case of polluting companies, environmental regulations make it possible to think of new products with high added value.

Innovation is a top priority when it comes to developing new products. Most companies want to offer a different product from what is offered on the market to meet the needs of potential customers better. Producers, therefore, need to set up a unique product experience focused on customers' needs. However, designing an innovative service offer that meets customers' expectations can be complex for those who need to learn more about the subject. How can producers improve products? Who are the stakeholders that will help achieve such a task? These questions need answers when dealing with regulations while the production process emits pollution.

2. *process improvement — or productivity/efficiency improvement — and therefore cost reduction.*

Reducing loads and costs has become an objective in all production companies. Many are the charges that apply to a company throughout its life cycle. The changes and the complexity of the processes have brought to light problems whose business plan profitability requires much more ingenuity. A production process represents a set of time-correlated activities that lead to a desired result. The company is made up of a set of processes that are complementary and which, by definition, must work perfectly with each other. Each aspect is of crucial importance for the overall process to run smoothly. The quality and efficiency of the processes are essential to optimize the results.

Process efficiency is the amount of effort required to achieve a business goal. In this sense, process efficiency is a measure of performance that considers the time and cost of performing a business process. Producing a product or providing a service are examples. Process efficiency is a common characteristic of successful organizations. Organizations that manage to make their processes efficient enjoy the following benefits:

- Increased productivity: People and machines operate at peak efficiency, increasing throughput.

- Increased profitability. Organizations improve their results by increasing their productivity while reducing their costs.

- Reduced errors and improved compliance. Efficient processes rely on automation technologies to replace manual tasks. This reduces the occurrence of costly errors. Additionally, when errors occur, organizations have processes to address them.

- Increased flexibility. The pandemic has further accentuated the need for operational flexibility. With effective processes, organizations can adapt quickly with minimal disruption to their business. In the context of this research, “well-designed” environmental regulations may offer an opportunity to change the production process to improve the products and services offered. In principle, both mechanisms can be directly linked to environmental regulation or enforced through investments in new capital and research and development expenditures.

Porter’s Hypothesis seems original, but when we analyze the argument in detail, we find similarities to an old discussion about the pressure a company can experience to transform. This theory started with Schumpeter (1936). He argues that companies are under constant pressure to transform and develop, but the pressure’s nature depends on the type of “pressure” the company faces. This pressure translates into competitors’ and suppliers’ behavior or the State implementing new regulations. The results of business transformation can be either the acquisition of new technology, the design of a new product, even a managerial change involving leadership, or the reorganization of organizational structures.

If well-designed and adequately implemented, Porter argues that stricter environmental policies can lead to the opposite result. Productivity increases or a new comparative advantage can lead to improved competitiveness. So, if we implement a stricter environmental policy, according to Porter, assuming the measure has at least one positive effect on the environment, we do not have to worry about competitiveness. In other words, if the Regulation does not harm the environment, the measure must be implemented because it improves the competitiveness of companies. Porter’s central argument is that governments design and implement the “right kind” policy instrument. Porter explains: “Transforming environmental concerns into a competitive advantage requires that we establish the right kind of regulation" Porter (1991: 168). According to Porter's Hypothesis, "the right kind of regulation" results in "a process that not only pollutes less but reduces costs or improves quality." More specifically, "the right kind of regulation" is seen as an instrument leading to appropriate new technical solutions and innovation, leading to a better allocation of resources. According to Porter, well-designed regulations serve several purposes.

Unlike the classic model, which analyzes the "proactive" reaction of the company to societal pressures (Freeman, 1984; Pasquero, 1980; Ackerman and Bauer, 1976; Jolly, 1990; Schuman, 1995), the problem relating to the relationship between environmental regulations and economic activities tend to become more as a source of economic opportunities rather than as a constraint to which companies are subject (Comolet, 1991; Elkington, 1987; Winter, 1989; Dilorenzo, 1991; Shrivastava, 1995; Lanoie and Tanguay, 1999). According to Michael Porter, environmental pressures and investments in this area help improve productivity (Porter, 1991; Porter and Van Der Linde, 1995). From this perspective, reducing pollution stimulates innovation, reduces the quantities of materials and energies used, and makes it possible to increase productivity.

Porter and van der Linde (1995) have criticized the traditional approach in environmental economics related to the effects of regulation on economic activities, which asserts that companies' compliance will produce additional private costs, which are compliance costs to the objectives defined in the regulations (Bontemps, Rotillon, 2003). The heart of their demonstration is to show that well-designed environmental regulations will, in most cases, induce innovation for companies. This innovation will eventually generate an income to cover compliance costs and generate additional profit opportunities. Porter and van der Linde follow the usual reasoning on the effects of innovation, making it possible to develop new products or processes, new organizational methods, or even open new markets. The authors try to recognize that in addition to the usual incentives for innovation (final demand and technological advances), Regulation's role appears to be an incentive factor for developing these innovations.

The authors develop multiple arguments on the incentive effects of regulation, starting with the claim that the pollution produced by companies wastes company resources. Indeed, most pollutants identified are often costly materials to produce and use. Consequently, pollution corresponds to suboptimal use of these resources, and it is rational for companies to substitute them with other less polluting products. Regulations can then have a signal effect on this waste of resources for companies by making them aware of pollution. For example, this situation has been the case with the changing status of waste from production processes.

Until the early 1990s, waste was not subject to an obligation to recycle very much, but as regulations became more stringent around 1997, companies became aware of their potential to use these resources. Then, the regulation reduces the uncertainty regarding the level of pollution allowed in the sector concerned. It thus allows companies to commit to investments, but on the condition that it defines a sufficient time horizon to ensure the amortization of these investments. By defining the acceptable pollution threshold, regulations will play a role in increasing competitive pressure. All companies will have to respect this threshold; companies that want to avoid price competition will be encouraged to innovate beyond regulation.

Ambec and Lanoie (2009) specified how companies could transform regulatory constraints into opportunities in work devoted to this Hypothesis. Adopting environmental innovations brings the company either lower costs or higher revenues. In the case of seeking opportunities to increase income, there are three main transmission mechanisms:

1. Better access to specific markets

2. The possibility of differentiating the company’s products
3. The use of techniques to control pollution

The company can play on lowering the following costs: regulatory costs, inputs, resources and energy, capital, and labor costs. Porter’s idea may be considered novel, but significant similarities emerge when examining the argumentation in detail in the long-term discussion of a company’s goal to transform. All this discussion goes back to Schumpeter (1936). According to this view, businesses always have pressure to grow and transform. However, whether such a transformation happens depends on the type of “pressure” the business faces. Transformation pressure can come from competitors, suppliers, or society (new regulations). The transformation can occur from technical adaptation and product development to management or organizational structure changes.

The conventional understanding of how environmental policy affects a business was a concern for Michael Porter (1991) and Porter and van der Linde (1995). Porter argues that if properly designed and implemented correctly, stricter environmental policies can lead to the opposite result: higher productivity or a new comparative advantage of some kind, which can lead to better competitiveness. So, if the regulator implements a stricter Porter-style environmental policy, assuming the measure has at least one positive effect on the environment, we do not have to worry about competitiveness. In other words, if the regulation does not hurt the environment, the measure must be implemented because it improves the competitiveness of companies. These additional costs will push companies to review their production process and innovation from a dynamic perspective. Thus, these innovative efforts will make it possible to reduce pollution control costs and increase productivity.

Productivity increases result from an improvement in the quality of the product offered (increase in the product's value) or from better use of inputs (reduction of production costs). Faced with the same regulations, some companies adapt faster than others (some have lower sanitation costs). Regulation, therefore, improves the competitive position of these companies vis-à-vis their less well-suited competitors. In addition, companies specializing in the production of reduction technologies will undoubtedly benefit from strict and well-designed environmental regulations. While environmental regulation increases the profits of regulated firms, systematic profit opportunities are absent without such regulation.

Porter's central argument is that governments design and implement the "right kind" policy instrument. As Porter explains: "Turning environmental concerns into a competitive advantage requires that regulator sets the right kind of regulation" (Porter, 1991:168). According to Porter, "the best environmental regulation" results in "a process that pollutes less and reduces costs or improves quality." More precisely, "the right kind of regulation" is an instrument that leads to new technical solutions or innovation and better resource allocation. According to Porter, well-designed regulations serve several purposes.

- First, regulations signal that efficiency gains and technological improvements are possible. According to Porter, the regulations aim to visualize the processes' ecological impact and potential technological and technical innovations. Without environmental regulations, companies are unaware of their ecological impact and potential improvements in efficiency and innovation potential.

-The second is that regulations can increase the company's environmental awareness. Environmental regulations align with standard reporting requirements where a company must report its emissions. This transparency of a company's environmental impacts is meant not only for the public, Porter says, but also for itself.

- The third argument for well-designed Regulation is that it reduces the uncertainty associated with many types of investments. For example, uncertainty enters within a well-designed environmental protection policy when investing in new technology or old conventional technology. This argument assumes that environmental policies will be applied consistently over time.

- The fourth argument: According to Porter, the fourth argument is that regulation contributes to better environmental awareness in general (note that this argument relates to the first and second, which also affect consumer preferences). Regulations force companies to process and transform their products to stay competitive and continue their business by offering quality products.

Porter builds his hypothesis based on "*well-designed environmental regulation*," requiring regulation to be market-based and stimulate business. As indicated, a valuable environmental regulation for improving competitiveness must have several criteria, such as the following:

It must provide businesses with a vast space for innovation to achieve the regulatory objective flexibly. According to Porter and Van der Linde (1995), the possibility that regulation may act as a stimulus for innovation arises because the world does not match the Panglossian belief that firms always make optimal choices. This will only be true in a static optimization framework where information is perfect and profitable innovation opportunities have already been discovered, so profit-seeking companies must only choose their approach.

1. Regulation must promote continuous innovation rather than focusing on a specific technology and achieving its goal by stimulating innovation. Porter and Van der Linde argue that regulation directly affects the innovation process. Successful regulatory reform efforts must consider the links between regulation and innovation. A triple typology of

regulation is used here for illustrative purposes. Economic regulation aims to improve the efficiency of markets in the supply of goods and services – which influences the innovation process. In the same context, the Organization for Economic Co-operation and Development (OCED) adds, "Social regulation protects the environment and the safety and health of society – its design can encourage innovation. Administrative regulation leads to the practical functioning of the public and private sectors – establishing certain fundamental conditions for technological progress."

2. Regulation implementation must be progressive to minimize uncertainty: Regulation implementation that impacts the production process can be complex, especially when there are many sources of uncertainty. In many industries subject to rigid production processes, regulatory interventions that ensure trust while maintaining incentives for innovation can be challenging to pin down. For this reason, the regulatory implementation process must be progressive to dissipate all sources of uncertainty.

According to the operational pattern and characteristics, regulations are of two types. Which is market-oriented stimulus regulation and command and control regulation. Well-designed regulation mainly targets the market-oriented stimulus regulation, which, without market-oriented regulatory measures, the further conclusion of Porter's hypothesis cannot hold. In short, strict environmental regulation with proper design can enable the company to produce large-scale innovation and innovative offset effects (Ambec, Cohen, Elgie, and Lanoie, 2011).

Stricter regulations aim to make the company more attentive to its polluting emissions, encouraging it to adopt a radical solution by improving products and production processes. In contrast, relatively lax regulation can only increase abatement costs without no innovative effect. It is possible that although the firm's production costs will increase in the short term, due to the offsetting effect of innovation, the firm will reduce its net costs and even end up making net profits.

The source of air pollution

Air pollution, as we experience it today, can have many sources. It can be of natural origin, for example, volcanic eruption, pollen, forest fires, and many other causes. However, in general, pollution comes mainly from human or anthropogenic activities. This category should be transport, individual and collective heat, industries, agriculture, incineration of household waste, and domestic activities.

Nicholas Z. Muller and Akshaya Jha (2017), who examined the effect of environmental policy on the scaling law between population and pollution in U.S. metropolitan areas, found that modern cities are engines of production, innovation, and growth. However, urbanization also increases domestic and global waste for household consumption and commercial production.

Lamsal, Martin, Parrish, and Krotkov (2013), in their article entitled "Scale Relationship for NO2 Pollution and Urban Population Size," observe that emissions are proportional to the size of the city. That pollution positively correlates with the city's size and the level of activity in the city. Another of their concerns is whether emissions evolve differently with population growth than economic growth or emissions. They find that population and economic growth are not inextricably linked.

When examining the relationship between urbanization, economic growth, and pollution in the United States between 1999 and 2011, Nicholas Muller and Akshaya Jha (2017) argue that a vital dynamic link between population, pollution, and economic growth influences environmental regulation. This relationship substantially impacts local air pollution emissions.

Their results suggest that environmental policies limit the adverse effects of urbanization and urban economic activities without interfering with city productivity benefits.

In another optic, Michail Fragkias, José Lobo, Deborah Strumsky, and Karen C. Seto (2013) report that 66% of global energy consumption occurs in urban areas, producing more than 70% of greenhouse gas emissions worldwide. They raise concerns about how urban size affects energy consumption and carbon dioxide (CO2) emissions. The authors found that from 1999 to 2008, CO2 emissions changed proportionately to urban population size. The relationship between city size and CO2 emissions evolves proportionally to the size of the urban population in the U.S. metropolitan areas, and large cities are more big polluters than small ones (Fragkias, Lobo, Strumsky, and Seto, 2013).

Motor vehicles are responsible for producing large amounts of carbon dioxide (CO2), carbon monoxide (C.O.), hydrocarbons (H.C.), nitrogen oxides (NOX), particulates (PM), and known substances as Mobile Source Air Toxicants (MSAT). Some of these emitted particles are Benzene, formaldehyde, 1,3-butadiene, and Lead (if leaded gasoline is still used). These elements and secondary by-products, such as ozone and secondary aerosols (nitrates and inorganic and organic acids), can have adverse health and environmental effects. Pollutants from motor vehicle emissions are related to vehicle type (light-duty or heavy-duty vehicles) and age, operating and maintenance conditions, exhaust treatment, type, fuel quality, wear of parts (tires and brakes), and engine- lubricants used. Concerns about the health effects of combustion emissions from motor vehicles have led to the introduction of regulations and innovative pollution control approaches worldwide.

As exhaust particulate emission controls become more widespread, emissions from sources other than combustion will make up a more significant proportion of vehicle emissions. Re-suspended road dust, tire wear, and brake wear are sources of non-combustion particulate emissions from motor vehicles. According to the EPA (2016), "*pollution emissions* are the term used to describe the gases and particles put into the air or emitted by various sources." In general, Pollution *Emission* is known as the release into the atmosphere of various gases, finely divided solids, or finely dispersed liquid aerosols at rates that exceed the natural ability of the environment to release, dissipate, and dilute or absorb them. These substances can reach concentrations in the air that cause undesirable health, economic, or aesthetic effects. In this study, pollution emissions are considered the leading cause of the deterioration of air quality. From there, environmental policies must be applied to solve the problem of air quality and climate change in general.

Quantifying motor vehicle emissions is essential for estimating their impact on local air quality and traffic-related exposures and requires the collection of data on travel activities in space and time and the development of emission inventories. The non-combustion emissions contain chemical compounds, such as trace metals and organic Matter, that may contribute to human health effects, but their current estimates are highly uncertain. Thus, although not regulated as exhaust emissions are, non-combustion emissions need to be adequately considered in future assessments of the impact of motor vehicles on human health, recommends the Health Effects Institute (HEI).

The National Park Service (NPS), one of the United States federal government agencies in charge of managing all national parks, most national monuments, and other natural, historical, and recreational properties, lists four primary sources of air pollutant types:

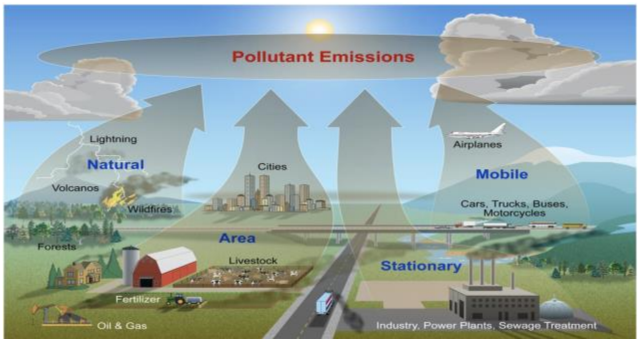
- **mobile sources:** refers to cars, buses, planes, trucks, and trains.
- **stationary sources:** the power plants, oil refineries, industrial facilities, and factories
- **local sources:** such as farmland, cities, and wood-burning fireplaces
- **natural sources:** such as windblown dust, forest fires, and volcanoes.

The EPA classifies Air Pollutants into two categories: primary and secondary pollutants. Primary pollutants originate from the main direct sources, such as mobile, stationary, and agricultural sources of air pollution. Secondary pollutants appear when two or more primary pollutants react in the atmosphere. (John Ray Cuevas, 2022).

Figure (2) below shows the different sources of pollution. The first source is mobile sources, which refer to cars, buses, planes, trucks, and trains. The second pollution source is stationary: power plants, oil refineries, industrial facilities, and factories. The third source of pollution is local sources, such as farmland, cities, and wood-burning fireplaces. Finally, the fourth source of pollution is natural sources: windblown dust, forest fires, and volcanoes. The figure demonstrates how these different sources converge in the atmosphere to produce polluting emissions. This illustration from National Park Services (NPS) helps to give an idea regarding the sources of pollution and how they converge to produce pollutant emissions.

Figure 2:

Mobile, stationary, area and natural sources emit pollution into the air.



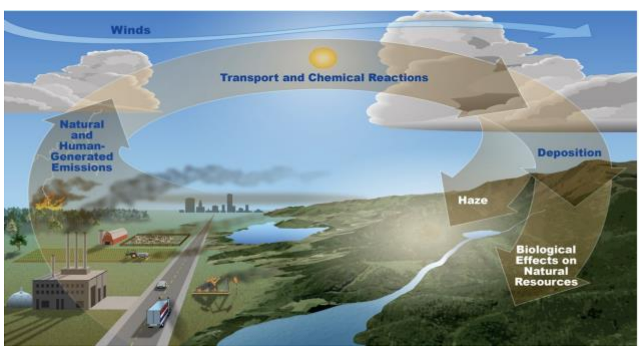
Note. National Park Service's illustration of Mobile, stationary, area and natural sources emit pollution into the air.

Primary air pollutants are air pollutants that are released directly from sources into the atmosphere. Examples of primary pollutants include NOx from vehicle exhaust, carbon monoxide, carbon dioxide, nitrogen oxide, nitrogen dioxide, and most hydrocarbons, many of which are closed. Secondary air pollutants are chemically bound products of primary pollutants. Acid rain that occurs when sulfur dioxide or nitrogen oxides react with water is a typical example of a secondary pollutants. Other illustrations of the secondary air pollutants category include nitric acid, sulfur trioxide, sulfuric acid, hydrogen peroxide, ozone, nitrates, sulfates, and other salts.

Figure (3) below, again the illustration of National Park Services (NPS), shows how the wind can carry air pollution very far from its place of production after forming pollutant emissions. The figure shows that air pollution can be produced in a specific location and spread across a city, county, or State by the movement of wind before causing harmful impacts.

Figure 3:

Wind moving air pollutants short or very long distances before they cause harmful impacts.



Note. National Park Service's illustration of how wind can move air pollutants short or very long distances before they cause harmful impacts.

The National Ambient Air Quality Standards (NAAQS) established by the Environmental Protection Agency (EPA) for the various air pollutants list the following nine pollutants among the primary pollutants in the atmosphere: Ozone (O3), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Special case, Sulfur dioxide (SO_2), Toxic air pollutants, Stratospheric ozone depleters, Greenhouse gas, and Lead.

According to EPA, tables (1) to (9) show the sources of the nine pollutants (Ozone (O_3), Carbon, monoxide (CO), Nitrogen dioxide (NO_2), Special case, Sulfur dioxide (SO_2), Toxic air pollutants, Stratospheric ozone depleters, Greenhouse gas, and Lead) among the primary pollutants in the atmosphere. On the other hand, they show each pollutant source's effects or impact on human health and the environment. Each table gives the sources of the primary pollutant and the effects linked to each source. They also produce information in an easy-to-understand way. They give insight into understanding the different sources of the primary pollutants. This information encourages people to take precautions against each source of major air pollutants on health and the environment.

1. **Ozone (O_3)**

"Ozone (O_3) is a highly reactive gas composed of three oxygen atoms. It is both a natural and a manufactured product that occurs in the Earth's upper atmosphere." (EPA, 2022). For EPA (2022), ozone can be created by a complex set of chemical and photochemical reactions, which involve so-called "precursor" compounds such as nitrogen oxides (NO_x), and volatile organic compounds (VOCs), including methane (CH_4) and carbon monoxide (CO). It is a gas naturally present in trace amounts in the atmosphere but has potentially toxic effects on living systems when these concentrations in the lower layers become too high. (American Lung Association, 2022.

Table 4:

Sources and effects of ozone

Sources of Ozone	Effects of Ozone
Burning gasoline	Asthma attacks
Coal and other fossil fuels	Sore throats
Volatile compounds from factories	Coughs
Volatile compounds from trees	Breathing difficulty
Ultraviolet radiation	Premature death
	Destroy plants and crops

Note. Table elaborated based on information collected from the EPA database.

2. **Carbon monoxide (CO)**

EPA (2022) defines carbon monoxide as “CO is a colorless, odorless gas that can be harmful if inhaled excessively. CO is released when something is burned. The main sources of CO in outdoor air are cars, trucks, and cars or other machines that burn fossil fuels.”

Table 5:

Sources and effects of Carbon monoxide (CO)

Sources of Carbon Monoxide	Effects of Carbon Monoxide
Engines of cars	Oxygen loos in the body
Furnaces	Dizziness
Heaters	Tiredness
Factories that burn fossil fuels	Headaches
Stove top	Triggers heart diseases
Clothing dryer	Collapse
Hot water heater	Nausea

Note. Table elaborated based on information collected from the EPA database.

3. **Nitrogen dioxide (NO_2)**

NO2 enters the atmosphere mainly during fuel combustion. NO2 is created from cars, trucks and buses, power plants, and off-road equipment emissions.

Table 6:

Sources and effects of Nitrogen dioxide (NO_2)

Sources of Nitrogen dioxide (NO2)	Effects of Nitrogen dioxide (NO2)
Power plants	Coughs
Car engines	Breathlessness
Nitrogen reacts with oxygen	Respiratory infection
	Acid rain

Note. Table elaborated based on information collected from the EPA database.

4. Particulate Matter

Particulate Matter or particulate pollution can be solid or liquid objects suspended in the air. The particle size must be at least 0.1 mm in size to remain airborne. There are two types of particles - coarse particles and fine particles.

Table 7:

Sources and effects of Particulate Matter

Sources of Particulate Matter	Effects of Particulate Matter
Road dust	Asthma
Sea spray	Respiratory problems
Construction debris	Premature death
Burning of fuel	
Power plants	

Note. Table elaborated based on information collected from the EPA database.

5. Sulfur dioxide (SO2)

Sulfur dioxide is a colorless, non-flammable gas with a pungent odor that irritates the eyes and respiratory tract. It can react on the surface of various solid suspended particles; it is soluble in water and can be oxidized in wind-borne water droplets. Sulfur dioxide comes mainly from the combustion of fossil fuels (coal, fuel oil). The oxygen oxidizes the sulfur impurities contained in the fuels in the air O2 to sulfur dioxide SO2. This gaseous pollutant is thus released by multiple small sources (domestic heating installations, diesel engine vehicles) and more extensive point sources (power or steam generation plants, district boiler rooms). Sulfur dioxide affects the respiratory system and the functioning of the lungs and causes eye irritation.

Table 8:

Sources and effects of Sulfur dioxide (SO2)

Sources of Sulfur dioxide (SO2)	Effects of Sulfur dioxide (SO2)
Burning of coal in power plants	Breathlessness
Burning of oil in power plants	Asthma
Factories making papers, chemicals, or fuel	Emphysema
	Eye, nose, and throat irritation
	Damage infrastructures

Note. Table elaborated based on information collected from the EPA database.

6. **Toxic air pollutants**

Toxic air pollutants are also known as atmospheric toxins. These pollutants cause cancer when they reach sufficient concentrations and exposure. They may also bring other serious health problems or environmental damage.

Table 9:

Sources and effects of Toxic air pollutants

Sources of Toxic air pollutants	Effects of Toxic air pollutants
Chemical plants	Cancer
Building Materials	Cancer
Food and water supplies	Breath deficiency
	Breathing problems

Note. Table elaborated based on information collected from the EPA database.

7. **Stratospheric ozone depleters**

EPA (2021) notices ozone depletion when chlorine and bromine atoms meet ozone in the stratosphere. They destroy ozone molecules. Ozone is destroyed faster than it can be created naturally. A chlorine atom can waste more than 100,000 ozone molecules before being removed from the stratosphere.

Table 10:

Sources and effects of Stratospheric ozone depleters

Sources of Stratospheric ozone depleters	Effects of Stratospheric ozone depleters
Conditioners	Skin cancer
Refrigerators	Eye problems
Aerosol cans	Harm plants and animals
Fire extinguishers	
Industrial Solvents	

Note. Table elaborated based on information collected from the EPA database.

8. **Greenhouse gas**

Certain gases that occur naturally in the Earth's atmosphere help trap heat near the Earth's surface. They are called "greenhouse gases" (GHG) and are essentially made up of water vapor, carbon dioxide (CO2 or carbon dioxide), methane (CH4), nitrous oxide (N2O), and ozone (O3). Without these gases, the average temperature on Earth would be -18°C, and life as we know it would become impossible (EPA).

For about two centuries, the atmospheric concentrations of specific gases have started to increase, but they were relatively stable before. Greenhouse gases remain in the lower layers of the atmosphere, part of the infrared radiation emitted into space by the surface of the Earth, heated by the Sun. Called the "greenhouse effect," this natural process has enabled the development and maintenance of life on Earth.

Since the industrial revolution in the 1750s, the greenhouse effect has been amplified by releasing large quantities of GHGs into the atmosphere. The massive use of fossil fuels such as oil, coal, or natural gas, deforestation, specific industrial processes and agricultural practices, and waste burial have notably significantly increased greenhouse gas emissions.

Table 11:

Sources and effects of greenhouse gas

Sources of Greenhouse gas	Effects of Greenhouse gas
Burned fossil fuels	Temperature changes
Cows	Higher sea levels
Rice paddies	Forest decomposition
Industrial sources	Coats damage
Decaying plants	Health problems

Note. Table elaborated based on information collected from the EPA database.

9. **Lead**

According to EPA (2021), Lead is a naturally occurring element found in small amounts in the Earth's crust. Although it has beneficial uses, it can be toxic to humans and animals, causing health effects. Lead is found in all parts of our environment - the air, soil, water, and even inside our homes. Much of our exposure comes from human activities, including fossil fuels, past use of leaded gasoline, certain industrial facilities, and the one-time use of lead-based paint in the houses (EPA). Lead and lead compounds are used in various products in and around our homes, including color, ceramics, pipes and plumbing materials, solder, gasoline, batteries, ammunition, and cosmetics.

Table 12:

Sources and effects of lead

Sources of Lead	Effects of Lead
Unleaded gasoline	Damages central nerve system
Power plants	Damages mental development of children
Lead plants	Lower IQ for children
Lead pipes	Kidney problem
	Heart attacks
	Strokes

Note. Table elaborated based on information collected from the EPA database.

Regulatory effects on productivity and efficiency.

From the U.S. Bureau of Labor Statistics (U.S. BLS, 2017) perspective, "*Productivity* is a measure of economic performance that compares the amount of goods and services produced (output) with the number of inputs used to produce those goods and services." The productivity concept directly implies that of efficiency. Abstractly, *efficiency* describes a situation in which limited resources are used to achieve desired goals without waste. Productivity measures economic efficiency, which shows how effectively economic inputs are converted into output. This study considers productivity as one of the independent variables on which the dependent variable, environmental regulation, will be explained.

From Porter's point of view, it is inappropriate for the traditional dichotomy to consider the environmental regulation and the power of businesses' competition capability as two parties in conflict. In traditional concepts, environmental protection activities impose a heavy economic burden on businesses, causing people to try to balance social welfare and private costs. Strict environmental regulations encourage companies to develop technological innovations, which helps them become competitive globally. Therefore, there is not necessarily a compensatory relationship between them (Porter, 1991). On the contrary, however, Porter believed that a static model balances the environment and the economy. Given such a model, companies seek to minimize costs while fixing technologies, products, production processes, and customer requirements.

A dynamic point of view is necessary to measure competitiveness. Porter asserts that international competitiveness is no longer a problem in a static model over the last decades but is a new dynamic model based on innovation. A more competitive business means higher productivity or lower costs than its competitors. Several case studies show that some large firms are not competitive internationally because they use the cheapest production inputs or have the most significant scale. However, they can keep up with technological developments and innovation. Competitive advantages are not possible through static efficiency or optimization with constrained conditions but by modifying the original constraint due to the ability to innovate to improve productivity.

Porter believes that in responding to the dynamic trend of international competition, each country must revise its traditionally static model of analysis and, instead, a dynamic perspective is needed to measure and assess the relationship between environmental regulation and competitiveness. In such a case, regulation should focus on the result rather than the process (Porter, 1991). As Porter exposes, in the pollution control process, companies may be less competitive due to increased costs, especially in international competition, compared to other foreign competitors who do not carry out pollution control activities, which have a temporary competitive disadvantage. However, since nothing stays constant forever, their continuous technological advancements will lead them to adjust production processes, adopt innovative technologies to reduce waste, make production more efficient, and improve productivity. In this way, environmental regulation can stimulate technological innovation, and through innovation, businesses can ultimately become more competitive and reduce pollution.

Porter thinks mainstream economists have opposing attitudes because they have made assumptions that do not fit the actual competition model, assuming the firm is experiencing a static competition model. According to him, without regulatory oversight, the company will exploit all beneficial business opportunities and not ignore Porter's so-called regulatory advantages. However, in real life, the company tends to find itself in a dynamic environment where its mix of technology and production inputs continuously changes and innovates, preventing it from making the optimal strategic decision and missing out on specific income-seeking opportunities. Therefore, if there is a stimulating power behind (regulation), there are still various beneficial opportunities, such as participation in pollution control activities, waiting for the company to take advantage of them. For example, environmental regulations force the company to control pollution, which drives its technological innovation, improves productivity, and ultimately generates a competitive advantage.

Therefore, Porter believes that well-designed environmental regulation can stimulate the company to achieve more technological innovation. It helps to improve the production process. In such a case, the innovation alleviates the economic burden, improves product quality, reduces production costs simultaneously, and improves productivity and competitiveness. Porter (1991) cites 3M (Minnesota Mining Manufacturing) as an example to illustrate the relationship between environmental regulation and competitive power to support his remarks. Since 1975, through its implementation of the pollution control strategy, it has saved costs of more than $480 million, and through the elimination of 0.5 million tons of waste and pollution, the energy usage costs were reduced by $650 million. This fact demonstrates that investment in pollution control will not impose any economic burden on the company. Instead, it will offset these higher costs through innovation and more competitiveness. In short, regulation can trigger trade-offs for innovation by substituting less expensive materials or better materials (Porter and van der Linde, 1995).

Regulatory effects on productivity

In Japan, as part of a research project initiated by the Ministry of Economy, Trade, and Industry, a research group pursued several case studies to examine what types of policies (regulations and other measures) would achieve technological innovation and environmental protection and the resulting increase in productivity, to deepen the relationship between environmental regulation and technological innovation. From this research, the relationship between environmental regulations and technological innovation or improved productivity is far from simple. It has become apparent that the cases cited as examples of environmental regulations creating technological innovation and increased productivity do not support such claims.

The number of companies actively taking environmental action on their own, either by implementing such action in the absence of environmental regulations or, where possible, by trying to achieve levels of protection of the environment higher than those required by these regulations, would have increased in recent years. As a background to these efforts, it highlights companies' motivation to take the lead in risk management efforts based on historical experience since implementing pollution control measures and changes in business management concepts reflect the increased environmental awareness among consumers and capital markets. However, Porter's hypothesis implies that the "well-designed environmental regulations" would foster technological innovation and improve business competitiveness. It should allow firms discretion to select technologies; when considering the form desirable the regulatory system should take, it seems vital to focus on making the mechanism as flexible as possible to provide the maximum number of incentives to companies.

Most studies on environmental policies' effect on productivity aim at the firm and industry level, with only a few papers adopting a macroeconomic perspective. Common approaches include cost function estimates, growth accounting, and efficiency measures adjusted for environmental outcomes. The studies at the level of the plants tend to compare the growth of traditionally measured productivity between the regulated and non-regulated plants, and the estimated effects are generally adverse as well as three robust. The effects of environmental regulation on MFP growth have a negative effect (Gollop and Roberts, 1983; Smith and Sims, 1985) or more negligible positives (Berman and Bui, 2001a, on productivity levels). Although no studies can control the potentially different characteristics of two plants or present a convincing argument to ignore these differences, there is a deficit in the effects of fixes or differences in the differences. Studies that attempt to control plant-level characteristics, including firm self-selection in countries with more lax environmental regulations, tend to find many significant productivity determinants (Becker, 2011).

Regulatory effects on competitiveness

When discussing the relationship between environmental regulation and industrial competitiveness, the "Porter Hypothesis" advocated by Professor Michael Porter in 1991 is often quoted. It reads, "Properly designed environmental regulations stimulate technological innovations that lead to cost reduction and quality improvement, resulting in domestic companies gaining a competitive advantage in the international market while improving industrial productivity. It disagrees with the conventional view that "environmental regulations will increase costs for companies and hurt productivity and competitiveness."

As the basis for this hypothesis, some firms' competitiveness, which forces to have a high environmental protection (chemical industry) cost among the U.S. industries in the international market, and the high productivity growth rate of Japan and Germany, which introduced stricter environmental regulations in the 1970s is mentioned. Although not mentioned by Porter, it also explains the "fact" that introducing stricter emission regulations under the Japanese Musky Act of 1978 led to the next breakthrough of Japanese car manufacturers in the U.S. market. From this point of view, even in the competition for environmentally friendly vehicle development, as mentioned initially, further tightening regulations ahead of other developed countries is an effective policy response.

However, the results of theoretical and empirical verification of the Porter hypothesis by many economists are somewhat negative, and there is no consensus on the validity of the hypothesis. The main reason for this is the environment ignored by the Porter hypothesis, such as competition between companies, strategic actions between companies and regulators, demand conditions, and financial support measures of the government in achieving technological innovation and productivity improvement. Various peripheral factors other than regulation may be involved. There is no possibility of improving productivity and competitiveness even if strict regulations exist where there is no possibility of technological innovation that will become apparent due to regulations. On the other hand, from the viewpoint of proof, it can be pointed out that it is challenging to extract the direct impact of environmental regulations as data while various factors are intricately intertwined.

Regulatory effects on innovation

According to the Porter hypothesis, “appropriate environmental regulations” that promote technological innovation and increase the competitiveness of companies should be, for example, regulations that leave room for discretion in the choice of technology of companies. When considering a desirable regulatory system, it is essential to establish a flexible mechanism to maximize the voluntary incentives of companies.

Koźluk and Zipperer (2014) found that even within an industry, environmental regulations on plant productivity can strongly depend on the characteristics of the plant. Gray and Shadbegian (2003) show that integrated mills, subject to stricter environmental regulations due to an integrated pulping process, significantly reduce productivity due to increased pulping costs, while the productivity of non-integrated factories does not show a substantial reduction. Similarly, Becker (2011) found no effect of environmental regulation on labor productivity levels in a large sample of factories. The study finds a negative effect on labor productivity by narrowing the sample to factories that have experienced a statistically significant variation in compliance costs over the years (only one-tenth of the sample).

At the same time, the effects of regulations on specific pollutants on productivity levels can vary, depending on the pollutant. Greenstone et al. (2012) found a persistent negative effect of total environmental regulations. While ozone regulations and particulate emissions regulations are estimated to harm productivity levels, sulfur dioxide emissions have no significant adverse effect, and carbon monoxide regulations even encourage productivity. The paper does not examine the reasons for these results, which may arise from several areas due to different prevention and reduction technologies readily available for various pollutants.

Aside from methodological issues such as data collection, model specification, and choice of variables, the conclusions of most studies lack generality. They assess regulations, targeting companies in specific industries (electric power, brewing, pulp and paper, and manufacturing, respectively) in different countries (the U.S. and Canada) or regions (coastal California) and different periods and backgrounds. None of the studies attempt to control for spillover effects. Only Greenstone et al. (2012) take plant closures into account, while Becker (2011) and, to a lesser extent, Gray and Shadbegian (2003) explicitly control for some firm characteristics that can boost productivity.

The extensive literature empirically examining the relationship between environmental and economic performance indicates a positive correlation. It is critical to understand why such a positive relationship can emerge empirically. Many authors have subsequently proposed theoretical bases for Porter's Hypothesis. Ambec and Lanoie (2008) thus explain at least seven reasons why improving a company's environmental performance can lead to better economic performance. These can be the result of either increased income or reduced production costs. Better environmental performance could lead to increased revenues in three ways: (a) better access to specific markets, (b) product differentiation, and (c) the sale of pollution control technologies. Better environmental performance may lead to cost reductions through four channels: (a) better risk management and relationships with external stakeholders; (b) the cost of materials, energy, and services; (c) the cost of capital; and (d) the cost of labor.

The relationship between the environmental performance effect on economic performance has been the subject of numerous articles, and several surveys and meta-analyses are available, including Wagner, 2001 Blanco et al., 2009 Horváthová, 2010; Albertini, 2013; Crifo and Sinclair-Desgagné, 2013; Crifo and Forget 2015. These articles used return on assets, equity, or market value as measures of economic performance. At the same time, toxic emissions, GHG emissions, environmental management certification (ISO 14001), and adoption of other international environmental standards have entered environmental performance measures.

Meta-analyses on the subject conclude that better environmental performance is generally associated with better financial performance. Twelve (12) studies rely on regression analyses of financial performance on environmental performance; Ambec and Lanoie (2007) report that only nine (9) studies have shown that better environmental performance is associated with better economic performance. Two (2) studies show no impact, while one (1) found a negative relationship. Likewise, Horváthová (2010) reports that about 55% of studies find a positive effect, and 15% find a negative effect. Blanco et al. (2009) focus on manufacturing companies and conclude that no blatant penalty is associated with environmental performance.

The impact of environmental policies on economic variables such as growth, international trade, investment, productivity, and employment is significant in the literature. The empirical literature of recent articles has provided interesting literature reviews (Dechezleprêtre and Sato, 2017; Cohen and Tubb, 2017; Kozluk and Zipperer, 2015). Without dwelling on these long discussions, the main conclusions of these different studies reveal the following aspects:

- The empirical literature shows that the economic cost of environmental regulation is relatively low. This situation happens when a productive technology generates lower costs for a particular production level following a strict and well-designed regulation, which takes the form of pollution abatement.

- Average effects on economic variables tend to be statistically insignificant or close to zero (some studies even find positive effects). However, environmental regulations can also lead to statistically significant adverse effects on economic performance in the future short term in energy-intensive or pollution-intensive sectors, for which regulatory costs are significant. However, the consensus is that these adverse effects are minor compared to other changes that affect the economy (changes in transport costs, proximity to demand, automation of production) and depend on the company's or industry's characteristics.

- The positive effect of environmental policies on innovation is, for its part, well established (Bellas and Lange, 2011; Calel and Dechezleprêtre, 2017), although these innovations induced by environmental policies do not lead to an increase in the overall performance of companies. (Dechezleprêtre and Sato, 2017; Kozluk and Zipperer, 2014).

In this same framework, Hibiki et al. (2003) found that with the ISO 14001 certification system, a statistically significant increase in market value from 11% to 14%, based on a sample of 573 Japanese manufacturing companies listed on the Stock Exchange of Tokyo is indicated. Wagner and Blom (2011) examine nearly 500 companies from the U.K. and Germany and find that implementing an environmental management system is positively associated with the financial performance of companies. Konar and Cohen (2001) use a sample of 321 S&P 500 manufacturing firms and find that a 10% reduction in toxic chemical emissions is associated with a $ 34 million increase in the firm's market value. These outcomes are consistent with investors' view of good environmental performance as an intangible asset.

Numerous micro-data studies have analyzed the impact of environmental policies on polluting emissions. The United States Clean Air Act (USCAA) and subsequent amendments are widely studied policies. It sets federal guidelines for improving air quality but leaves much of its implementation and enforcement to the county level. If a county exceeds an emissions cap set by the federal government for a particular pollutant, it is "out of compliance" and, therefore, must introduce more stringent regulations to reduce emissions. Most USCAA studies analyze the effect of the policy on ambient emissions (ozone, SO2, PM) using the temporal variation in county compliance status. These studies show that assigning a non-compliance status results in lower ambient emissions. Greenstone (2004, 2009) uses data from the U.S. Toxic Release Inventory (TRI) to analyze the impact of USCAA standards on air pollution between 1987 and 1997, focusing on the steel industry. This study found that factories in non-compliant countries reduced their total lead emissions by 7.1% compared to compliant countries. Focusing on the chemical industry, Gamper-Rabindran (2009) finds that emissions of volatile organic compounds decreased by 21% between 1988 and 2001. Gibson (2016) found that regulated facilities reduced their emissions of fine particles between 33 and 38% compared to non-regulated installations.

In one of the few studies using non-U.S. data, Najjar and Cherniwchan (2018) analyze the impact of air pollution regulations in Canada on pollution levels and intensity. They combine Canada's National Pollutant Release Inventory pollution data with company-level financial data from the Annual Production Survey. Over 2004-2010, they found that regulations are associated with a 15% reduction in fine particle emissions and a 33% reduction in **NOx** emissions. Evaluating the impact of environmental policies on pollution at causal levels remains a challenge. One of the reasons is the nature of environmental policies. For others, when discrete policy changes – such as other rigors applying to different facilities – are analyzed, treatment selection is based on the endogenous characteristics of the facility, making it challenging to disentangle their effects. This last reason prevents researchers from observing a credible counterfactual: how the shows would have happened without the policy.

The second issue examined is the impact of environmental regulations on business performance, both environmentally and economically. Most studies that examine the link between the economic and environmental performance of companies report a positive relationship between these two dimensions. This result is probably unsurprising since good environmental performance (better energy efficiency) can increase profits. Regarding the economic impacts, the effects of environmental regulations are sometimes harmful but of low intensity. This observation is essential for political decision-makers. However, redistribution mechanisms and the fiscal neutrality of pricing policies can play a vital role in improving political acceptance of environmental policies and cushioning their socio-economic impacts for particularly affected groups. Since the results of the studies find only minor negative impacts of environmental policies on economic performance, it is even more interesting to note that environmental policies - emission standards or economic instruments such as taxes or permits emissions in fuel markets - appear to lead to improved environmental performance.

In their research two years after Porter's hypothesis was announced, Jaffe and Palmer (1997) present three different variants of Porter's hypothesis. This hypothesis's "weak" assertion posits that environmental regulation will stimulate certain types of environmental innovation. The "narrow" variable, on the other hand, asserts that flexible environmental policy regimes provide more incentive for firms to innovate than prescriptive regulations, such as technical standards, which more than offset the cost of compliance. Lanoie et al. (2007) tested the statistical significance of these different variations of Porter's hypothesis. The analysis was performed on a unique database that includes observations from 4,200 establishments in seven OECD countries. In general, they found strong support for the "weak" variant, qualified support for the "narrow" variant, and qualified support for the "strong" variant as well.

In the automotive industry, environmental regulations are seen as an incentive for innovation, given the competition to address current environmental issues. Technological innovation in the automotive manufacturing sector is considered the key to the coexistence between the environment and the economy, a balance that is becoming increasingly important these days.

Air pollution as a microeconomic fact

Deville (2010,128) asserts that environmental economics refers to the economics of pollution, which can be considered as the production of a nuisance and the human reactions concerning it, resulting in a loss of well-being assimilated by the neoclassical theory to a loss of utility or satisfaction. Like environmental economics, the microeconomics of air pollution draws its theoretical universe from the notions of externality, property rights, collective goods, and optimum pollution. These situations are “market failure.” In the framework of “standard” microeconomics, it is assumed that there is no divergence between private and social costs nor between private and social benefits. This means there is no difference between the costs and the benefits for the agents and the community.

The price system appears as a common denominator that summarizes all agent interactions. It allows an evaluation of collective well-being. Implicitly, prices are assumed to correctly measure the “social values” of goods and the potential addition or reduction in social welfare that their production or use by a particular agent brings. It is presupposed that agents base their economic calculations on the price system and behave competitively (and therefore consider it a given). In that case, market equilibrium leads to a Pareto optimum, where improving the satisfaction agent without decreasing that of another is impossible. In perfect competition, the price system guides agents towards efficiently using the resources available to the community.

There are cases where prices do not play the role assigned by the theory of perfect competition and where private costs and benefits differ from social costs and benefits. These are the situations where one agent’s consumption or production decisions directly affect the satisfaction or profit of other agents without the market evaluating and charging or rewarding the agent for this interaction. There are also externalities or external effects. In the case of externalities, the price system no longer guides agents toward socially optimal decisions, resulting in inefficient production and consumption activities. These externalities can be classified into four categories, depending on whether they are positive or negative external effects and whether they concern production or consumption:

External economies of production appear when specific actions of a company benefit other agents without the company being paid for the advantages procured. The example of the beekeeper and the orchard is a classic illustration of this: the orchard provides flowers for gathering pollen and thus contributes to the production of honey without its owner being able to receive payment for this service rendered. The production externality is reciprocal since the bees fertilize the flowers without the beekeeper claiming payment. External consumption economies exist when consumers benefit from other agents without monetary compensation. For example, when someone repaints the facade of someone else's house to maintain his garden or flowers on his balcony, this brings much satisfaction to his neighbors, who do not compensate him for the service rendered.

The third category of external effects concerns external "diseconomies" of production. We speak of an adverse external impact when the decisions of a specific agent harm other agents without any financial compensation. In the case of external diseconomies of production, the "inconvenience" is a firm. Industrial pollution constitutes the most typical case of external diseconomy of production. When an oil tanker empties its tanks on the high seas or when toxic fumes degrade the air quality in an urban area, the companies responsible for the pollution disturb the fishers and the inhabitants without the market spontaneously setting any price for these nuisances. There is no market for the clear ocean water or a city's clean air.

Finally, we are in the presence of external diseconomies of consumption when the consumers are the source of inconvenience or nuisance for other agents. Tobacco and excessively noisy music can originate from external diseconomies of consumption from which non-smokers and those who appreciate calm, and tranquility suffer. Consumption is also the source of pollution and environmental degradation, which constitute external diseconomies, for example, when the exhaust fumes of automobiles disturb pedestrians or when the owner of a piece of land builds a house with questionable aesthetics.

Research main theoretical contributions and implications

In response to the discrepancies observed in verifying Porter's hypothesis, the study delves deeper and understands the reasons behind these differences. We recognized that previous research approached the hypothesis by examining existing regulations without considering the crucial aspect of well-designed policies. It is important to note that Porter's hypothesis does not suggest that any regulations will automatically spur innovation. Instead, it emphasizes the significance of well-designed policies in fostering innovation, effectively controlling air pollution, and promoting economic growth. By overlooking this critical aspect, previous studies may have inadvertently missed the true essence of the hypothesis.

Through this research, we have sought to shed light on the importance of understanding and implementing well-designed environmental regulations. Doing so can create an environment that supports innovation, effectively addresses air pollution, and facilitates sustainable economic activities. Our findings contribute to the existing literature by highlighting the prerequisite of well-designed policies in the context of Porter's hypothesis. Policymakers and researchers can benefit from this knowledge to enhance their understanding of the relationship between environmental regulations, innovation, and economic growth. The study's main theoretical contribution is identifying the optimal tax rate for air pollution. Through microeconomic models, we have determined that this tax rate should be equal to the marginal cost of the polluter, denoted as **T*= Mc**. This approach aims to prevent pollution at its source rather than simply taxing the adverse effects of pollution on the environment.

The hypothesis stipulates that regulations must be carefully designed to meet Porter's hypothesis's prerequisites. They should aim to provide incentives for businesses to adopt cleaner and more sustainable practices, thereby encouraging innovation in pollution control technologies and processes. These regulations should also consider the economic implications and provide flexibility for businesses to adapt and comply. For instance, regulations employing market-based approaches, such as pollution taxes, can incentivize companies to invest in research and developing cleaner technologies. These approaches create a competitive environment that encourages innovation and allows businesses to find the most cost-effective ways to reduce pollution while maintaining economic activity.

Furthermore, regulations promoting collaboration between industry and policymakers foster research and development efforts, leading to innovative solutions for pollution control. This collaboration can help bridge the gap between air pollution emissions and its impact on human health and the environment, driving technological advancements and economic growth. By implementing such well-designed regulations, policymakers can effectively address air pollution concerns while promoting economic activity. This approach aligns with the core principles of Porter's hypothesis, emphasizing the importance of regulations that encourage innovation, control pollution, and sustainably stimulate economic growth.

Summary

The second chapter of this research focused on the literature review on environmental regulation within the framework of Porter's Hypothesis. This literature review explored both theoretically and empirically. From a theoretical point of view, this literature review evokes the classic approach that considers environmental regulations as an additional burden on the economic activities of the subject companies. From this point of view, environmental regulation negatively impacts companies' profits, which are affected by environmental regulations. On the other hand, Porter's hypothesis considered revolutionary in this field, approaches the problem of environmental regulation differently. According to this hypothesis, a "well-designed" environmental regulation can increase production costs at first; it motivates the firms subject to it to create new production processes to create innovation, productivity, and competitiveness. The literature review showed that the verification of this hypothesis gave divergent results. Many studies have found Porter's hypothesis to hold, while others have found the opposite. This divergence is due to the non-observance of Porter's hypothesis, which stipulates that environmental regulations must be "WELL-DESIGNED." Using statistical data from existing environmental regulations can only give divergent results. We must first develop the "well-designed" environmental regulations, apply them to polluting firms, and verify Porter's hypothesis well after. That is the task that this research has undertaken. Propose an environmental regulation that meets Porter's hypothesis criterion before verifying it.

CHAPTER THREE: METHODS

Overview

This research aims to establish a link between the sources of air pollution and environmental policy to build a regulatory framework capable of allowing improvements in air quality and, at the same time, supporting economic growth, two realities long considered antagonistic. The study first attempts to understand what Porter and van der Linde (1995) mean by "*strict and well-designed policy*" and then proposes market-based regulation. Strict and well-designed are the two predominant characteristics of a regulation respecting the criteria of Porter's hypothesis. Chapter four discusses These two concepts in chapter four, dealing with findings. The proposed policy, which refers to Porter's vision (strict, well-designed, and flexible environmental regulations), drives and guarantees a win-win situation regarding social welfare and private net benefits of companies operating within the framework of such regulations. The objective is to apply this new policy to polluting emissions data to test the statistically significant relationship between environmental regulation and innovation and between environmental regulation and productivity. First, verify the study's hypotheses that environmental regulation positively influences productivity and innovation. Then, if this is the case, support Porter's hypothesis. The study focuses on how environmental control affects economic performance or how economic growth affects environmental quality. Creswell (2013) proposes that the description of the methodology should follow steps in conducting a scholarly methods study. He proposes that the description of the methodology should contain the theory name, origin, source, developer of the theory, a topic where one finds the theory applies, identify proposals of hypotheses, and provide rationale based on the theoretical framework.

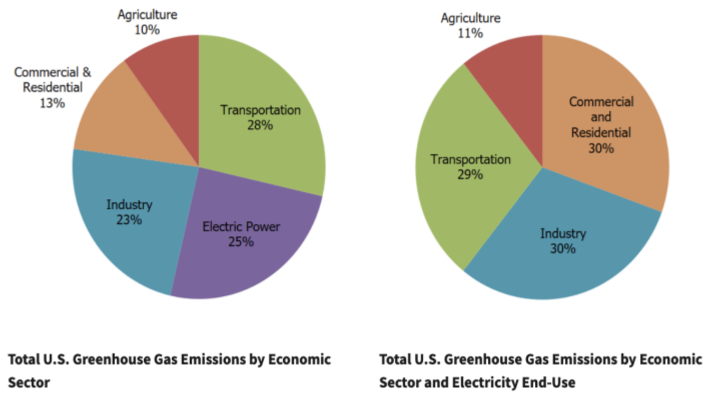
The total greenhouse gas emissions breakdown in the United States

This study analyzes air pollution in the transport industry, the second sector of air pollution after energy in the United States economy (EPA,2021). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the transport sector is essentially composed of the movement of people and goods by cars, trucks, trains, ships, planes, and other vehicles. Most of the transport industry's greenhouse gas emissions are made up of carbon dioxide (CO_2) emissions related to the combustion of petroleum products, such as gasoline, in internal combustion engines. The primary source of greenhouse gas emissions related to the transportation sector is passenger cars, medium and heavy trucks, and light trucks, including sport utility vehicles, pickup trucks, and minivans. These sources account for more than half of emissions from the transportation sector. The remaining greenhouse gas emissions from the transportation sector come from other modes of transportation, including commercial aircraft, ships, boats, trains, pipelines, and lubricants, as described by EPA (2019).

Figure (4) below shows the breakdown of total greenhouse gas emissions in the United States by economic sector in 2019 according to data collected by EPA. The figure shows that the transportation industry produces 29% of greenhouse gases. EPA ranks transportation number one for air pollution. The electricity sector produces nearly 25% of greenhouse gases and is second. The manufacturing industry is third, with 23% of greenhouse gas production. Commercial and residential produce 13% of greenhouse gases and fourth place. Finally, agriculture produces 10% of greenhouse gases and is the fourth industry producing air pollution. To get an idea of the above, EPA (2021) provides the following illustration:

Figure 4.

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2021.



Source: U.S. Environmental Protection Agency (2021). Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990-2019. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

The above figure shows how the US EPA classifies industries concerning the importance of their Greenhouse gas emissions volume. EPA ranks transport at the top of the sectors producing more greenhouse gas with 29% of emissions, followed by the electricity sector with 25% and industry with 23%. Transport and electricity alone emit more than half of the greenhouse gas in the USA (54%). On this basis, the choice of the transport sector motivated this study to illustrate its empirical part.

Design

This research design is a blueprint or plan outlining the research methods, steps, or procedures the study will follow to collect and analyze data, research sample size, and participants. The design of a theoretical microeconomic study refers to the concepts and models describing the behavior of economic agents and their interactions, particularly in the markets. This approach uses mathematical tools and statistical methods to model the functioning of the areas it studies. In the 19th century, this was the first form of the mathematization of the economy. At that time, a new economic trend appeared, aiming to describe the economy's overall functioning based on the individual's behavior. The current economists consider that the individual represented in a theoretical model, the "*homo-economicus*," seeks to maximize his utility in an environment where he must nevertheless consider the means at his disposal and the other economic agents.

The research problem determines the type of design that the study will use. The design of this research dissertation falls into the category of applied research and is mainly quantitative, which implies the mastery of the microeconomic approach. It is mainly the cause-and-effect relationship. This quantitative research measures the quantity of data widely used in the transportation industry. The approach used is essentially analytical with econometric techniques and microeconomics analysis. In this research, microeconomics will use mathematical models with marginal reasoning to determine the optimal equilibrium situations of companies to describe and establish the regulation considered a catalyst for the growth of economic activities and air pollution control. This applied research with a quantitative design focuses on three main designs: Data collection, measurement, and analysis. This paper describes the procedures: Study participants, research methods, data collection, data analysis, and design research.

This study's design also has an experimental conception aspect, which establishes an occasional relationship where a particular cause leads to the same effect, and the cause will continue so that the degree of association is significant. The procedure is vital to control all the factors. This experimental design uses more measurements and more groups over forty-one years. An actual design is necessary to establish relationships between variables (cause and effect)—this design of random distributions (Mishra and Alok, 2017).

This research design emerges from the research purpose and the research questions. Environmental research always follows a multidisciplinary approach. A multidisciplinary study involves many methods that vary according to the themes and topics. This research uses quantitative methods for an empirical evaluation. The quantitative design highlights the econometric conclusions obtained from the data and essential information collected. This research's conclusions will reflect these econometric results derived from the information, numerical data obtained, and analyses. This method will help describe the data. It will consist of collecting data and organizing them in one way or another according to the criteria that the study will develop. The analysis will also make it possible to make statistical inferences and observe trends or patterns, predominantly as the data comprises time series.

Research Questions

This research focuses on knowledge, asking ***what type of environmental regulations meet Porter's Hypothesis criteria, ensuring environmental protection, and promoting competitiveness and the growth of economic activities?*** This study revolves around a central question supported by a few other subsidiaries. Among the subsidiary questions, there are three questions that this research will cover:

(1) How should economic theories address the relationship between economic growth and environmental quality?

(2) What effect does the environmental public policy have on promoting economic activity growth?

(3) What role does imperfect information play regarding the signals sent to corporations and their ability to accurately understand and act on those signals?

Research Hypotheses

The two principal hypotheses this study expects to evaluate are:

H01: There is no relationship between environmental regulation that would reduce pollution.

and promote economic growth.

Ha1: There is evidence that well-designed environmental regulations lead to increased productivity and innovation.

Ho2: There is a significant relationship between environmental regulations and economic growth, which shows that environmental regulation is a negative externality for economic growth.

Ha2: There is evidence that well-designed environmental regulation is a positive externality for economic growth and improves air quality.

Participants and Setting

The study participants were drawn from the transportation industry and federal government agencies. To conduct this project, some institutions and people at the state and national levels participated in developing this work. The collaboration with Washington State's Department of Ecology (ECY) and the Department of Transportation (DOT) from October 2021 to February 2022 helped identify this project's essential data. A team of Andrew Wineke, MacGregor, and Duerr Miriam, all from the Department of Ecology, provided statistics related to emission inventory. The Department of Transport provided data related to Transportation innovation and productivity, and Energy agencies gave statistics related to Energy innovations and productivity. Finally, the Revenue Department provided the regulation revenue. Most of the information and data for this work is available from the internet websites of these public institutions.

The participation was basically in collaboration in obtaining the statistical data collected by these agencies as part of their routine work. The data or time series used in this work were collected from the Federal Reserve Economic Data (FRED) website. FRED is an online database consisting of millions of economic data time series from national, international, public, and private sources. FRED created and maintained by the Research Department at the Federal Reserve Bank of St. Louis, goes far beyond simply providing data: It combines data with a potent mix of tools that help the user understand, interact with, display, and disseminate the data.

For this research, the sample size is forty-one years, representing the maximum number of observations in the data set available for all variables under study. The sample could have been extended, but it was constrained to have only forty-one observations due to a lack of data availability. The data are annual and cover a period from 1980 to 2020. Since environmental economics is a contemporary science, forty years of observation seems reasonable for studying this kind. The most stringent requirements are in the statistical framework, where specific statistical laws require a sample size of thirty (30) observations, for example, the Normal distribution law required in the econometric estimations (Gujarati and Porter 2019, 45).

Measurement and operationalization of study's major variables

Porter's Hypothesis states that well-designed environmental regulations can bring benefits to businesses by encouraging innovation and boosting their competitiveness, which in turn may partially or wholly offset the costs associated with regulatory compliance. It emerges from this Hypothesis three variables, namely *Environmental regulation (E.R.), Innovation, and Competitiveness.*

1. **Environmental regulation (E.R.)**

The carbon dioxide emissions will measure environmental Regulation (E&R) in metric tons from the transportation industry. For the Federal Reserve Bank of St. Louis (FRED), this variable is defined as Transportation Carbon Dioxide Emissions: All Fuels for the United States

(EMISSCO2TOTVTCTOUSA). To obtain the monetary value in U.S. dollars, they will be multiplied by the pollution rate "***carbon dioxide emission* transportation marginal cost***." Kylie Pomerleau and Elke Assen (2019), illustrating a carbon tax's revenue, economic, and distributional impacts, modeled an example of a carbon tax enacted by the federal government. This proposal would enact a carbon tax in 2020 equal to $50 per metric ton of carbon and increase annually by 5%. The carbon tax would apply to a broad tax base, covering all energy-related carbon emissions in the United States and border-adjusted. The authors of this study did not fully explain the origin of the $50 amount. On the other hand, the American Transportation Research Institute (2020), in their study on "An Analysis of the Operational Costs of Trucking: 2020 Update," gives the average marginal cost of transport per hour of $67 and the average marginal cost of transport per mile of $69. Tables (1) and (2) give the average marginal cost per mile and the average marginal cost per hour.

This study uses the marginal cost of transportation per hour to find the Environmental Regulation composite variable (E.R. = Carbon dioxide emission* $67) from 1980 to 2020. According to the EPA (2021), air pollution is the most significant environmental health risk impacting society. The Clean Air Act requires the EPA to set national ambient air quality standards (NAAQS). The NAAQS are currently established for carbon monoxide, lead, ground-level ozone, nitrogen dioxide, particulate matter, and sulfur dioxide for six common air pollutants, called "criteria air pollutants." These pollutants are present throughout the U.S. They can harm health and the environment and cause damage. This study focuses on Carbon Dioxide, an essential pollutant, measured per metric ton. The study will consider carbon dioxide emissions from all sectors, all fuels for the United States.

Table 13:

Average Marginal cost per Mile, 2011-2019

Motor Carrier Costs	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vehicle-based									
Fuel Costs	$0.590	$0.641	$0.645	$0.583	$0.403	$0.336	$0.368	$0.433	$0.396
Truck/Trailer Lease or Purchase Payments	$0.189	$0.174	$0.163	$0.215	$0.230	$0.255	$0.264	$0.265	$0.259
Repair & Maintenance	$0.152	$0.138	$0.148	$0.158	$0.156	$0.166	$0.167	$0.171	$0.143
Truck Insurance Premiums	$0.067	$0.063	$0.064	$0.071	$0.074	$0.075	$0.075	$0.084	$0.068
Permits and Licenses	$0.038	$0.022	$0.026	$0.019	$0.019	$0.022	$0.023	$0.024	$0.023
Tires	$0.042	$0.044	$0.041	$0.044	$0.043	$0.035	$0.038	$0.038	$0.036
Tolls	$0.017	$0.019	$0.019	$0.023	$0.020	$0.024	$0.027	$0.030	$0.034
Driver-based									
Driver Wages	$0.460	$0.417	$0.440	$0.462	$0.499	$0.523	$0.557	$0.596	$0.533
Driver Benefits	$0.151	$0.116	$0.129	$0.129	$0.131	$0.155	$0.172	$0.180	$0.160
TOTAL	**$1.706**	**$1.633**	**$1.676**	**$1.703**	**$1.575**	**$1.592**	**$1.691**	**$1.821**	**$1.652**

Source: American Transportation Research Institute (2020) on An Analysis of the Operational Costs of Trucking: 2020 Update (p 19).

Table 14:

Average Marginal cost per Hour, 2011-2019

Motor Carrier Costs	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vehicle-based									
Fuel Costs	$23.58	$25.63	$25.78	$23.29	$16.13	$13.45	$14.50	$17.07	$15.62
Truck/Trailer Lease or Purchase Payments	$7.55	$6.94	$6.52	$8.59	$9.20	$10.20	$10.39	$10.45	$10.21
Repair & Maintenance	$6.07	$5.52	$5.92	$6.31	$6.23	$6.65	$6.58	$6.72	$5.62
Truck Insurance Premiums	$2.67	$2.51	$2.57	$2.86	$2.98	$3.00	$2.95	$3.32	$2.68
Permits and Licenses	$1.53	$0.88	$1.04	$0.76	$0.78	$0.88	$0.92	$0.95	$0.90
Tires	$1.67	$1.76	$1.65	$1.76	$1.72	$1.41	$1.50	$1.50	$1.42
Tolls	$0.69	$0.74	$0.77	$0.90	$0.79	$0.97	$1.05	$1.17	$1.34
Driver-based									
Driver Wages	$18.39	$16.67	$17.60	$18.46	$19.95	$20.91	$21.97	$23.50	$21.01
Driver Benefits	$6.05	$4.64	$5.16	$5.15	$5.22	$6.18	$6.78	$7.10	$6.31
TOTAL	**$68.21**	**$65.29**	**$67.00**	**$68.09**	**$62.98**	**$63.66**	**$66.65**	**$71.78**	**$65.11**

Source: American Transportation Research Institute (2020) on An Analysis of the Operational Costs of Trucking: 2020 Update (p 20).

According to the American Transportation Research Institute (ATRI, 2020, 18), 2018, the transport sector encountered record demand and the highest tonnage in 20 years. In the ensuing contraction of 2019, several independent factors worked to reduce transportation operational costs. In 2019, transportation industry costs contracted significantly from $1,821 to $1,652, a decrease of 9%. The hourly cost was approximately $65.11, compared to $71.78 in last year's report. These two parameters are presented in Tables 1 and 2.

Over the same period, private transportation costs have increased from $2.73 in 2018 to $2.80 in 2019. Although National Private Truck Council (NPTC) cost metrics include fixed "administrative" costs, it should be noted that these administrative costs have decreased from 29 cents per mile in 2018 to 24 cents per mile in 2019. The growing cost gap between for-hire and private fleets may shift to more private fleet trips to for-hire carriers (ATRI, 2020).

2. Competitiveness

The variable Multifactor Productivity for Manufacturing captures the competitiveness of Other Transportation Equipment Manufacturing (NAICS 3369) in the United States. The Federal Reserve Bank of St. Louis (FRED) defines this variable as reflecting the reciprocal influences on the economic growth of some factors that are not explicitly accounted for on the input side, including technological change, returns to scale, improved skills of the workforce, better management techniques, or other efficiency improvements.

3. Innovation

The research and development of the transport industry captures the innovation variable. The Federal Reserve Bank of St. Louis (FRED) defines this variable as Manufacturing Durable Goods Sector: Transportation Equipment: Contribution of Research and Development Intensity [MPU5350193]. All these data are available at the Economic Research Division of the Federal Reserve Bank of Saint-Louis (2021).

Procedures and Data collection

This research procedure tells how the data was collected. The data for this study was not easy to collect. Initially, there was talk of working with the Washington State Department of Ecology (ECY) and the Washington State Department of Transportation (DOT). After several contacts from October 2021 to February 2022, it turned out that the data needed for this research was not available at the level of local government agencies. For the personnel of these various state agencies, they recommend consulting certain agencies at the federal level to see if these data will be available at the level of the federal government agencies. At the Federal Reserve Bank of St. Louis level, these few data were found to illustrate this research empirically. The section on research limitations in the fifth chapter discusses the characteristics of these data in detail. The data was collected by consulting the Federal Reserve Economic Data (FRED) internet files of the Federal Bank of St. Louis branch. The Documentary method, which consists of consulting documents, files, and archives, was used to collect the data for this research. The availability of data on the FRED site imposed the sample size. Data collection for this study was carried out from the FRED database with the help of this institution's collaborators, who made it possible to find the data type for this study.

This study aims to propose an environmental regulation that can improve air quality and protect the environment. This environmental public policy proposal, which corroborates with Porter's hypothesis, is essentially based on the market's microeconomic principles, illustrating the behavior of the polluting producer and the consumer suffering the effects of pollution. The microeconomic analysis helped find a tax level at the rate t*, equivalent to the marginal cost of polluting a firm's production. The conclusions of this study demonstrate that if the tax rate is equal to the marginal cost of production, the environmental regulation will be able to promote not only the air quality but also the growth of the productive activities of the subject company.

This environmental regulation proposal forces polluting firms to bear all the consequences of their productive activities on the economy. This constraint guarantees that when firms enter the market, this decision will coincide with the general interest. They will only enter if this entry's benefits are more significant than their activities' social costs. The superiority of the proposal derived from Pigouvian taxation lies in its ability to send economic agents a long-term signal reflecting the social cost of their activity. If the tax is well designed, the firm is motivated by maximizing its profit or minimizing its cost and producing the amount that generates the socially optimal pollution level. This proposal for environmental regulation also calls about environmental economics, highlighting principles such as social optimum and profit maximization. It is almost imperative to reconcile the protection of the environment and the growth of economic activities.

The approach is to test Porter’s hypothesis with the proposed regulation, which, in principle, according to the vision of this research, meets Porter’s criterion of “well-designed policy” and will prove a positive and significant relationship between productivity and environmental regulations on the one hand and between innovation represented by Research and Development and environmental regulations on the other hand in the Transport sector. For this purpose, the procedure requires that the principles of social-economic optimum and profit maximization be presented first, and then the microeconomic analysis using the Pigouvian tax as an appropriate instrument for the proposal of said regulation. After presenting the social, economic optimum, and microeconomic analysis from which the regulation proposal will emerge, the results of the empirical analysis will be presented. Analyzing statistical data using the econometric method will make it possible to answer research questions and test the formulated hypotheses.

This research requires the statistical series to be chronological. The statistical analysis of the chronological series will be used to realize that the said series is stationary (without unit root) and appropriate for a statistical study that would lead to expected results. The two estimated models must establish a direct, positive, and statistically significant relationship between the independent variable, Environmental Regulation (E.R.), and the two dependent variables, Total

Factor Product (TFP) and innovation represented by Research and Development (R&D) expenditure. The statistical approach is first to analyze the statistical series at this stage. Once series are stationary, estimate the models and verify the validity of the econometric results (statistical tests and econometric hypotheses). Finally, interpret the results. Data Analysis

The Data Analysis section identifies the type of data analysis, and a concise rationale for the type of analysis is provided. In other words, why is the chosen analysis the most appropriate to test the hypotheses? The rationale needs to be supported by this research. For each identified analysis, this research discusses all assumption tests and how they are tested, the statistic used to report the effect size and the convention used to interpret it, and the alpha used. In this section, the study identified statistical procedures for each hypothesis. The chosen statistical procedures are consistent with the collected research questions, hypotheses, and data type. Thus, this section has been organized according to the research hypotheses.

The connection between the theory, data, and the research question

The connection between the theory, data, and the research question can be explained as follows:

1. Porter's Hypothesis theory: Porter's Hypothesis suggests that well-designed environmental regulations can stimulate innovation and productivity, leading to a competitive advantage for firms and industries. It posits that stricter and well-designed environmental regulations can drive companies to develop cleaner technologies, improve production processes, and ultimately enhance economic performance.

2. Data: To investigate how environmental regulations curb air pollution and enhance production, productivity, and innovation, the study will need relevant and reliable data. This data could include information on environmental regulations, air pollution levels, industrial production,

economic indicators, innovation measures, and other related variables. In the case of this study, environmental regulation, research, and development (Innovation), and total productivity Factor (competitiveness) are data series that will help answer the research's central question.

3. Research question: The research question directly aligns with Porter's Hypothesis theory by examining the relationship between environmental regulations, air pollution control, and their impact on production, productivity, and innovation. It seeks to understand how environmental regulations effectively achieve their intended goals while considering their potential impact on economic performance.

The connection between Porter's Hypothesis theory, data, and the research question lies in testing the theory's validity through empirical analysis using data on environmental regulations, air pollution, and economic indicators. The results show that well-designed regulations lead to reduced pollution levels and, at the same time, foster production, productivity, and innovation within industries. By analyzing the data and conducting statistical tests or econometric modeling, the study evaluates the relationship between environmental regulations, air pollution, and economic outcomes, providing evidence to support Porter's Hypothesis in the transportation industry.

Data Analysis

The data collected to illustrate the environmental regulation proposal will first be analyzed descriptively. At this descriptive stage, it will be a question of interpreting the meaning of the descriptive statistics and giving them meaning in the context of this study. Then, an econometric analysis will be made where two models will be estimated for each variable of interest. Descriptive analysis will analyze collected data to help describe and summarize historical data meaningfully so that insights emerge. The descriptive analysis will make it possible to answer the question, "What happened?" Descriptive analysis will help provide basic information on the variables under study. It will also highlight potential relationships between variables to identify variations over time. The econometric analysis will make it possible to verify the research hypotheses and answer the study's various questions. Econometrics is the analysis par excellence in this type of studys where it is a question of verifying a hypothesis. See if the independent variable significantly explains the dependent variable. This method of data analysis also allows to see if there is a direct correlation between the two variables and if that is statistically significant. Both statistical and econometric tests will allow verification and conclusions to be drawn according to the results obtained.

This process and analysis step consists of analyzing and interpreting the collected data. This step will use statistical and econometrics software such as SPSS, EViews, or Stata to process collected data. Quantitative data processing can be more complex depending on the methods used and the amount of data compiled. Since the data will be in time series, all techniques relating to time series processing will be applied (unit root test, autocorrelation of series, multicollinearity, and heteroscedasticity).

To propose this regulation, this research follows a scientific approach through the following stages: the observation phase of the fact, which is linked to the public policy phenomenon provided by environmental economics and statistics. The abstraction is the phase that simplifies reality by dissociating the essential aspects from the secondary ones. *Abstraction* is an operation that consists of isolating certain essential elements while neglecting others. The deductive phase includes the development of hypotheses, the development of laws through causal reasoning, and the theory verification phase, which compares theory with reality to test its relevance. The theory can be verified using statistical series and mathematical and econometric models. As the facts have verified the theory, it is accepted; if not, it is rejected. This methodological approach is identical to scientific research except concerning experimentation, which is challenging for social sciences; economics does not rely on laboratory work.

Additional Potential Data for the Study

While the proposed alternative approach using carbon dioxide emissions and industry marginal cost provides valuable insights, it is essential to acknowledge other potential data the study would have ideally collected if well-designed environmental regulations were available. These additional data points could further enrich the analysis and provide a more comprehensive understanding of the impacts. Some of these potential data elements include:

1. Compliance Costs: Well-designed environmental regulations often come with compliance costs, including the expenses associated with implementing pollution control technologies, monitoring emissions, and meeting regulatory standards. Collecting data on compliance costs would provide a more accurate representation of the financial burden imposed on the transportation industry.

2. Industry-Specific Factors: Understanding the unique characteristics and dynamics of the transportation industry is crucial for assessing the impact of environmental regulations. Data on factors such as fleet size, types of vehicles, fuel consumption, and operational practices would enable a more granular analysis of the industry's expenditures and the potential effects of regulations.

3. Regulatory Incentives and Subsidies: Well-designed environmental regulations often introduce various incentives and subsidies to encourage industry compliance and promote the adoption of cleaner technologies. Collecting data on these regulatory incentives would enable a more comprehensive understanding of the financial implications for the transportation industry.

4. Market Dynamics: Environmental regulations can have both direct and indirect impacts on market dynamics, including changes in supply and demand patterns, market shares, and industry competitiveness. Collecting data on market dynamics and analyzing them in conjunction with the estimated expenditures would provide a more holistic view of the potential effects of regulations.

5. Environmental and Health Benefits: Well-designed environmental regulations aim to achieve environmental improvements, such as reduced greenhouse gas emissions and improved air quality. Collecting data on these regulations' environmental and health benefits would help assess their overall effectiveness and societal impact.

While the proposed alternative approach using assimilated data provides valuable insights into the transportation industry's expenditures, it is essential to acknowledge the limitations and consider additional data elements that would have been ideal to collect. These data points would enhance the study's comprehensiveness and provide a more robust analysis of the potential impacts of well-designed environmental regulations. Future studies should strive to incorporate these data elements to gain a more thorough understanding of the relationships between regulations, industry expenditures, and societal benefits.

Summary

The third chapter of this dissertation related to the methods used to develop this research ranges from research design to data analysis through research questions, research hypothesis, and data collection. Research Design is essentially quantitative. The research consists of one central question and three subsidiary questions. It also makes two assumptions about the existence of an environmental policy that supports economic growth and protects air quality. The secondary data is available on the Federal Reserve Branch of Saint Louis website, and EViews software helped with data processing.

Since the study aims to establish a link between the sources of air pollution and environmental policy through a regulatory framework allowing air quality improvements and simultaneously supporting economic growth, the study follows the following steps. First, it attempts to understand what Porter and van der Linde (1995) mean by "*strict and well-designed policy." Microeconomic* analysis of these two concepts requires a quantitative approach (Graphics and Equation Models). After developing the regulation proposal based on microeconomic principles, the regulation proposal will be verified. Finally, a results discussion concludes the research.

CHAPTE FOUR: FINDINGS

Overview

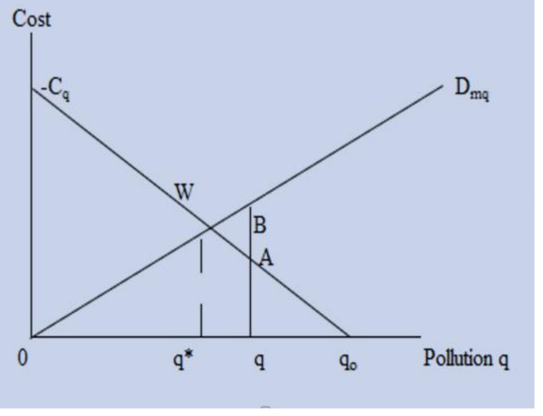
This research aims to associate economic activities with a pollution control regulation proposal consistent with the Porter hypothesis. Regulation is likely to promote the growth and productivity of economic activities simultaneously as it improves air quality. The proposal for this regulation comes from the microeconomic analysis of the polluting producers' behavior by imposing a Pigouvian tax on them. The first section of this results chapter presents the graphical microeconomic understanding of economic optimum and environmental equilibrium. The graphical demonstration approach adopted in this study is the one that Verlaenten (1991) proposed in his attempt to reconcile economics and ecology in his attempt to reconcile economics and ecology in environmental economics analysis. Verlaeten (1991) highlights the ecological imbalances underlying the production model. The idea is to maximize profit and net social benefit by minimizing ecological risk. Therefore, Minimizing the ecological risk amounts to changing innovation and productivity. The second section, which uses the microeconomic analysis, introduces the Pigouvian tax in the production process and the decision-making of the polluting company, which will lead to an optimal tax equal to the marginal cost of production and the marginal damage. Finally, the last section presents the econometric results of the estimates of two models testing this proposition of environmental regulation to affirm or invalidate Porter's hypothesis.

Analytical Results

The Pollution Optimum

Figure 5.

The Marginal cost and marginal damage



The line D_{mq} constitutes the monetary evaluation of the marginal damage of the residents linked to the quantity of polluting discharges, which determines the quality of the environment. The term marginal means that the damage is assessed for the last or additional unit. Each unit of pollutant added creates more damage than the previous unit added. The higher the pollution, the greater the damage. This marginal damage is assumed to be increasing.

The line C_q of marginal cost

To have all the damage generated by a certain amount of pollution, one should calculate the air under the curve. The line $\mathbf{C_q}$ represents the marginal cost of pollution reduction for the company. While the less the company pollutes, the more difficult and costly it is to clean up more. When there is no abatement effort, the cost is zero, and the quality of pollutants emitted is maximum and equal to $\mathbf{q_0}$. The level of pollution is linked to the level of production, which maximizes its profit and minimizes its cost (at the production optimum, the two are equal). For the company, q_0 constitutes its private optimum. Without any intervention, the company will not produce the below. It is more difficult to lose a kilo when someone is very close to their ideal weight than when they are far from it. The less the company pollutes, the more complex and costly it is to reduce pollution (read the curve backward starting from $\mathbf{q_0}$). The marginal cost of achieving zero pollution is, therefore, very high. $\mathbf{C_q}$, therefore, decreases with pollution. If the company is not subject to any constraints and seeks to minimize its costs, it will produce so that the pollution level is maximum. In this case, the company does not bear the abatement cost. From the general interest point of view, residents suffer maximum damage more significant than the economic optimum $\mathbf{q_*}$.

A corollary of this result is that the economic optimum does not generally imply the total absence of pollution. A gap exists between the private optimum $\mathbf{q_0}$ and the optimum social $\mathbf{q_*}$**.** The company privatizes all the gains but socializes the damage to the environment! It imposes a negative externality on the other agents. The social optimum corresponds to minimizing the damage's sum (areas under the curves) and reducing pollution costs. On the graph, this sum is equal to the area of the surface **q0qA + 0qB = 0BAq0**. The pollution is socially optimal for any level of pollution q when points **A** and **B** coincide (point **W**. Figure 5). At point **W**, the pollution level is such that it equalizes the marginal harm and the marginal cost of pollution abatement. If the company considered, in its economic calculation, the damage suffered by residents, there would no longer be any externality. Since the pollution attaches to $\mathbf{q_*}$, the externality is said to have been internalized.

Economically, zero pollution does not exist. It would be economically inefficient because it is far too expensive. This would be a utopian objective since any activity, even natural, pollutes. If the company considered the damage it causes to the environment and other agents, there would be no externality and, therefore, no environmental problem from an economic point of view.

The non-coincidence between the private optimum and the social optimum constitutes a justification for the intervention of the State to regulate, either by methods that limit the actions of agents (coercion) or by methods that push them to find solutions on their own (incentive).

An externality is internalized when the social and private optimum gap has been eliminated.

Economic optimum and Environmental Equilibrium

Coase and Ronald (1960). Cornes and Sandler (1986), and most recently, Daniel Phaneuf and Till Requate (2021, 75-7), have argued that the degradation of the production factors used by economic activity is nothing but a set of external effects or responses from the natural framework for the insertion of the activity generating costs for the community at the time of production and beyond. The costs are distributed over a non-economically determined horizon, which depends upon insertion. These costs are called Social Costs. At the beginning of their appearance, the social costs were not integrated into the calculations, justifying the payments made by the economic agents belonging to the community, as Berry and Martha Field (2021, 66-69) described. The only accounted costs determine the price of goods and services on the market within the framework of the principle of individual behavior, maximizing the producer's profit and consumer's utility. Thus, everything with a market has a cost, and all costs are relative to a market. This happens because the sphere of human activities functions as a platform for exchanges in specific "places." Markets value everything monetarily: commodities by their prices, men or more precisely, labor power by wages. Outside the market, there is no typical value imposed on everyone except in the context of philosophy, morality, religion, art, or science, and this, with the difficulties and sometimes the known cruelties.

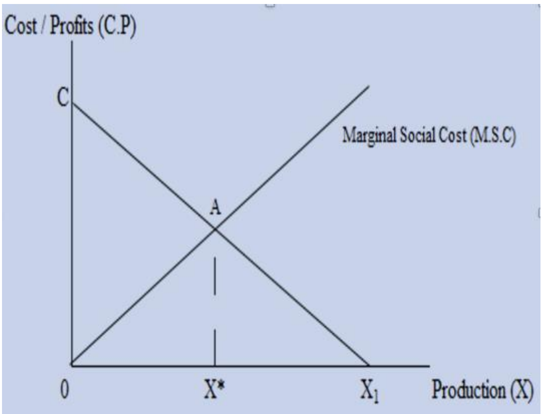
So, the market is, by definition, a dialogue between economic agents who, apart from being traders, have nothing a priori equal. Thus, historically, it was necessary to limit the sovereignty of the market by "mechanisms" equalizing conditions prior to exchange. Thus, the market can realize an economic optimum that has been socialized. In short, for goods such as air without a market or for which the market is failing, just as we correct the economic calculations of efficiency to socialize the results, these calculations must be corrected to consider the assimilation capacity of the natural environment to human activities.

Social Costs and Economic Calculations

The externalities linked to the production process must be integrated into economic calculations to define the collective optimum. The maximum profit generally does not correspond to the maximum social benefit (Baumol & Oates, 1998, pp. 36-42). By considering the marginal social cost and the marginal profit of the firm, it is possible to extrapolate a graph representing the production, the social optimum, and the maximization of the profit for the firm. G*raph 6* presents the production level of a polluting firm in the horizontal axis. The vertical axis presents the profits and costs corresponding to the production levels (**X**). Straight lines are for simple convenience to illustrate profits and costs. Line **CX1** represents the firm's marginal profit from each additional production unit. The line is decreased by the diminishing returns to scale hypothesis (Nicholson & Snyder, 2012, pp. 310-312). The more the production increases, the more the unit costs increase and, consequently, the more the profit per unit of production decreases. The firm maximizes its total profit at a level of production of **0X1**. Its total profit is then equal to the area of the triangle **0CX**$_1$.

Figure 6.

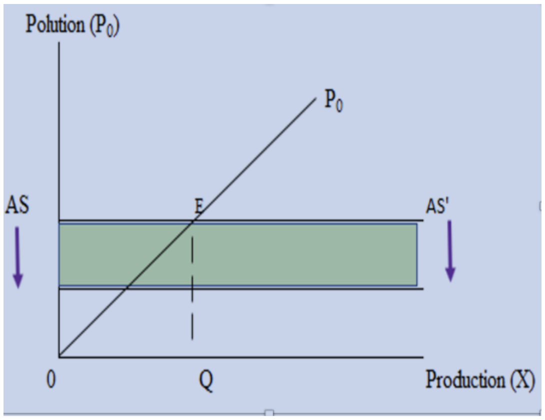
Production, social optimization, and profit Maximization



The more the firm produces, the more it pollutes. It is reasonable to consider pollution to analyze the environmental balance and the marginal social cost (**MSC**) line, the cost caused by pollution. There is a socially optimal production level for the community, 0X*, at the intersection of the marginal social cost and the marginal private profit. This production level is lower than that which maximizes private profit (**0X*< 0 X1**); the optimal social benefit implies maintaining a certain pollution level whose social cost equals area **0AX*** in Figure 6. Therefore, the net collective advantage equals the area **0CA = 0CAX*- 0AX***. In their theoretical writings on externalities theories, Phaneuf and Requate (2021) think Paretian is the social optimum because any movement around point **X*** decreases the net social advantage. The community must claim this type of balance and eventually achieve it when ad-hoc (Strict regulation, which refers to Porter Hypothesis) decisions are taken. The social cost of pollution is known. This situation implies that economics and ecology are not necessarily reconcilable by the different meanings of the term pollution in the two systems. However, this is different from the situation that this study supports. This study seeks to establish a win-win situation under Porter's hypothesis.

Figure 7.

Environmental Balance



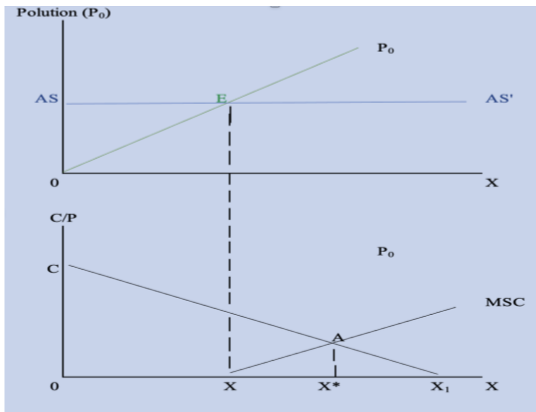
Any pollution constitutes a shock in an environmental system that announces a growing imbalance in the pollutants volume discharged. The broken balance appears when the quantity of pollution exceeds the assimilation capacity of the environment. In **Figure 7**, the horizontal line **ASAS'** represents the environment's assimilative capacity, while line **0P0** represents the amount of pollution.

The balance of assimilation breaks when the pollution exceeds point **E**, to which the level of production **X** corresponds. This level is not optimum, representing the maximum flux a receiving environment can support during a given period. However, this quantity is not precise, so the line **ASAS'** is in a zone of indeterminacy (hatched zone). Moreover, one cannot identify a threshold from which pollution appears. Point **E** represents an environmental ceiling and an economic threshold. Beyond the zero level, pollution leads to imbalances in the environment. However, it appears when it reaches the maximum bearable from the Environmental point of view (level **X** of point **E**) that it becomes a nuisance and results in a social cost from the Economic point of view (Baumol & Oates, 1988, p. 57).

Chart 8 brings out the duality. The Economic Social Optimum is at the level of production X* (**Figure 6**), which is higher than the pollution production **Q** resulting from the environmental ceiling **E** (**Figure 7**).

Figure 8.

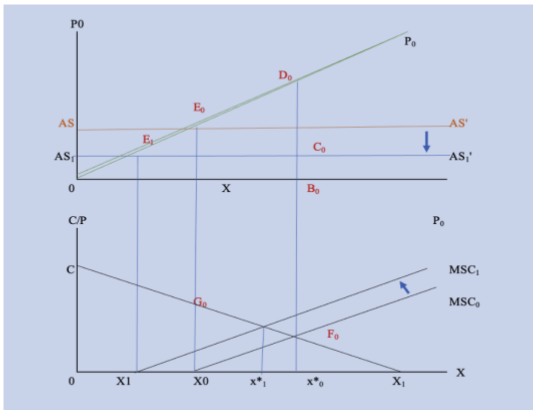
Environmental Balance and Social Economic Optimum



The economic calculation of equalizing social costs to marginal profits can also lead to a production level incompatible with the Environmental balance (**0X* > 0Q**) by putting it together (**Figure 6** and **Figure 7**). When the community is highly aware of pollution, the damage rating is very high, with pollution beyond assimilative capacity deemed unbearable. Then, the straight line of the marginal social cost (**MSC**) is close to 45 degrees oblique so that the level of economic activity remains compatible with the environmental balance (the coincidence of the points **X** and **X***). Such a balance is only possible if all the environmental components likely to be affected by pollution enter the utility function of individuals, and economic calculation has the practical ability to assess the damage. Finding a balance between Economic and Environmental considerations is fundamentally a question of time or the dynamic evolution of the environment (Phaneuf & Requate, 2021, pp. 75-7). In graph 8, in the upper part, **E** represents the point **AS** from which the assimilation capacity of the environment exceeds, and pollution entails a social cost for the community. The social cost line **MSC** increases from **Xo**, corresponding production level at **E**.

Figure 9.

Environment and Economic Activities balance



The Economic optimum function of the marginal private profit (**CX1**) and marginal social cost (**MSC**) lines is at the level of production **$0X_0$***, which is incompatible with the maximum environmental **$0X_o$: $0X_o^*$> $0X_o$**. The production gap between the Environmental optimum and the Environmental maximum is the environmental gap: **$X_0X_0^* = 0X_0^* - 0X_0$**. If, during the initial period, the production level stands at **OX_0***, the quantity of pollution generated will be **B_0D_0**, the proportion of which **B_0C_0** will be assimilated; the non-assimilated surplus **C_0D_0** then constitutes a stock accumulated in the environment, which lowers the assimilation capacity of the environment accordingly. So, in the second period, it is no longer described by the line **ASAS'** but by **AS_1AS_1'** with **ASAS' - $AS_1AS'_1$ = C_0D_0**. The point **E_1** has the analog of **E_0** indicative of the level of production entailing a social cost for the community. This level is **$0X_1$**, and the resulting economic optimum is **X_1***. Thus, when the stock of pollution increases, the social cost appears for lower production levels; the extreme case is a reduction in production to a zero level when the stock of pollution reaches the assimilation capacity of the environment (**0As**). Consequently, incompatibility between the environmental balance and the economic optimum appears as proceeding from a conflict between the objective of immediate maximization of the collective advantage and the search or the recognition of the need for assimilation of environmental pollution in the long term. Thus, the well-understood collective advantage in the long term would consist in minimizing the environmental risk by maintaining production at level **$0X_0$**, the community then suffering a loss of net profit equal to the surface of the triangle **$X_0F_0G_0$**.

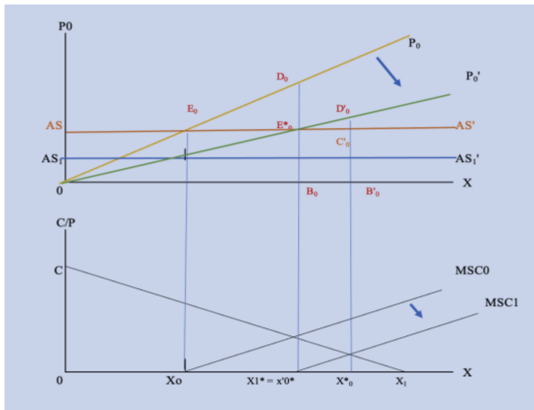
In other words, the incompatibility between the environmental balance and the economic optimum is proceeding from a conflict between the objective of immediate maximization of the collective advantage and the search or the recognition of the need to assimilate environmental pollution in the long term. Thus, the well-understood long-term collective benefit would consist in minimizing the environmental risk by maintaining production at the $0X_0$ level, the community then suffering a consequent loss of net profit.

The optimum economic function of marginal profit (CX) and marginal social cost (MSC) is at the level of production 0X0*, which is incompatible with the environmental maximum. The production gap between the Environmental Optimum and the Environmental Maximum is the environmental gap. If the production level is at a given point during the initial period, the quantity of pollution generated **Q**, the proportion of which will be assimilated; the non-assimilated surplus then constitutes an accumulated stock in the environment, which correspondingly lowers the assimilation capacity of the environment. Thus, in the second period, it is no longer described by the same level of assimilation, which will be less than that of the previous period, generating point E1 analogous to E0, indicating the level of production entailing a social cost for the community. Thus, when the stock of pollution increases, the social cost appears for lower production levels;

the extreme case is a reduction in production to zero when the stock of pollution reaches the assimilation capacity of the environment.

Figure 10.

The Use of a clean technology or Innovation



The reconciliation constraints between the economy and the environment are becoming more flexible due to the introduction of clean technologies (innovation) and actions to restore (or clean up) environments. F**igure 10** illustrates the introducing of a new clean technology (innovation) **$0P_0$',** which reduces pollution for a given production level.

X_0* --> B_0 D_0 = X_0' --> B_0 E_0* ←-----→ B_0 E_0*< B_0D_0

We then find the dynamics illustrated by graphic 9. The economic optimum goes from **X_0***to **X_0*' with X_0*' > X_0*;** however, this new optimum **X_0***', analogous to the first **X_0***, remains, although with lesser intensity, incompatible with the ecological balance or generates residual pollution lowering the assimilation capacity of the environment (**A_SA_S' --> $A_{S1}A_{S1}$'**). The abatement or the restoration of the environment insertion avoids the fall production related to the capacity of assimilation of the environment. It reduces or even cancels the downward movements of the **A_SA_S'** line.

The reconciliation of economic imperatives and the assimilation of pollution by the environments of insertion passes by isolated or joint actions of reducing production, introducing clean technologies, abatement, or restoring the environment's integration of human activities. All these actions are difficult to implement because cleaning up or restoring any environment is not always technically possible. According to Gomiero (2016), soil development ranges from 500 to 10,000 years. Humanity does not know how to make cultivable and fertile soil through the intermediary of humus. Moreover, the techniques men currently possess, those of hydroponic agriculture, do not allow for feeding or watering without the soil. Next, it is impossible to define the appropriate techniques immediately, which are most often costly, and, above all, they must be studied not to induce new pollution. Production cannot be reduced significantly at the macro-economic level without damage to the social order. Indeed, the socialization of income created by production is linked to an economic efficiency nourished by accumulation, i.e., continuous increases in production.

For the technical and social difficulties, the techniques of abatement or restoration of the environment are expensive, meaning that they add additional costs to those to which economic agents are accustomed and raise the question, "which should clear these costs?" In the market context, under price transparency, the additional costs will be passed on to consumers, giving them more power in democracy elsewhere so that there is a risk of an increase in the general level of prices in the event of abatement or restoration of a large scale, which is within the framework of a situation of Keynesian unemployment. Indeed, if macroeconomic production decreases to fixed prices, excess supply sets in on two markets: producers are rationed on the goods market and consumers on the labor market. A price drop would be needed to obtain a Walrasian equilibrium in this context. However, it is an increase in these that is most likely. For example, in certain regions, the abatement of water entails levying a fee from consumers by the basin agencies. In addition, pollution, or restoration (on a large scale) can act as an oil shock. Increases in production cost reduce installed capital's profitability and, therefore, investment, which causes both Keynesian unemployment and contained inflation. It may move towards classic unemployment and simultaneity of three crises in the long term reprimed by contamination. It is also necessary to be attentive to the fact that the abatement started and paid for by the community at a precise moment will only have these effects considering several speeds. For example, entering a pollutant firm into a specific environment will have effects later or produce externalities in another environment to the first.

Marginal cost and Marginal Benefit

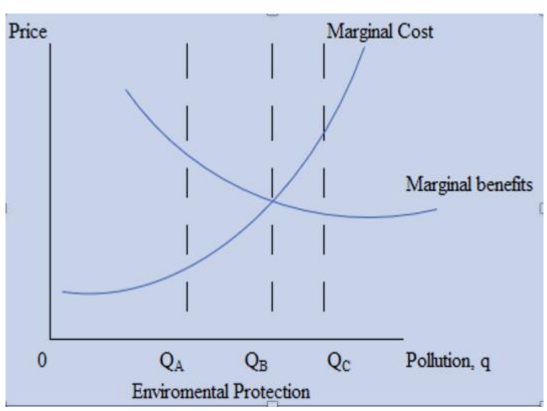
Timothy Taylor (2011, 285-287), when discussing the benefits and costs of the US environmental regulations, finds that the policymaker's objective would be to avoid environmental rules that would provide the highest amount of environmental protection, where the marginal costs are higher than the marginal benefits. Marginal analysis tools can illustrate pollution abatement's marginal costs and benefits. When air pollution is high, this is accompanied by low environmental protection. **Figure 11** presents a theoretical model of this situation. At the quantity $\mathbf{Q_B}$, which corresponds to the crossing of the marginal cost and marginal benefit curve, there are several relatively cheap and easy ways to reduce air pollution, and the marginal benefits of reducing this pollution reduction are high. At point $\mathbf{Q_A}$, allocating more resources to fight pollution is reasonable. However, as the scope of environmental protection increases, cheap and easy ways to reduce pollution begin to dwindle, and more expensive methods must be used. The marginal cost curve rises.

Timothy Taylor (2011) thinks that as environmental protection increases, the firm gets the most extensive marginal benefits first, followed by the more minor marginal benefits. As environmental protection increases to reach the amount of pollution QB, the difference between marginal benefits and marginal costs narrows. At the quantity $\mathbf{Q_C}$, the marginal costs will exceed the marginal benefits. At this level of environmental protection, the firm needs to allocate resources efficiently because it wastes too many resources to reduce pollution.

Figure 11. Marginal Costs and Marginal Benefits of Environmental Protection Pollution abatement is an expense. The company must sacrifice resources. The marginal costs of pollution abatement generally increase because the cheapest and easiest abatements can be made, leaving the most expensive methods for later. The marginal benefits of pollution abatement generally diminish because one can start by taking the actions that offer the most benefit, and those that offer the most negligible benefit can wait until later. As the company moves closer to $\mathbf{Q_B}$, some might argue that using market-driven environmental tools to limit pollution abatement costs becomes essential.

Figure 11.

Marginal cost and Marginal Benefit



This remark by Timothy Taylor (2011) is the basis of the marginalist approach to environmental regulation, an approach adopted by this study. The marginalist analysis of environmental regulation would decrease the marginal costs of production and increase the marginal benefit, which is the objective pursued by the regulator.

Microeconomic Analysis of the Theoretical Regulation Proposal

At the start of this microeconomic analysis for determining the optimal tax to be applied on polluting firms, it is assumed that pollution (**q**) is a waste due to production and can never be dissociated from production. This hypothesis means that it is not possible to produce without pollution and that pollution is not emitted without production. Production and pollution costs are inseparable since the company emits pollution at zero cost. As a result, the company could improve its production process due to environmental regulations, for example, to be efficient by producing at a lower cost, reducing pollution, and maximizing profit.

According to Porter (1991), environmental issues appear to improve the company's productivity and competitiveness. This "win-win" perspective is often called the "Porter Hypothesis," contradicting the traditional postulate of the negative link between environmental actions and business competitiveness (Porter, 1991; Porter & Van der Linde, 1995). According to Porter, developing environmental regulations produces expenses and transformations that can increase costs. However, responding to these constraints also involves innovation efforts to improve production processes, efficiently use inputs, and find new production by-products. Porter believes that the benefits resulting from these measures ultimately exceed their costs. Applying the regulations is far from curbing the competitiveness of companies concerning competitors.

In a competitive economy, it is accepted that the optimal environmental policy comes down to a Pigouvian tax on emissions. Arthur B. Cecil Pigou, an English economist who proposed this tax in 1920, wrote "The Economics of Welfare." The introduction of this tax requires an understanding of microeconomic concepts. A review of basic microeconomics notions is crucial for understanding here. These few essential and straightforward microeconomics principles relate to short-term competitive equilibrium.

Let us assume a straightforward economy in which there are producers and consumers. The first produces a homogeneous good that the second consumes. Suppose also that the producers are all identical and have the same production cost function **C(x)**, with **X** the quantity of a good produced. We assume that the marginal cost of production is positive **Cx > 0** and increasing.
(**Cxx** > **0**). These assumptions mean that production is done under diminishing returns to scale regime, meaning that as an investment in a particular area increase, the rate of profit from that investment, after a certain point, cannot increase if other variables remain constant.

On the consumer side, they are also identical with a utility function **U(x)** of consuming a quantity of good **X**. We make the following assumptions: **Ux** > **0** and **Uxx ≤ 0**. The hypothesis of decreasing marginal utility reflects a satiety mechanism: the utility derived from a good unit's consumption decreases with the quantity of goods already consumed. Finally, we assume that the number of producers equals the number of consumers and that these producers and consumers operate in a competitive market. A competitive market occurs when producers and consumers consider the market price to be given. They consider the price effect of their consumption or production decision negligible. They are "price takers" (Varian, 2020, p. 390).

We can now show that the competitive equilibrium corresponds to an economically efficient situation. Economic efficiency occurs when all goods and factors in an economy are distributed or allocated to their most valuable uses, and waste is eliminated or minimized and not permitted. To characterize the equilibrium, we must first describe the behavior of those intervening in the market.

A representative producer will produce a suitable quantity that maximizes his profit:

$$\mathbf{Max}_{x}\ \pi = \mathbf{p.x} - \mathbf{C(x)} \qquad \textbf{(1)}$$

The competitive market hypothesis appears in the optimization function, and the price p does not depend on y, the producer decision variable. The First Order Condition (FOC) of this function gives the equation that defines the quantity of the good that will be produced and offered on the market by the producer:

$$\mathbf{P = C_{xx}(x).} \qquad \textbf{(2)}$$

This is a fundamental result of microeconomics: *a producer fixes his production level by equalizing price and production's marginal cost in a competitive market.*

Similarly, the consumer sets his consumption level by maximizing his surplus:

$$\mathbf{Max}_{x}\ \mathbf{U(X) = U(x) - P \cdot X} \qquad \textbf{(3)}$$

FOCs leads to

$$\mathbf{P = U_{xx}(X).} \qquad \textbf{(4)}$$

In a competitive market, the consumer fixes his consumption by equalizing the price and marginal utility.

Short-Term competitive equilibrium

We have just described the spontaneous equilibrium situation of the economy. Three conditions, therefore, define it:

• Producers maximize their profit

• Consumers maximize their utility

• The quantities offered by producers are greater than or equal to quantities demanded by consumers.

It is a technical constraint that, combined with the first constraint, the equilibrium turns into a simple equalization of the quantities offered and demanded. It would contradict the objective of maximizing profit to produce quantities that would not be sold. The equilibrium is qualified as short-term because we assume that the producers will produce no matter what. We assume that they have already decided to enter the market. It is also assumed that the producers and consumers are all the same and are in the same number. The three conditions are then rewritten:

• The representative producer maximizes his profit

• Representative consumer maximizes utility

• The quantity produced by one equals the quantity consumed by the other, the quantity that we denote x.

These three conditions are written mathematically:

$$\mathbf{P = U_{xx}(X) = C_{xx}(X)} \qquad \textbf{(5)}$$

At competitive equilibrium, the consumer's marginal utility is, therefore, equal to the producer's marginal cost. We will denote **p*** and **x*** as the values of **P** and **X**, which respect equations (5) defining the competitive equilibrium.

The competitive equilibrium optimality

It can be demonstrated that equilibrium is economically efficient, which means that social welfare is maximized at equilibrium. This function describes the general interest as the sum of the economic agents' surpluses. Again, as agents are identical and in equal numbers, we can simplify this function by considering only the consumer and the representative producer. The social optimum, therefore, corresponds to the following equation:

$$\mathbf{\underset{x}{Max}\ \pi = [P \cdot X - C(x)] + [U(x) - P \cdot X] \Leftrightarrow \underset{x}{Max}\, U(x) - C(x)} \qquad \textbf{(6)}$$

The term **P · X** disappears from the well-being function since it is a transfer between agents. We then directly obtain the FOC, which coincides nicely with the competitive equilibrium defined by (5).

$$C_{xx}(x) = U_{xx}(x) \quad (7)$$

Thus, under the assumptions made, the competitive market leads to an economically efficient situation. No public intervention is necessary, and competition is sufficient to coordinate each in the interest of all. We made very simplifying assumptions by considering homogeneous producers and consumers in identical numbers, equating social optimum with the sum of surpluses, and considering an economy with one market. In the most general framework, this result remains valid and is expressed in the form of two theorems. On the other hand, it is no longer valid when external costs and pollution are introduced.

Introducing Pollution

Assume that a quantity of pollution **q** accompanies the production of **x**. This pollution creates damage, translated in monetary terms described by a function **D (q)**. We assume **Dq > 0** and **Dqq ≥ 0** (where Dq = damage caused by pollution q, and Dqq marginal damage of q). The second hypothesis forbids that the environmental damage of the last unit of pollution decreases when pollution increases, which seems to respect a general law of the functioning of ecosystems. Polluted people, whom we assume to be distinct from producers and consumers, bear this damage.

Furthermore, we assume that the representative producer now has a production cost that depends on production and pollution: **C = C (x, q)**. As in the previous part, we will continue to assume that **Cx > 0** and **Cxx > 0.** (**Cx** = cost to produce **X** and **Cxx** = marginal cost)

Regarding pollution, an assumption is made that **Cq < 0** - *the more pollution decreases, the more the production cost increases*. By definition **- Cq** is the marginal cost of pollution control (or abatement). We will then assume that **Cqq < 0**, assuming diminishing returns in pollution control cost. Finally, we will assume that **Cxq** = **Cqx ≤ 0**.

Assuming **Cxq = Cqx ≤ 0** is very significant. This condition gives two possibilities:

Cxq = Cqx < 0 and Cxq = Cqx = 0.

- If **Cxq = Cqx = 0**, this means that the marginal cost of production is not affected by pollution, and therefore, the level of production is never affected by the pollution level. Thus, production and pollution control are separable activities for the producer. To reduce pollution, the producer always uses "*end of pipe*" technologies (which have a cost described by **Cq** and **Cqq**) and never reduces production. Implicitly, this means that to reduce pollution, the cost of *end-of-pipe* solutions is always lower than the profit lost by a reduction in production, leading to an equivalent reduction in pollution.
- If **Cxq = Cqx < 0**, the production cost decreases with the pollution level. Unlike the previous case, production and pollution are linked. The producer will combine end-of-line solutions and a production cost reduction to reduce its pollution. This second possibility interests this study in the search for an environmental policy favoring production by controlling pollution. Given the initial hypothesis, it is assumed that production and pollution are linked.

The social optimum

Before characterizing the competitive equilibrium, it is necessary to identify the optimal situation, which is the maximization of a function of well-being, which now includes environmental damage **(Dq)**:

$$\mathbf{W}(\mathbf{x},\mathbf{q}) = \mathbf{U}(\mathbf{x}) - \mathbf{C}(\mathbf{x},\mathbf{q}) - \mathbf{D}(\mathbf{q}) \qquad \textbf{(8)}$$

Where: $\mathbf{W}(\mathbf{x},\mathbf{q})$ = Well-being function, **U(x)** = Utility function, **C (x, q)** = production cost and **Dq** = Damage cost.

whose FOCs are:

$$\left\{ \begin{array}{c} \mathbf{Uxx}\ (\mathbf{x}) = \mathbf{Cxx}\ (\mathbf{x},\mathbf{q}) \\ \\ -\ \mathbf{Cxx}\ (\mathbf{x},\mathbf{q}) = \mathbf{Dqq}\ (\mathbf{q}) \end{array} \right\} \qquad \textbf{(9)}$$

These FOCs of equation (9) show that the first part informs the equalization of the marginal cost of production and the marginal utility of the economy without pollution. The second part prescribes *the equalization of the marginal cost of pollution control cost with the marginal pollution damage*. This second condition reflects the trade-off between the damage generated by pollution and the costs caused by its reduction. Without public intervention, the competitive market cannot reach this optimum.

Competitive balance without public intervention

It satisfies the two conditions of profit maximization and consumer surplus and the condition of equality of the quantity produced and consumed, namely:

$$\max_{x,q} \pi = P \cdot X - C(x, q) \quad \textbf{(10)}$$

and $$\max_{x} U = U(x) - P \cdot X \quad \textbf{(11)}$$

We notice that the producer now has two choice variables, **X,** and **q** while the consumer chooses only his level of consumption, **X**. In addition, this interaction does not consider the behavior of polluted people since they have no decisions to make (the chosen variables are limited to **x** and **q**). The FOCs of these two private optimization programs [(10) and (11)] then define the competitive equilibrium:

$$\max_{x} \pi = P \cdot X - C(x, q) = P - C_{xx}(x) \rightarrow P = C_{xx}(X)$$

$$\max_{x} U = U(x) - P \cdot X = U_{xx}(x) - P \rightarrow P = U_{xx}(X)$$

$$\Rightarrow \boxed{P = C_{xx}(x, q) = U_{xx}(X)}$$

This equation means that the price is equal to the consumer's marginal utility and the producer's marginal cost.

$$\left\{\begin{array}{l} p = Cxx(x, q) = Uxx(x) \\ \\ -Cxx(x, q) = 0 \end{array}\right\} \quad \textbf{(12)}$$

Comparing these equations with equations in (9), which define the social optimum, it appears that the second condition diverges the competitive equilibrium from the social optimum in a competitive equilibrium without public intervention. At competitive equilibrium, we have:

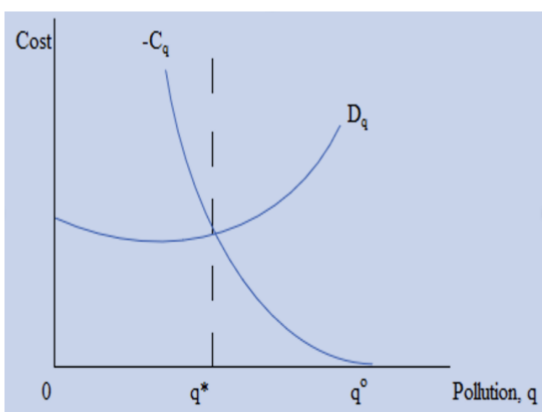
• Too much pollution

• Too much production if $\mathbf{C_{xq} = C_{qx} < 0}$ since the excess pollution will decrease the marginal cost of production and encourage the producer to produce more.

These results can be presented graphically in Figure 12. The horizontal axis describes the pollution level, while the vertical axis describes the marginal costs and damages associated with pollution. The social optimum of pollution cost **q*** corresponds to the intersection of the two curves. This pollution level is lower than the spontaneous pollution level of the producer, which is in **q°** (defined implicitly by $\mathbf{-\ C_q\ =\ 0}$). This condition returns to the initial hypothesis, which considers pollution a waste of production with a cost equal to zero.

Figure 12.

Social optimum of Pollution



According to Kolstad (2011, 291-304), the economic analysis recommends public intervention to bring the producer from **q°** to **q***. This need for public intervention is fundamentally determined by the damage being an external cost. By definition, “the external cost is a cost not borne by the person at the origin and is not taken into account by the market." (Hanley, Shogren and White 2007). To show this, let us suppose that the producer bears the damage from which he is the origin. He then maximizes:

Max π= P · X - C (x. q) - D (q), meaning that **−Cxx (x, q) = Dqq (x, q)**. The competitive equilibrium, this time, coincides with the social optimum. An external cost is a special case in which the competitive market does not allow the optimum to be achieved. We also use the more general term "market failures" to designate these situations" (Hanley et al., 2007; Kolstad, 2011; Baumol & Oates, 1988).

The Pigouvian tax

Modified assumptions

Let us identify the policy that can restore the competitive process's efficiency. Before that, we will modify the assumptions by making the environmental aspect of the economy more obvious and keeping its productive dimension because pollution emission is just a waste. More precisely, we will assume two cases:

- **Cxq = Cqx = 0** means that the marginal cost of production is not affected by pollution, and therefore, the production level is never affected. It also means that the cost of production and the cost of pollution control are additively separable: **C (x, q) = V (x) + F (q)**. It always assumes diminishing returns in pollution control and production.
- **Cxq = Cqx < 0**, the production cost decreases with the pollution level. To reduce its pollution, the producer will combine end-of-line solutions and a reduction in production.

Where **Cxq** = production marginal cost and **Cqx** = marginal abatement cost.

Let us explain this point by considering, for example, the producer's behavior in the competitive market. It solves the function:

Max π= P· X - C(x,q).

However, because pollution and production are additively separated in function, we can ideally consider that he optimizes his production and pollution separately, which gives:

$$\begin{cases} \underset{x}{\mathbf{Max}}\ \boldsymbol{\pi} = \mathbf{P.X} - \mathbf{C(x,q)} \\ \underset{q}{\mathbf{Min}}\ \mathbf{C\ (x,q)} = \mathbf{C(x,q)} \end{cases} \Rightarrow \begin{cases} \mathbf{p} = \mathbf{C(x)} \\ -\mathbf{C(q)} = \mathbf{0} \end{cases} \qquad \textbf{(13)}$$

The above equations show that the producer will initially maximize his profit by minimizing production costs. By assumption, the cost of production also contains the cost of pollution.

According to Baumol and Oates (1988), since the pollution is targeted, it is crucial to look closely at the two optimization programs and monitor the productive aspect, influencing the environmental behavior of the polluter and, more generally, on environmental policy.

-C(q) = 0 means that we are at point $\mathbf{q^o}$ in graph (12), where the producer emits the pollution at the cost of $0.

What does it mean a marginal cost equal to zero?

If the firm faces a marginal cost equal to zero, the total cost will equal fixed cost. However, it is also possible that the firm operates in a range of economies of scale where marginal cost is falling. In that case, marginal cost equaling zero may still mean a positive marginal cost on earlier units, in which case total cost is more significant than fixed cost. In other words, the marginal cost, if zero, would mean that it costs nothing to produce one more unit of a commodity. The effect on total cost with a zero marginal cost is that the total cost is unaffected and is embodied in the fixed cost component.

• Suppose there are **n** producers and the pollution control cost of polluter **i** is written $\mathbf{C^i_q(q_i)}$ with $\mathbf{q_i}$ the pollution level of producer-polluter **i**. We will then assume that the producers have different pollution control costs (the cost of production and the pollution control reduction being inseparable). We assume that $\mathbf{C^i_q} > 0$ and $\mathbf{C_{qq}} < 0$.

- We will also assume that a regulator controls the general interest. He can use a tax on emissions whose rate is **t**, meaning a tax that makes the polluter pay for each unit of pollution emitted at a tax rate of **t**.

With these new hypotheses, we will proceed with the analysis by identifying the response of any polluter to the tax, then characterizing the social optimum, and finally identifying the fiscal optimum, which will match the social optimum and the responses to environmental factors of polluters (Hanley, Shogren, and White 2007).

The Producer *i*'s Program, when facing an emissions tax

Kolstad (2011) advises restricting the environmental dimension of producer behavior. He seeks to minimize a cost, which is the sum of two terms, the cost of pollution control and the payment of the tax on the pollution emitted:

$$\mathbf{\min_{q^i} C(X, q) = C(x^i, q^i) + q^i . t} \qquad \textbf{(14)}$$

which leads to the first-order condition

$$\boxed{-\boldsymbol{C^i q(X^i)} = \mathbf{t}} \qquad \textbf{(15)}$$

One can notice the formal proximity with the competitive behavior of the producer who fixes his production by equalizing his marginal cost of production with the price. This equation (15) describes the reaction function of polluter ***i***, the production level corresponding to the quantity of pollution that he will choose to emit in response to a tax at rate t. He will equalize his marginal cost with the tax rate in this case.

At the optimum of pollution, the general interest comes down to the sum of pollution control costs and the environmental damage caused by the producers' emissions. Mathematically we have:

$$\underset{q_1 \cdots q_i \cdots q_n}{\mathbf{Max}} \left[\sum_{i=1}^{n} \mathbf{C^i q}\,(\mathbf{x_i})\right] - \mathbf{D}\left(\sum_{i=1}^{n} \mathbf{q_i}\right) \qquad \textbf{(16)}$$

Where: - $\sum_{i=1}^{n} \mathbf{C^i q}\,(\mathbf{x_i})$ = The sum of the costs of production inseparable with the pollution control cost, and

$- \mathbf{D}(\sum_{1}^{n} \mathbf{qi})$ **=** The damage caused by the producers' emissions

The optimum is then defined by the *n* FOCs of this above program:

$$-\mathbf{C^1_q\,(x_1) = \ldots = - C^i_q\,(x_i) = \ldots = - C^n_q\,(x_n) = D_q\,(\textstyle\sum q_i).} \qquad \textbf{(17)}$$

$\mathbf{x_1^*, \ldots\ x_i^*, \ldots\ x_n^*}$ denote the *n-tuple* which satisfies these equations. We equalize the marginal costs of Production (and abatement) with the marginal damage.

According to Latzko (2020), since it is often laborious to measure the damage produced by environmental degradation, the environmental policy should be at least profitable. A cost-effective policy produces various environmental improvements at the lowest possible cost. Considering Latzko's (2020) observation, equation (17) can be rewritten, ignoring the last term, D(∑qi). Thus (17) becomes:

$$-\mathbf{C^1_q\,(x_1) = \ldots = - C^i_q\,(x_i) = \ldots = - C^n_q\,(x_n).} \qquad \textbf{(18)}$$

Pigouvian tax rate

Is there a tax on emissions making it possible to achieve the optimum defined by equation (17)?

Yes! The comparison of (15) and (17) shows that it suffices to set a tax with ***a rate t* equal to the n marginal costs*** of polluters to have an effective environmental policy:

$$\boxed{\mathbf{t^* = - C^1_q\,(X_1) = \ldots = - C^i_q\,(Xi) = \ldots = - C^n_q\,(X_n)}} \qquad \textbf{(19)}$$

Equation (19) theoretically represents the environmental policy that this study proposes. This equation theoretically says that if the policymaker applies a tax rate equal to t*, which would equalize the marginal costs of **n** polluting producers, this policy would be efficient and respect the social optimum.

The effectiveness of this proposed regulation, which refers to the Pigouvian tax, is based on two properties:

- The Pigouvian tax is first and foremost effective because it equalizes the marginal costs of ***n*** polluters. However, this equalization helps to minimize the pollution control costs to achieve total pollution. This is the principle of "Equimarginal."

According to Agarwal. (2022), the "equimarginal Principle" is a widely used concept in managerial economics. This Principle provides a basis for the optimum utilization of all inputs to a business to maximize profitability. This Principle is also known as the principle of maximum Profitability - allocating available resources to achieve maximum benefit.

- The Pigouvian tax's optimality is valid in a particular context where an essential characteristic must be specified. The regulator is fully informed. Indeed, to determine the optimal tax, he must know all the equation functions (19) defining the optimality.

The microeconomic models' analysis concludes that Porter bases his "well-designed environmental regulation" concept on this level of tax **t***. At **t***, the regulator is correctly informed and knows all the marginal costs, which equalizes the marginal damages at optimum.

Marginal Costs (MC) that equalize the pollution tax are the change in the total cost resulting from the acquisition or production of an additional unit. To calculate marginal cost, divide the difference in production costs by the change in quantity. Analyzing the concept of marginal cost helps determine how much a firm can achieve economies of scale to optimize production and operations in general. If the Marginal Cost of making one additional unit is less than the unit price, the producer can make a profit. Marginal cost is an essential economic concept because it can help a firm maximize its output through economies of scale. A firm maximizes its profits by producing until the marginal cost (MC) equals marginal revenue (MR).

Equation (19) is the proposed regulation stated and demonstrated throughout this study. Suppose the legislator sets a tax at a rate ***t**** equal to the n marginal costs of the polluters and the marginal damage. In that case, this regulation will be effective because it will equalize the marginal costs of the abatement n polluters. It also makes it possible to obtain a level of pollution that equalizes the marginal costs of abatement with the marginal damage.

This proposal regulation based on the Pigouvian tax is much better than the other instruments, such as standards and subsidies, which are only valid in a competitive context where entry-exit is free (Browning & Zupan, 2019, pp. 203-203). It is also said that there are no barriers to entry. This is a condition that can be very restrictive. This regulation, therefore, makes the polluting firms bear all the consequences of their productive activities on the economy. This ensures that when they decide to enter the market, this decision will coincide with the general interest. They will only enter if the benefits of this entry are more significant than the social cost of their activities. The superiority of the Pigouvian tax lies in its ability to send economic agents a long-term signal reflecting the social cost of their activity. If the tax is well-designed, the company is driven by maximizing its profit or minimizing its cost and producing the quantity that generates the socially optimal pollution level.

Porter's Hypothesis Prerequisites

The famous neoclassical economist Milton Friedman believes that the pursuit of maximum profit remains the sole purpose of business and its fundamental objective. Speaking of the social responsibility of Business, Milton Friedman (1970, 17) affirms that: "There is one and only one social responsibility of business–to use its resources and engage in activities designed to increase its profits so long as it stays within the rules of the game, which is to say, engages in open and free competition without deception or fraud." A productive company or industry cares about the interests of its shareholders and those of other partners or stakeholders. Such an enterprise is where goods and services come from, which have more value for the neighboring community than the resources used to manufacture them. There is no company without this economic efficiency objective. Efficiency is translated in the current vocabulary as "creation of value."

This firm, which is supposed to profit by producing goods and services for the community, works in each environment. Suppose it turns out that its production is accompanied by Pollution, which is a generally negative externality in most cases. In that case, the regulator must intervene to guarantee the production of goods and services useful for the population's survival and to protect the environment. This double task incumbent on policymakers is the basis of Porter's hypothesis.

Evoking the concept of "well-designed" or "properly designed," Porter and Van der Linde (1995) were referring to environmental Regulations that will achieve the two mentioned responsibilities of promoting products and protecting the environment. These two tasks, which are priorities for policymakers, are translated into economic terms by the Concept "effectiveness and efficiency" of regulated companies.

Effectiveness is the quality of what makes it possible to achieve the expected results and is directly related to the idea of competence. From a broader perspective, effectiveness can also be the action that produces the desired effects.

Efficiency measures the use of resources in the process, also defined as the cost-benefit of achieving specific objectives: choosing the correct method, Baumol (1967). It is a critical term in a company because it allows the firm to generate profitability by ensuring a good, even outstanding, quality of service. Efficiency is obtaining a satisfactory result with the minimum possible effort. It is simply the optimization of the resources used to produce a result. This results establishes a process that optimizes the company's resources but guarantees an excellent result.

According to the Productivity Commission (2013), for economists, economic efficiency is the critical criterion applied to evaluations of policies and programs. Essentially, aggregate economic efficiency is achieved when individuals in society maximize their utility, given the resources available in the economy. This means that an increase in economic efficiency improves the welfare of community members - the goal of most policy or regulatory efforts. The concept of efficiency has several dimensions. Overall, economic efficiency requires the satisfaction of productive, allocative, and dynamic efficiency.

Under some conditions, markets can be shown to allocate resources to the products people prefer to maximize economic Efficiency. These efficiency concepts apply equally well to public sector activities — taxation, spending, Regulation, and policy-making- than everyday market goods and services. The difference is that prices are allocative for market goods and services (Adam Smith's invisible hand). To ensure both the growth of economic activities and the control of air pollution, environmental Regulations must promote the effectiveness and Efficiency of the business.

Link Between Efficiency and Marginal Cost

The two notions do not link at first sight directly. However, when we introduce another concept, "The economy of scale," it becomes possible to establish a link that will allow us to meet the requirements of Porter's hypothesis, "Properly designed policy." A company benefits from economies of scale when an increase in the volumes produced leads to a decrease in its unit production cost. Generally, a company incurs fixed and variable costs in its production activities.

Unlike fixed costs, independent of the production volume, variable costs increase with the volumes produced. In determining whether there are economies of scale, it is necessary to distinguish:

- The average cost of production (or unit cost) of a company, which corresponds to the total costs (fixed and variable) divided by the volume of production; and

- The marginal cost of production corresponds to the cost of producing an additional unit. Economies of scale appear when the marginal cost is lower than the average cost. These findings highlight two sources of economies of scale:

- The existence of fixed costs: the higher they are, the more the average cost decreases when production increases, provided that the marginal cost remains lower than the average cost. Indeed, the fixed costs are spread over a larger production volume.

- A decreasing marginal cost: the marginal cost is more likely to be lower than the average cost and, therefore, to give rise to economies of scale, as it decreases when production increases.

Conversely, there are diseconomies of scale when the average cost increases with the volumes produced. This situation happens when the marginal cost is higher than the average cost. This scenario is observed when it becomes more and more expensive for the company to increase its production and the marginal cost increases.

Furthermore, it is helpful to distinguish between economies of scale internal to the firm, which have their origin in the firm's cost structure, and economies of scale external, which are linked to the expansion of production at the market level and benefit all companies in the sector. Internal economies of scale result from increasing returns to scale due to the cost advantages that the company can achieve. Increasing returns to scale are closely associated with the degree of market concentration. Thus, the higher the returns to scale, the more the market is likely to be concentrated. When a single firm can produce profitably, and no potential competitor can cover its costs due to the impossibility of enjoying the same returns to scale as the firm already in the market, the market shrinks to the presence of a natural monopoly. Internal economies of scale give a competitive advantage to companies that benefit from them when they lead to lower prices and higher sales. Economies of scale are, therefore, a source of market power (Varian, 2010: 444-460).

Efficiency and public policies

Speaking of Efficiency and Public Policy, the Australian Productivity Commission (2013) Precisely stated this:

> These efficiency concepts apply equally well to public sector activities — taxation, spending, Regulation, and policymaking than to everyday market goods and services. The difference is that prices play the allocative role for market goods and services (Adam Smith's invisible hand). Under some conditions, markets can be shown to allocate resources to the products most preferred by people in such a way as to maximize economic Efficiency and actual economic costs. Beyond that, in response to a significant market failure or other reasons, such as redistribution or risk management to improving quality of life, governments make decisions that affect production, consumption, and 'investment. To

ensure that these decisions improve general welfare, they must satisfy the criterion of Economic Efficiency.

Marginal cost Concept

The purpose of marginal cost (**MC**) analysis is to determine how a firm or industry can achieve economies of scale to optimize production. In economics, the marginal cost of production changes the total cost of production resulting from the production of one additional unit. To calculate marginal cost, divide the change in production costs by the change in quantity. The producer can profit if the marginal cost of making another unit is less than the unit price.

The marginal cost of production is vital in management accounting because it can help a firm or an industry optimize its production through economies of scale. A firm can maximize its profits by producing until the marginal cost (**MC**) equals marginal revenue (**MR**) ==> **MC=MR.** Marginal cost is an essential economic concept because it can help a firm maximize its output through economies of scale. Analyzing the concept of marginal cost helps determine how much a firm can achieve economies of scale to optimize production and operations in general. The producer can make more profit if the marginal cost of making one additional unit is less than the unit price. A firm maximizes its profits by producing until the marginal cost (**MC**) equals marginal revenue (**MR**). While it has been asserted that "marginal cost is the difference between all current costs necessary for a given production or service and those necessary for this same production, increased or reduced by one unit," this definition can be reformulated: the marginal cost is the change in total cost caused by a change in production (increase or decrease) (Varian, 2021).

In practice, it is necessary to specify that a company does not generally vary its production unit by unit but by tranche, batch, or series. Technical constraints require that several units be produced each time there is ***n*** manufacturing launch. Therefore, in a company varying its production by series, for a given production level, the marginal cost is equal to the cost of the last series manufactured to reach this level. By dividing the marginal cost of the production series by the number of units composing this, we obtain the unit marginal cost of the series. Finally, the marginal cost assumes that all else is equal. However, in practice, the impact of additional production on the productivity of staff and machinery or organizational costs should be taken.

The Notion of Technical Optimum

Economic demonstration proposes to compare the marginal unit cost to the average unit cost. The average cost is expressed as follows: $AC = \frac{TC}{Q}$. When activity levels increase, the company goes through a phase of increasing returns (the phenomenon of the economy of scale and the effect of experience) before diminishing returns (a phenomenon of diseconomies of scale). Consequently, in the first phase (increasing returns), the MC of production decreases. Then, it passes through a minimum to finally increase in a second phase (diminishing returns). Moreover, if the marginal cost, meaning the additional total cost generated by an additional unit produced, is lower than the average cost (total cost/number of units already produced), the average cost continues to fall.

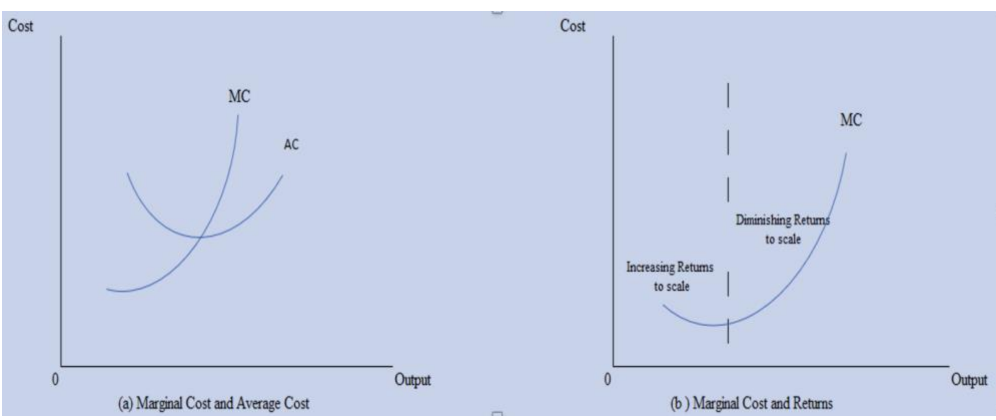
On the other hand, when the marginal cost becomes higher than the average cost, the last unit produced is more expensive than the average of the units already produced. Therefore, the average cost will increase. So, the average cost will be at minimal when marginal cost equals average cost-profit peaks when price or marginal revenue equals the marginal cost. If an additional good or service is less expensive than the average cost, its production implies an overall more advantageous unit cost. If we check the graph (13), the average cost (A.C.) is at its lowest point when it is equal to the marginal cost. This level of production is called the ***technical optimum***. However, beyond the technical optimum, the tons produced at increasingly high costs result in a necessarily increasing average unit cost. Consider the following graph by tracing the evolution of the **AC** curve by that of the **MC** curve (13a).

On the other hand, the marginal cost (MC) corresponds to the cost induced by an additional quantity produced. A U-shaped curve graphically represents the marginal cost curve:

1. Initially, the average cost decreases when the quantities increase (the fixed costs are spread over more products produced and returns increase). Each additional unit lowers the average cost, and the marginal cost decreases.
2. Then, in the second step, each additional unit increases the average cost. In this case, the marginal cost increases after having decreased. The returns become diminishing. The minimum of the marginal cost curve is where the return begins to decline (13b).

Figure 13.

Marginal Cost graphing representation.



Mathematical Expression of marginal cost

Marginal cost is derived from the total cost. The total cost can be expressed as a function: TC = f(Q). The total cost varies according to the volume of the quantities produced. Marginal cost equals the ratio of the change in the total cost and the change in quantity: $MC = \frac{\Delta CT}{\Delta Q}$.

Mathematically, the marginal cost is a function of the quantities produced equal to the derivative of the total cost function. This concept is helpful in representing the evolution of costs mathematically and studying the theory of possible applications of marginal cost in economics and management.

Marginal cost is equal to the derivative of the total cost. It is equal to the ratio $MC = \frac{\Delta C}{\Delta x}$. Where:

MC = marginal cost

Δx = variation in quantities produced

ΔC = change in the total cost

Assuming theoretically that Δx represents an infinitely slight variation tending to zero, the limit of the ratio $\frac{\Delta C}{\Delta x}$ is the derivative of C, called C'. Let C(x) be a function depending on a single quantity X. This definite function of IR+ in IR is called the total cost of the production function. This function breaks down into the sum of total variable cost VC (x) and total Fixed Cost FC:

CT(x) = VC(x) + FC

When **X** (quantity produced) is zero, we have C (0) = F and VC (0) = 0.

TC(x) = VC (x) + FC,

The function of the marginal cost of production is the cost linked to producing an additional unit of output (Gayant, 2014). An increase in the total cost of production due to the production of an additional unit is called the marginal cost of production and is denoted MC:

MC(x) = C(x+1) – C(x) or MC(x) = C(x) – C(x-1). When we move from output x to the neighboring output (x + Δx), the change in total cost is equal to

C (x + Δx) – C(x). These two previous formulas are equivalent. Since C(q+Δq) – C(q)Δq, respectively.

$$mc(x) = \lim_{\Delta q \to 0} \frac{C(x + \Delta x) - C(x)}{\Delta q}$$

which is the marginal cost of production, defined by the relative change in total cost when the change in production Δq becomes small. So, the marginal production cost function is equal to the derivative of the total production cost function:

MC: IR0+→ IR: x → Mc(x) = C'(x) = dC(x) (continuous case) or equal

Δ C(x) (discrete case).

The production cost per unit of goods produced is called the average production cost and is noted by MC. CM: IR0+→ IR: x → CM(x) = C(x) x

Imperfectly divisible good.

The marginal cost of production measures the change in total cost for an additional unit of production:

C m (x) = C (x + 1) − C (x).

Perfectly divisible good.

The marginal cost of production measures the change in total cost for an infinitely small change in the quantity produced: Cm (x) = dC = C'(x) dx

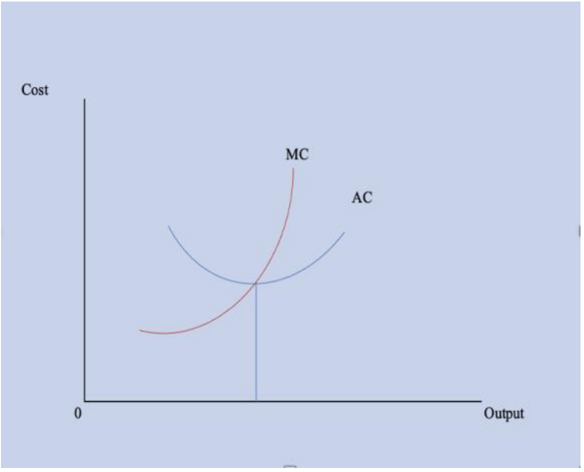
Remark: When one (1) is small compared to x, economists consider that C(x+1) − C(x) is approximately equal to the derivative number C' (x).

What Happens if Marginal Cost Equals Average Cost (MC = AC)?

Figure 11 presents the representative curve of Marginal Cost (MC) and Average Cost (AC). The graph is easy to understand. It explains the evolution of the AC curve by that of MC. When AC equals the marginal cost, the average cost is at its lowest. The level of production associated with this situation is called the technical optimum. If an additional ton is less expensive than the average, it is evident that its production implies an overall more advantageous unit cost. However, the tons produced at increasingly high costs exceed the technical optimum, resulting in an increasing average unit cost.

Figure 14.

Marginal cost and technical optimum



The production's minimum average cost corresponds to an optimal quantity produced x, for which the average cost equals the marginal cost. The marginal cost is secant with the average cost for the level of output such that production is done at the minimum unit cost:

AC(x) = MC(x). So, the optimal quantity to produce ***X***, which minimizes the average cost, is given by **MC(x)**. Mathematically speaking, we affirm for all the cases that the optimal quantity ***z*** is the abscissa obtained after the projection of the point of intersection of the curves defined respectively by the average cost of production and the marginal cost of production on the abscissa axis. Using the geometric interpretation of the derivative and having only the curve of the total cost of production shows that the optimal quantity x is the abscissa of the point of contact of the tangent led by the origin to this curve (Simon & Blume, 1994, pp. 60-61).

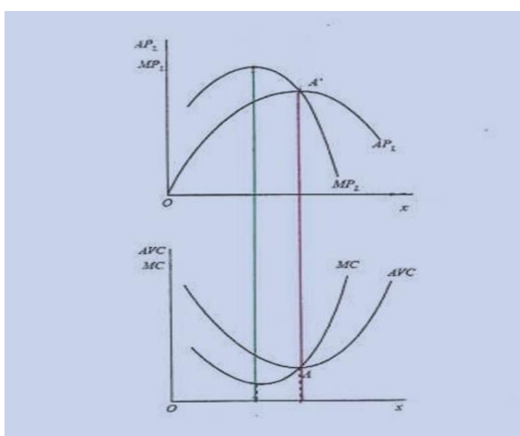
Links between Productivity and production costs

Understanding the cost must be accompanied by the returns associated with the production factors. The cost curves evolve inversely to the productivity curve, the average cost being able to be interpreted as the inverse of average returns (Figure 11). Suppose the contribution to the production average cost of a given production factor, such as labor, has increased. In that case, the average productivity of this factor has fallen and vice versa. In the case of a single factor of production, this implies diminishing returns (Magnan de Bornier, 2003).

The optimal production quantity must be identified once the different costs have been determined. This optimum is determined by comparing these costs with the selling price (p). The company's profit will be the difference between its revenue or turnover (the proceeds from the sale of the quantity produced (Q), R= P*Q) and the total cost of production C (Q). This difference P*Q - C(Q) is called profit; it first increases as a function of the production level when marginal costs are low, then decreases when they increase sharply. It, therefore, passes through a maximum. The first so-called "technical" optimum is reached when the production level corresponds to the maximum unit profit – when the average cost is at its minimum.

Figure 15.

Links between productivity and costs



The above graph gives two main lessons:

1. Maximum Marginal productivity corresponds with Minimum Marginal cost.
2. Maximum average Productivity corresponds with Minimum average cost.

The economic optimum corresponds to the maximization of profit, which is the objective of the producer; it is reached when the derivative of the profit function [(Q) = P*Q - C(Q)] to Q is equal to zero, P* = C'(Q), C'(Q) which represents the marginal cost. The marginal revenue (Rm = the additional revenue obtained per additional unit sold), equivalent to the price of the product, is equal to the marginal cost (Cm). In a context of pure and perfect competition, the price is given to the producer by the market, and the revenue R(Q) depends only on the quantity produced. The marginal revenue Rm is equal to the price p*. Thus, the producer will produce until the marginal cost of production is equal to the price, a situation represented in Figure 12 by the quantity Q1. Beyond this point, any additional goodwill production costs more than it will not yield. Below this, the producer renounces a potential profit. Q1 is, therefore, the level of production that maximizes profit.

The “price above average cost” rule may only apply to average variable costs in the short term. The production decision does not consider fixed costs and is based solely on variable costs. The price can be between the average cost and the average variable cost. In this case, there is production, but the profit is negative because the fixed costs cancel out the profit extracted from an average variable cost higher than the price. However, the economic losses are more significant if production stops because all the fixed costs must be assumed. This scenario is equivalent to a simple minimization of losses by covering only part of the depreciation through production revenues, which is preferable to a total loss (Magnan de Bornier, 2003).

Finally, the conditions of profit maximization based on prices and costs make it possible to define, for each price level p, an optimal quantity of production Q1 such that C’(Q) = P. We thus obtain the supply function of the producer. This producer-supply function consists of the increasing part of the marginal cost function, exceeding the average cost function (Figure 13a).

Marginal Cost as a Management Decisions Tool

This study proceeds to develop the productive capacity to avoid the saturation of the existing structure. In this case, the marginal cost includes the unit variable and the additional structure's costs. It keeps the existing structure to avoid saturation but compensates for the shortcomings with an increase in variable charges. In this case, the marginal cost containing only variable charges will increase more significantly than the average unit variable cost. If the structural costs increase and the variable charges are not proportional, there is also no equality between unit variable cost and marginal cost.

If the selling price, on the other hand, is lower than the marginal cost of the offer, the decision will then be made to refuse the offer. The notion of marginal cost can also be used to choose between producing or subcontracting an order. If the purchase cost is lower than the marginal cost, the decision will be made to have it done subcontract. If the purchase cost exceeds the marginal cost, the decision will be to produce. In a tie, the choice will depend on other organizational or strategic criteria (Greenlaw & Shapiro, 2017, pp. 155-180).

The marginal cost allows certain companies in specific sectors to differentiate the price of the same product by customer segment, thus determining the tariffs according to time slots or the importance of consumption. This differential pricing policy must respect certain conditions not to compromise the company's overall profitability: it must avoid transferring customers from the usual price to the marginal price. It should only concern a small part of sales. It must avoid creating a reaction from the competition, which would risk bringing all market prices below the company's average cost. In the event of a decision to disinvest (or disengage), the marginal cost can theoretically apply. If this is not the case, it is prudent to practice it only above the average cost (beyond the technical optimum) to avoid the risk of not covering the initial fixed costs. The marginal cost = unit variable cost - gain from the structure reduction. It is challenging to reduce fixed costs (for example, equipment acquired cannot always be resold). Similarly, certain variable charges can only be reduced later.

Marginal Cost and Pricing

The firm sets its price at competitive equilibrium to equalize marginal cost, maximizing its total profit. Thus, the company produces if the selling price is higher than the marginal cost if the cost of the last unit produced does not exceed the revenue that the company can draw from it. Thus, the firm's equilibrium is defined at the intersection between the marginal cost curve and the selling price curve.

Empirical Illustration of the Environmental Regulation Proposal

Theoretically, the Study is based on Porter’s Hypothesis, which departs from the traditional approach to environmental regulation. This research uses microeconomic analysis, which uses the mathematical model and econometric technique to determine the optimal economic quantities to establish the preferred environmental balance. The mathematical models used are a tool to explain what seems abstract clearly. Econometrics will help to test assumptions about both economic theory and econometric requirements.

Data Sets Description

The data to illustrate the environmental regulation proposed by this study are those of the Transport industry provided by Federal Reserve Economic Data (FRED) internet files of the Federal Bank of St. Louis branch. The two estimated models will establish a positive and statistically significant relationship between the independent variable, Environmental Regulation (ER), and the two dependent variables, Total Factor Product (TFP), for competitiveness and Research and Development (R&D), for innovation represented. The dependent variable, Environmental Regulations, a composite variable, will be measured by the volume of pollution in Metric Tons of CO2 (Not Seasonally Adjusted) multiplied by the marginal cost of production of the Transport industry. This variable gives the dollar value of pollution taxation in the transportation industry. Regarding Total Factor Product, one of the first model's independent variables is measured in Manufacturing: Durable Goods: Other Transportation Equipment (NAICS=3369) (IPN3369N). Finally, the competitiveness variable is entered by Research and development of the Transport sector captured by Transportation Equipment: Contribution of Research and Development Intensity (MPU5350193).

Research questions

This study revolves around a central question supported by a few other subsidiaries. This research focuses on knowing ***what type of environmental regulations meet Porter's Hypothesis criteria, ensuring environmental protection, and promoting competitiveness and the growth of economic activities.***

Among the subsidiary questions, there are three questions that this research will cover.

(1) How should economic theories address the relationship between economic growth and environmental quality?

(2) What effect does the environmental public policy have on promoting economic growth?

(3) What role does imperfect information play regarding the signals sent to corporations and their ability to understand and act on those signals accurately.

Research Hypotheses

The two principal hypotheses this study expects to evaluate are:

Ho1: There is no relationship between environmental regulation that would reduce pollution and promote economic growth.

Ha1: There is evidence that well-designed environmental regulations lead to increased productivity and innovation.

Ho2: There is a significant relationship between environmental regulations and economic Growth, which shows that environmental regulation is a negative externality for economic growth.

Ha2: There is evidence that well-designed environmental regulation is a positive externality for economic growth and improved air quality.

Models Specification

The first estimations, which consisted of investigating whether the variables used are stationary to avoid spurious regressions, showed that the three series [Research and Development (RD), Productivity (TFP), and Environmental Regulation (Reg)] are not stationary in level. When we regress using OLS, the following models of three non-stationary variables:

$$\mathbf{TFP = \alpha + \beta REG + \varepsilon.} \quad \textbf{(22)}$$

$$\mathbf{RD = \partial + \theta REG + \eta} \quad \textbf{(23)}$$

Where: β and θ > 0

TFP = Total Factor Productivity (represents productivity).

RD = Research and development (represents innovation and competitiveness).

REG = Environmental Regulation (represents tax on pollution: Total Carbon Dioxide Emission From all sectors multiply by the rate by ton metric)

$\alpha, \beta, \partial, and\ \theta$ are parameters. $\varepsilon\ and\ \ \eta$ are random terms.

As the raw data are not stationary, they have been logarithmically transformed. Thus, the transformed models are the following:

$$\mathbf{LRD = \partial + \theta\ LREG + \eta}$$

LTFP = α + β LREG + ε.

Where ***θ*** *and* ***β*** *>* ***0***

Descriptive Statistics

The statistical description of the data was done in two steps. The first step was to find the descriptive statistics of the raw data without transformation. The descriptive statistics of the raw data presented in Table 1 and the frequency tables in the appendixes show that the raw data are not stationary. A stationary variable has a constant mean and constant variance across observations. In the case of time series, it is a constant mean and variance through time. Also, the dependence between two observations must be linked to their relative positions in the series (to the distance that separates them) and not to their absolute positions, commented Brockwell and Davis (2001, 45-57). Stationary variables are encouraged in econometrics, especially when working with time series and using ordinary least squares as an estimation method. The stationary series helps solve several econometric problems (autocorrelation, multicollinearity, and heteroscedasticity), compromising the results. Graph 1 in the appendices shows the trend of the raw variables before their log transformation.

Table 15:

The descriptive statistics of the raw data

Measure	MEAN	MEDIAN	MAX	MIN	SD	SKEWNESS	KURTOSIS
RD	438169.5	416866.5	869977.5	108438	230544.1	0.261828	1.713889
TPF	254236.9	235741.8	350074.2	211029	43628.23	1.122108	2.731622
REG	1158287	1211406	1349187	904829.5	137023.8	-0.472228	1.972549

Measure	Jarque-Bera	Probability	Sum	Observations
RD	3.294176	0.19261	17964950	41
TPF	8.727081	0.012733	10423713	41
REG	3.327237	0.189452	47489780	41

Note: RD = Research and Development, REG = Regulation, TFP Total Factor Productivity.

The unit root tests applied to the series also shows that each raw series has a unit. **Tables 3, 4,** and **5**, which present the results of these tests, give the value of the probability above the critical threshold of 5%. On the other hand, tables 6, 7, and 8, which give the results of the unit root test of the data in logarithm, give probability values below the threshold of 5%, which means that the transformation of the data into logarithm to remove the unit-roots and log data have become stationary. **Graph 2** in the appendices shows the trend of the log variables before their log transformation.

Table 14 gives the descriptive statistics of the data transformed into a logarithm which helped make data stationery.

Table 16:

Descriptive statistics for log data

Measure	MEAN	MEDIAN	MAX	MIN	SD	SKEWNESS	KURTOSIS
LRD	10.12342	10.23247	10.96817	8.885884	0.599337	-0.35213	1.943082
LREG	11.65269	11.70471	11.81243	11.41292	0.122906	-0.60775	2.11299
LTFP	9.388497	9.32597	9.721378	9.215228	0.159233	1.003709	2.534584

Measure	Jarque-Bera	Probability	Sum	Observations
LRD	2.755638	0.252128	415.0604	41
LREG	3.868066	0.144564	477.7602	41
LTFP	7.254167	0.026594	384.9284	41

Note: LRD = Log of Research and Development, LREG = Log of Regulation, LTFP = Log of Total Factor Productivity.

In this table, the average is 11.652 (in Euler or Naperies logarithm: e = 2.71828) for the logarithm of the regulation variable (LREG), which is a variable composed of the volume of carbon dioxide emissions and the tax of $67, which is the transport industry's marginal cost per hour. This average tells us that if a tax corresponding to the marginal cost of the transport industry were applied from 1980 to 2020, an average of **$1,158,287** million (with a standard deviation of $137,023.8) would have been collected by the federal government each year from the carbon dioxide emissions. This average annual sum would motivate the transport industry to engage in research and development to improve productivity and production processes. The revenue from this tax on carbon dioxide emissions would be in the range of **$1,349,187** million Maximum and $**904,829.5** Minimum for a total sum of $47,489,780 for the industry.

As for the Research and Development (LRD) variable, which measures the "Innovation" variable, its average is 10.12342 (in Euler or Napierian logarithm: e = 2.71828), or **$438,169.5** Million (with a standard deviation of $1.82Million), which would represent the amount spent on research and development in order to bring the innovations necessary for improvements in the transport sector, one of the industries known to be polluting in the United States. Research and development (R&D) expenditure would range between $57,998 million maximum and $7,229 million minimum, for a total expenditure equal to **$17,964,950** for the industry from 1980 to 2020. This amount relative to the volume of carbon dioxide emissions remains less for equipment acquisition and less polluting production processes for industry innovation.

The Productivity variable (LTFP), which was measured by "Multifactor Productivity for Manufacturing: Transportation Equipment Manufacturing in the United States," has an average of 9.388497 (in Euler or Napierian logarithm: e = 2.71828), or **$254,236.9** (with a standard deviation of **$43,628.23**), which would represent the amount perceived in terms of productivity in the industry. The amount collected in terms of productivity would be in the range of $350,074.2 maximum and $211,029 minimum, for a total amount of $10,423,713 for the transport industry from 1980 to 2020.

The unit root tests applied to the series also show that each raw series has a unit. Tables in Appendix One present the results of these tests, giving the probability value above the critical threshold of 5% (p>5%). The p-value is the probability that measures the degree of certainty with which it is possible to invalidate or reject the null hypothesis. A lower p-value provides more substantial evidence against the null hypothesis.

On the other hand, table Appendix Two gives the results of the unit root test of the data in logarithm, giving the probability values below the threshold of 5%, which means that the transformation of the data into logarithm has removed the unit roots and log data have become stationary.

Appendix 3. gives the correlation matrix. The LRD variable's and LTFP correlation is 0.348684, about 35%, below 50%. Given this degree of correlation, there is only a weak correlation between Research and Development and Total Factor Productivity. Research and Development expenses only have a 35% effect on Total Factor Productivity. While the correlation between LTFP and LREG, which is 49%, is close to 50%, the two variables influence each other by almost 50%. Finally, the correlation between LRD and LREG is well above 50%, with 92%. Research and development expenses are 92% correlated with revenue from environmental regulations. In the case of the Transport industry, the research and development variable captures the innovation variable in this sector. Innovation is correlated with environmental regulation.

Results

The study results are organized to answer the research questions, achieve the study objective, and test hypotheses. They are presented in the form of tables for both soundness and clarity. To achieve this research objective and answer the questions for testing the hypotheses, we use two estimated relationships to assess whether environmental regulation (E.R.) significantly explained the research and development variable that measures Innovation **[LRD = F(LREG)].**

Another relation utilized is that which links environmental regulations to the productivity of the sector under examination **[LTFP = F(LTFP)]**, which allows us to see whether environmental regulations (E.R.) significantly explain productivity (LTFP).

Table 17.

Estimation results for Dependent Variable: LTFP

Variable	LTFP			
	Coeff.	SE	t-Statistic	Prob.
Constant	2.043879	2.112158	0.967673	0.339
LREG	0.630294	0.181249	3.477493	0.013
R^2	0.236685			
SE of regression	0.14089			
F-statistic	12.09296			
Probability (F	0.001			
Durbin-Watson	0.287782			

Note: Result from the model estimation linking productivity (TFP) to environmental regulation (ER).

Table 18.

Estimation results for Dependent Variable: LRD

Variable	LRD			
	Coeff.	SE	t-Statistic	Prob.
Constant	-42.20572	3.546568	-11.90044	0
LREG	4.490745	0.30434	14.75567	0
R^2	0.848089			
SE of regression	0.236572			
F-statistic	217.7297			
Probability (F-statistic)	0			
Durbin-Watson	0.171255			

Note: Result from the model estimation linking Research and Development (R&D) to environmental regulation (ER).

Table 15. presents the results of the relationship between environmental regulations and Total Factor Productivity. These results show that the R^2 statistic, the coefficient of determination between these two variables, is 24%, which means that environmental regulations alone would explain 24% of the productivity of the transport industry if a tax of $67 were applied for each Metric Ton of CO_2. The other 76% would be explained by other variables that come into play in this process for productivity in the transportation industry. The coefficient linked to the regulation variable is 0.63 (β = 0.63). Its t-student equals 34,77 with p < 5%, proving that the coefficient is statistically significant. Durbin-Watson statistic equal to 0.288 attests to the absence of autocorrelation of the residuals, and the F-statistic of 12 proves the absence of heteroscedasticity. This coefficient, being in logarithm, can be interpreted in terms of elasticity. This value of *0.63* indicates that if the tax on carbon dioxide increased by one percent, the Total Factor Productivity would increase by 0.63%. This coefficient has a positive sign, indicating that the two variables evolve in the same direction. When one variable increases automatically, the other variable increases as well.

Environmental regulation is a variable that positively impacts productivity in the case of the Transport industry. The coefficient of the environmental regulation variable, which is nothing more than the emission tax, is statistically significant but also positive. This result confirms our hypothesis and validates Porter's hypothesis, which motivated this study. The fact that regulation is positively and statistically positive about productivity lends credence to Porter's hypothesis that well-designed regulation serves as a stimulus for productivity and innovation.

On the other hand, the constant of this model is equal to 3.637087; although it is positive, this constant is not significant (t-Statistic = 1.437879, with p = 0.1584 > 5%). This means that any variables other than environmental regulations do not explain productivity. This insignificant constant does not interest this study, and there is no point in paying too much attention to it.

Table 16, which presents the results of the second estimated equation, gives an R2 of 0.85 or 85%, indicating that environmental regulations explain 85% of the behavior of the research and development variable. If the legislator had set a tax equal to $67, which corresponds to the marginal cost of the transportation industry, this environmental regulation would determine 85% of research and development for the transportation industry. The positive coefficient linked to environmental regulation and equal to 4.49 ($\beta = 4.49$) attests to a positive relationship between environmental regulations and research and development. The two variables move in the same direction. The variables are in logarithms; this coefficient can be interpreted in elasticity. For a 1% increase in environmental regulations, research and development will increase by around 4.49%. A 14.76 (with p.5%) T-statistic proves this coefficient is statistically significant. The Durbin-Watson statistic of 0.171 shows the absence of autocorrelation, while the F-statistic of 217.73 attests to the absence of heteroscedasticity.

In this second model for verifying the results, we again find that the same coefficient linked to the environmental regulation variable, which represents the emission tax in this study, is statistically significant, a positive sign. *Environmental regulation* is a variable that positively influences research and development, which is the variable that captures innovation in the transport industry. This result confirms our hypothesis and again validates Porter's hypothesis, which was the basis of this study. The fact that the regulation variable is positively and statistically positive against the research and development variable lends credence to Porter's hypothesis, which asserts that a well-designed regulation would serve as a stimulus for innovation and productivity, the engine of competitiveness, according to Porter and Van der Linde. It is also constant that the constant of this model is equal to -49.83797. This constant, although significant, is not positive (t-Statistic= -11.73402, with P=0.000 < 5%). Any variable other than environmental regulations does not negatively explain research and development (innovation). The negative constant does not interest this study, and we will pay less attention to the constant.

Given the questions and hypotheses formulated in this research, we now proceed to the determination of what contribution to knowledge the results indicate. We began with the question: ***What type of environmental regulations meet Porter's Hypothesis criteria to be established, ensuring environmental protection, and promoting competitiveness and the growth of economic activities?*** Considering these results, it appears that the type of environmental regulations meeting the criteria of Porter's hypothesis is the one that would impose a tax on air pollution and the environment in general, equal to the marginal cost of production of the firm or industry. For the transport industry, $67, which represents the marginal cost of the transport industry, would help this sector to increase its production activities and, at the same time, reduce air pollution. According to a 2017 study conducted by c2es.org (2019), a $49 per metric ton of carbon dioxide tax could generate approximately $2.2 trillion in net revenue over ten years from (2019 to 2028). This proposal is lower than the one proposed in this study, and $49 per metric ton has no theoretical or empirical basis. It is just scenarios that have no theoretical basis.

How should economic theories address the relationship between economic growth and environmental quality?

Given these results, economic theory can no longer consider the relationship between economic growth and environmental regulation as an equivocal or conflicting relationship. This relationship must now be oriented according to Porter's vision. Environmental regulation should be seen as a stimulus for the growth of economic activities, as evidenced by the empirical results.

Environmental regulations must be “well-designed.” This “well-designed” concept is the condition for environmental regulation to stimulate economic activity.

According to economic theory, the relationship between economic activities and environmental regulation can be addressed in several ways. Firstly, it is essential to recognize that environmental regulation can positively and negatively impact economic activities.

One perspective is that environmental regulations can lead to increased innovation. When businesses are required to comply with stricter and well-designed environmental regulations, they are often motivated to find new and more efficient ways of production. This can lead to the developing of new technologies, processes, and products, which can drive innovation and productivity growth.

Additionally, environmental regulations can also create new market opportunities. For example, the demand for environmentally friendly products and services has grown steadily. By embracing and adapting to these regulations, businesses can tap into this expanding market and potentially gain a competitive advantage. However, it is also essential to consider potential costs and challenges associated with environmental regulations when they are flexible and well-designed. Compliance with stricter regulations may require businesses to invest in costly upgrades, which could initially affect their productivity and profitability. This cost burden may disproportionately impact smaller businesses or industries with limited resources. Therefore, economic theory should also address the potential trade-offs and guide how to mitigate these costs while still achieving environmental goals. Economic theory should recognize the positive relationship between environmental regulation, innovation, and productivity. It should emphasize the potential benefits of embracing well-designed environmental regulation.

What effect does the public environmental policy have on promoting the growth of economic activities?

This study shows that environmental regulation has a positive effect on economic activity. All the relationships between regulation and research and development on the one hand and total factor productivity on the other showed a positive relationship. This relationship implies that well-designed environmental regulation will evolve in the same direction as research and development, considered the innovation engine. Likewise, it will evolve in the same direction as the company's productivity or industry subject to it. A well-designed policy is a condition for this effect to be positive, as desired by Porter's hypothesis. The same condition must be applied here concerning the effects of environmental policy on economic activity.

Public environmental policy can have a positive effect on promoting economic growth in several ways. Firstly, Public environmental policy can stimulate innovation and the development of new technologies. When governments set clear environmental goals and provide well-designed policies and development in sustainable technologies, it encourages businesses to invest in innovation. This can lead to new industries, job opportunities, and economic growth.

Furthermore, public environmental policy can enhance the quality of human capital. By prioritizing environmental education and awareness, governments can foster a knowledgeable and skilled workforce in sustainable practices. Public environmental policy can indirectly affect economic growth through improved public health and well-being. When environmental regulations are in place to reduce pollution and protect natural resources, it can result in cleaner air, improving public health. Healthy and productive individuals contribute to a thriving economy.

It is important to note that the effectiveness of public environmental policy in promoting economic growth can depend on various factors, such as the specific policy measures implemented, the level of enforcement, and the overall economic context. However, when designed and implemented effectively, public environmental policy can create a win-win situation by promoting environmental sustainability and economic growth.

What role does imperfect information play regarding the signals sent to businesses and their ability to understand and act accurately on those signals?

The information must be considered an instrument of public policy on the environment. It aims to modify the polluter's informational environment (benefits and costs) via informational signals to encourage him to adopt less polluting behaviors voluntarily. The principle is that the public authorities create and disseminate information or subsidize its creation and dissemination. More directly, this information will lead to the adoption of less polluting behavior by the polluter. This information may relate to technical abatement solutions and their costs or environmental damage. Depending on whether it relates to one or other of these dimensions, the incentive mechanisms for polluters are significantly different: The information relates to abatement solutions. The polluter can be directly encouraged to abate because the arrival of new information makes him discover the existence of profitable abatement actions while saving raw materials or reducing the energy bill (so-called "no regrets" actions). In practice, this approach is often used with an economic or regulatory instrument. The information thus provided enables the 'regulated' to comply with regulatory requirements at a lower cost and more efficiently or to adjust more effectively to the price signal of the economic instrument. The information concerns environmental damage or the environmental quality of an industrial site or a product.

In this context, the polluter's incentive is much more indirect. It arises from the fact that the information is conveyed to agents such as consumers, NGOs, or local associations representing the populations living near a polluting industrial site. Such groups exert pressure on the polluter via their purchasing behavior, such as moving to eco-labeled products, or via political channels, such as applying pressure on elected officials or organizing boycotts.

Imperfect information can play a significant role in how businesses perceive and respond to signals related to environmental regulation. When information about environmental regulations and their impact on innovation and productivity is not readily available or easily understandable, businesses may need help to interpret and act upon those signals accurately.

One aspect of imperfect information is more awareness or knowledge about environmental regulations and their implications. Businesses may need to be fully informed about the specific requirements and standards set by regulatory bodies, or they may need access to reliable data and analysis on the potential benefits and costs of complying with these regulations. This lack of information can make it difficult for businesses to assess the potential positive impacts of environmental regulation on innovation and productivity.

Another aspect of imperfect information is the uncertainty surrounding enforcing and implementing environmental regulations. Businesses may need clarification about the consistency and rigor with which regulatory agencies will enforce these regulations. This uncertainty can create a risk perception and discourage businesses from investing in innovation or adopting sustainable practices. In some cases, businesses may delay or avoid compliance altogether due to uncertainties about the consequences of non-compliance.

Moreover, imperfect information can also lead to the misinterpretation or miscommunication of signals related to environmental regulation. If businesses do not fully understand the objectives and benefits of these regulations, they may perceive them as burdensome or unnecessary. This can result in resistance or opposition from businesses, hindering their ability to act upon the signals provided by environmental regulation accurately.

Governments and regulatory bodies can take several steps to mitigate the role of imperfect information. They can enhance communication and transparency by providing precise and accessible information about environmental regulations, their objectives, and the potential benefits of compliance. This can help businesses better understand the signals and make informed decisions regarding innovation and productivity. Governments can also provide support mechanisms, such as technical assistance and incentives, to help businesses overcome information barriers and facilitate the adoption of sustainable practices.

Overall, addressing the issue of imperfect information is crucial to ensure that businesses accurately perceive and act upon signals related to environmental regulation. By improving access to information, enhancing communication, and providing support, businesses can make more informed decisions that align with the positive impacts of environmental regulation on innovation and productivity.

Research hypotheses verification

The results obtained above will also help test the hypotheses of this work formulated earlier. The two principal hypotheses this study expects to evaluate are:

H01: There is no relationship between environmental regulation that would reduce pollution and promote economic growth.

Ha1: There is evidence that well-designed environmental regulations lead to increased productivity and innovation.

Ho2: There is a signification relationship between environmental regulations, and economic growth shows that environmental regulation is a negative externality for economic growth.

Ha2: There is evidence that well-designed environmental regulation is a positive externality for economic growth and improves air quality.

The test for verifying the first and second hypotheses will be done on the above results. Since the relationships linking environmental regulation to research and development (innovation), on the one hand, and total factor productivity, on the other hand, are all positive and significant, it can be said that for the first and second hypotheses, the null hypotheses are rejected to accept the alternative hypotheses. The rejection of the null hypothesis for the first hypothesis means that it is possible to find an environmental public policy capable of promoting economic growth while guaranteeing air pollution reduction.

The policy proposed in this research, which consists of setting a tax equivalent to the marginal cost of production of the firm or industry, has shown that such a tax supports the growth of innovation and the increase in productivity in the transport industry, is one of the major polluters in the Nation. A tax equal to marginal cost is the policy that meets the criterion of Porter's hypothesis, as this research has just demonstrated.

The rejection of the null hypothesis in the context of the second hypothesis means that environmental regulation is a positive externality for economic growth, verifying Porter's hypothesis, which states that "well-designed and stringent regulation imposes costs on affected firms, regulation will trigger innovations that ultimately overcompensate for regulatory costs." According to the logic of this hypothesis, known as the Porter Hypothesis, environmental regulation is a positive externality that encourages innovation and productivity, thus allowing the company to be competitive.

Discussion

This study is based essentially on the Porte hypothesis philosophy. In this hypothesis, Porter, and Van der Linde (1995) indicate that “well-designed environmental regulation can serve at least six objectives.” This could lead to greater efficiency in the use of resources intended for production and improve companies’ performance in terms of competitiveness. It forces companies to review their ways of doing things regarding production processes and reducing and controlling polluting emissions.

The research started from these concepts to answer the following question:

1. ***What type of environmental regulations meet Porter’s Hypothesis criteria to be established, ensuring environmental protection, and promoting competitiveness and the growth of economic activities?***

The results of this study have shown that a regulation based on the Pigouvian-type market principles is the solution. Equation (18) answers an emissions tax that achieves the optimum. This equation shows that it suffices to fix a tax of a rate t* equal to the n marginal costs of the polluters to guarantee the protection of the environment, particularly the quality of the air.

Empirical verification confirmed this assertion. Regarding the econometric estimates of two relationships that have been specified, it should be noted that this research has formulated two equations to verify the proposed regulation. The first relation specified is that between Research and Development (R&D) and Environmental Regulation:

- $\mathbf{RD = \partial + \theta\ REG + \eta}$

The used variables containing the unit root were transformed into logarithms to make them stationary. Thus, the specified relation becomes:

- $\mathbf{LRD = \partial + \theta\ LREG + \eta}$

The Environmental Regulation variable is a composite variable that contains Carbon Dioxide emission in metric tons multiplied by $67, which is the tax rate that equals the marginal cost per hour of the transportation industry. This means that before verifying Porter's hypothesis, defining a "well-designed" environmental policy is imperative. For this work, this well-conceived public policy is equivalent to a tax of $67, which represents the Marginal Cost/hour of the Transportation Industry.

After estimating the specified model, the results showed that this proposed environmental regulation significantly explained research and development expenditures, which measured the Innovation variable at 85%. Since the coefficient linked to the regulation variable is positive, the two variables R.D. et REG evolve in the same direction. A 1% increase in regulation would increase research and development (R&D) expenditure by 4.5%.

The second model specified to verify the proposed regulation is:

- **TFP = $\alpha + \beta$ REG + ε.**

In the same way as the first model, the raw variables were not stationary to transform them. The study made use of logarithm. The model specified in the logarithm is:

- **LTFP = $\alpha + \beta$ LREG + ε.**

After estimating this model, the results affirmed that the regulation significantly explained the Total Factor Productivity at nearly 24%, and the two variables evolved in the same direction. An increase in the regulation of 1% would lead to an increase in productivity of 0.63 %.

The conclusions of this study differ from several studies done in the past. Previous studies have yet to consider the prerequisites before testing the validity of Porter's hypothesis. This, however, is what constitutes the difference. Verifying this hypothesis with data collected from existing policies is a gross error. Such an approach will only lead to biased results. It is first necessary to define a new environmental policy, apply it, and collect the data for verification. This study assumes that the proposed regulations were in force throughout the period under examination (1980-2020). The regulation variable in several studies was represented only by the volume of carbon dioxide emissions in metric tons as in the case of Gollop and Roberts (1983), Broger et al. (2013), Boyd and McClelland (199), Domazlicky and Weber (2004). The regulation variable is composite (Carbon et al. * **$67** tax rate). The **$67** is the equivalent of the industry's Marginal Cost of Transportation per hour. Our microeconomic proof shows in equation **(21)** that the tax should equal the marginal cost of the subject firm or industry.

2. *How should economic theories address the relationship between economic growth and environmental quality?*

In light of the results obtained in this study, economic theory should no longer consider environmental regulations as a barrier to economic activities. The idea is to find “well-designed” environmental regulation, as stated by Porter and Van der Linde (1995):

Porter and van der Linde (1995, 100) state that appropriately crafted environmental regulation can serve at least six following purposes:

1. Regulation signals companies about likely resource inefficiencies and potential technological improvements.
2. Regulation focused on information gathering can achieve significant benefits by raising corporate awareness.
3. Regulation reduces the uncertainty that investments to address the environment will be valuable.
4. Regulation creates pressure that motivates innovation and progress.
5. Regulation levels the transitional playing field.

6. Regulation is needed in the case of incomplete offsets.

Porter's hypothesis is based on John Hicks's "induced innovation" hypothesis, first introduced in Hicks' book "The Theory of Wages. He proposed that "a change in the relative prices of the factors of production is itself an incentive to the invention, and the invention of a particular kind – aimed at economizing the use of expensive factor which has a high price." (1932,124). As an environmental regulation increases the implicit price of pollution emissions that are considered to result from the production process, the company should make efforts to reduce the production of this pollution.

While acknowledging induced innovation as an important explanatory factor of positive correlation, Porter and Van der Linde point to other factors relatively neglected in the prior literature. For example, he ignores "Technology Lock-in," a concept that prevents companies from carrying out innovations, leading to an increase in profits.

3. ***What effect does the environmental public policy have in promoting economic activities growth?***

Porter and Van der Linde (1995, 100-101) state that Innovation and growth of economic activities reacting to environmental regulation can take two broad forms. Companies are becoming more thoughtful about managing pollution once it occurs, including dealing with toxic materials and emissions, reducing the amount of toxic or harmful materials generated (or converting them into marketable forms), and improving secondary processing. The second form of Innovation refers to environmental impacts while improving the relevant product and associated processes. In some cases, these "innovation offsets" may exceed compliance costs. This second type of Innovation is central to our claim that environmental regulation can increase industrial competitiveness.

4. ***What role does imperfect information play regarding the signals sent to corporations and their ability to understand and act on those signals accurately?***

The perfect competition model assumes perfect information about buyers and sellers. This means that buyers and sellers not only know the full range of prices charged for goods and services, but they also know the sellers' production capabilities and the buyers' utility preferences. If we assume this condition is unsatisfactory, we are in imperfect information due to ignorance or uncertainty. The impact of misinformation can extend beyond the party that ignorantly makes the wrong decision.

Phaneuf and Requate (2017) discuss the problem of imperfect information and information asymmetry between all agents involved in the design and execution of environmental policies. Imperfect information alters the effectiveness and efficiency properties of environmental policy instruments. Pindyck (2007) asserts that imperfect information plays a vital role in environmental economics in the form of uncertainty, which corresponds to the situation where the policymaker cannot fully observe the damage and reduction cost functions. Phaneuf and Requate (2017.61) note that firms typically know their abatement cost functions with certainty. Once the regulator estimates these functions, one can wonder how the estimation error will influence the performance of the various public policy instruments. By intuition, errors in estimation will lead to an imprecise environmental policy.

Imperfect information introduces uncertainty in the abatement cost and the damage function. It leads to the ineffectiveness of environmental policy instruments due to the inability of the legislator to properly observe the damage or abatement function of the polluting firm or industry. Phaneuf and Requate (2017, 86-87) draw three conclusions from this situation:

- First, the ex-post efficiency properties of emission taxes and tradable permits diverge when introduced to uncertainty.
- Secondly, in the case of a hybrid policy (a policy with several instruments), if the policymaker's abatement costs are higher than expected, companies can pay an emission fee to obtain pollution rights beyond the original price. If the abatement costs are lower than forecast, the regulator can obtain reductions in pollution by buying back permits. In both cases, the loss of efficiency is less than that which would occur under a license-only or tax-only approach.
- Finally, Phaneuf and Requate (2017) suggest that environmental policy can be formulated in such a way as to lead to ex-post efficiency (as opposed to loss of efficiency) if polluting firms are incentivized to disclose their cost structure to the regulator honestly.

Empirical studies on environmental regulation, innovation, and productivity have often presented contradictory results. Some works confirm the "Porter hypothesis," while others contradict it and instead attest to the classic economic model, which considers pollution a negative externality whose effects lead to additional costs that can decrease business productivity and reduce profits.

Thus, many studies have established the link between pollution reduction and improved productivity and innovation as a positive effect of environmental regulations and the renewal of the traditional paradigm on environmental economics (Lanoie & Laplante, 1992; Shrivastava, 1995; Berry & Rondinelli, 1998). Since the early 1990s, much research has been conducted to test Porter's hypothesis and was based on the correlation analyses between environmental regulation standards in specific industries and the evolution of the productivity and innovation of the companies working in these industries. Several of them produced more divergent and almost contradictory results. While some works tend to validate Porter's hypothesis (Azzone & Bertèle, 1994; Shrivastava, 1995; Lanoie & Tanguay, 1999), others confirm the main arguments of the classical model (Boyd & McCelland, 1999; Palmer et al., 1995).

The relationship between environmental regulations, productivity, and innovation remains very contradictory. These controversies relate to the specification of estimated models, the variables' definition, or the environmental issues' complexity and the reductive character of the "cost-benefit" analysis (Olivier Boiral, 2004). Many studies that have attempted to test Porter's hypothesis have used existing data from past environmental regulations, whereas Porter states that environmental regulations must be "well-designed" and stringent. As in most previous studies, pushing to verify or test Porter's hypothesis without holding this essential condition would only lead to contradictory results. This research proceeded differently and resulted in the validation of Porter's hypothesis. The approach used here was to propose an environmental regulation in the form of a tax whose rate would be equivalent to the marginal cost of production of the company or industry. This approach is proposed by microeconomic theory when analyzing the behavior of the polluting producer. Once this tax rate was found, it was applied to carbon dioxide emissions to obtain the total revenue from this regulation. It is this regulatory variable (REG) that has been related to Innovation (R&D) and productivity (TFP). The results showed a positive and significant relationship between innovation and regulation. The same results again attested that this relationship between productivity (TFP) and environmental regulation (REG) was also positive and significant.

Summary

This chapter relating to the findings has been a question of first presenting the concepts that support the regulation proposal graphically. Then, it demonstrated the theoretical presentation of this proposal, which is essentially based on the microeconomic theory of the behavior of the polluting producer in the presence of the pollution tax, representing a negative externality. Equation (19), which represents the proposed regulation policy, teaches that if the tax rate on pollution is equal to the marginal cost of production of the polluting factory or industry, this tax rate will promote the growth of economic activity since the product (service) is made at the minimum cost and allows to promote the air quality. It is also demonstrated in this chapter that the essential criterion of Porter's hypothesis is considered by corresponding the well-designed concept with the economic notion of efficiency. Finally, the presentation of the results showed that the results were statistically positive for the two models tested, and all the hypotheses were verified. This conclusion implies that this policy, based on microeconomic theory and tested with data from the transportation industry, can control air quality and simultaneously promote growth.

CHAPTER FIVE: CONCLUSIONS

Overview

The desire for environmental regulation to ensure excellent air quality and to protect the environment, in general, is an area of rising emphasis for policymakers and the scientific community. The difficulty is that these environmental regulations are not unanimously endorsed due to a persistent belief that environmental regulations negatively impact economic activities and reduce productivity and make subject companies less competitive. Public policymakers have an essential role in environmental protection. They must contribute to and promote environmental protection by establishing effective public environmental policies guaranteeing the social optimum and favoring the polluting companies' profit. Environmental policies are based on many instruments that have evolved in recent years, with a trend favoring so-called economic instruments over regulations and standards.

Porter and Van der Linde (1995) diverge as well, by affirming that it is possible to have a regulation guaranteeing environmental protection and supporting economic activity. The conclusion of this work first presents a discussion addressing the different research questions by discussing each one and considering the results, the literature, other studies, and the relevant theory. Then, it presents the study's implications and will come to the limitations. Finally, we present the recommendations for further research will end this last chapter of the study.

Restatement of the Problem

This work has attempted to resolve the problem linked to the divergent results of studies on Porter's hypothesis to fully understand the scope of the "well-designed" concept, which constitutes the key to applying this hypothesis. According to Porter and Vander Linde (1095), well-designed environmental regulation can benefit businesses by encouraging innovation and boosting their competitiveness, which can partially or entirely offset the costs associated with regulatory compliance. Stricter and more flexible regulations encourage innovation. This study used microeconomic models to find a practical approach in terms of the Pigouvian tax to be applied to pollution to produce more at a lower cost and simultaneously control air quality. This regulatory proposal would help fight against pollution ex-ante while several regulations control pollution ex-post.

Proposed Solution to the Central Question

The main question addressed in this study was to know what type of environmental regulations meet Porter's Hypothesis criteria, ensuring environmental protection and promoting competitiveness and the growth of economic activities. Previous studies seeking to verify the validity of this hypothesis have ignored the essential aspect of the authors' statement, namely, "well-designed policy." This means that for an environmental policy to produce the effects of innovation and competitiveness, this policy must be "well-designed." Microeconomic models have made it possible to find an efficient regulation in the form of a tax rate that would equalize the sum of the industry's marginal production costs (or a firm's marginal production cost). This policy proposal can be summarized in an equation (15):

$$-\boldsymbol{C^i q(X^i)} = \mathbf{t}$$

or in equation (19):

$$\mathbf{t^* = - C_1q\ (X1) = ... = - C_{iq}\ (Xi) = ... = - C_{nq}\ (Xn).}$$

The marginal cost of the transportation industry was equal to **$67** on average, according to the American Transportation Research Institute (2020). Considering **$67** as the pollution tax rate, we multiplied it by the volume of pollution per metric ton emitted from 1980 to 2020 to find this pollution's monetary value, which served as an independent variable in the two estimated models. After estimation, it turned out that environmental regulation, captured here by the monetary value of pollution, significantly explained innovations and productivity in the transport industry.

The results of the first model (**Table 5, p.142**) showed that the R2 statistic, the coefficient of determination between these two variables, is **24%**, which means that environmental regulations alone would explain **24%** of the productivity of the transport industry if a tax of $67 were applied for each Metric Tons CO_2. The coefficient linked to the regulation variable is **0.63** (**β = 0.63**), indicating that if the carbon dioxide tax increased by one percent, the Total Factor Productivity would increase by **0.63%.** This coefficient has a positive sign, indicating that the two variables evolve in the same direction. When one variable increases automatically, the other variable increases as well.

The second model (**Table 6, p.142**) gives an **R^2** of **0.85** or **85%**, indicating that environmental regulations explain 85% of the behavior of the research and development variable. The positive coefficient linked to environmental regulation and equal to **4.49** (**β = 4.49**) attests to a positive relationship between environmental regulations and research and development. The two variables move in the same direction. The variables are in logarithms; this coefficient can be interpreted in elasticity. For a **1%** increase in environmental regulations, research and development will increase by around **4.49%**.

Implications

Twenty-eight years after its formulation, Porter's hypothesis has revolutionized the perception of the relationship between environmental regulation and economic growth. From the statement of the hypothesis itself, it is clear that a positive link between regulation and the growth of economic activities through innovation is possible, but it must be proven empirically. The empirical verification of this hypothesis led to divergent results for two reasons:

- Poor definition of the variable measuring the concept of environmental regulations. For most studies, this variable has been measured by existing data from previous environmental policies.
- Failure to consider "strict and well-designed regulations." These concepts are prerequisites for the applicability of Porter's hypothesis. It is difficult to verify this hypothesis if the environmental policy is neither well- designed nor strict.

Having examined the scope of Porter's hypothesis, this study first graphically explained the notions of the optimum economic and environmental balance, the two essential notions of this work. This approach aims to minimize the environmental risk by bringing out the duality at the equilibrium point of a pollution ceiling at the environmental level and an economic threshold. Finally, this graphic analysis has shown how the reduction of Pollution is conceived by introducing new technology, probably resulting from "well-designed" environmental regulations.

This study is based on microeconomic theory as part of the analysis of the behavior of the polluting producer to propose a regulation in terms of the Pigouvian tax, whose tax rate is equivalent to the marginal cost of production of the polluting firm or industry. A tax equal to the marginal cost of production conforms to the requirements of Porter's hypothesis that regulations that would stifle economic activities to boost productivity be "well-designed" or "strict." The proposal of a tax rate equal to the marginal cost of production before verifying or testing Porter's hypothesis contributes to the literature on Environmental Economics or a possible solution for the policymaker to promote air quality and support economic activity growth.

The marginal cost concept in economics is essential because it helps business managers determine whether production costs align with the profits derived from production. Production costs vary with production quantity and are often caused by the need to place larger orders due to the law of diminishing returns. Business managers need to understand the concept of marginal cost in economics to produce goods at an optimal level and mitigate production costs to realize profits. If the costs begin to exceed the profit from the sale of goods, the company may face severe financial jeopardy. Marginal cost in economics is a determining factor for variable costs. Marginal cost in economics is associated with returns to scale. Return to scale decreases as the cost of the goods and services produced often increases as the order increases. When this happens, companies get less output for their money. It will constitute an increase when the cost of the goods and services produced will often continue to decrease as the order increases. Companies should, therefore, be aware of when marginal costs begin to rise significantly.

On a theoretical level, Porter's hypothesis is fascinating. Having been the subject of debate since the 1900s, several researchers have rushed to verify the validity of the hypothesis. The results from these previous studies were not homogeneous. Given these divergent results, this study raises the question of where this divergence of results originates. After thoroughly analyzing the hypothesis, the previous research needed to incorporate the condition of the Porter hypothesis before being tested. This condition states that: "well-designed environmental regulation" can benefit companies by encouraging innovation and boosting their competitiveness, which can partially or wholly offset the costs associated with regulatory compliance. Hence, this study sought to know what "well-designed regulation" meant.

By browsing the microeconomic literature, we have associated the concept of "Well-designed" with the concept of efficiency, which means achieving maximum productivity with minimum wasted effort or expense or a person working in a well-organized and competent way.

From the microeconomic efficiency concept, this study used microeconomic analysis tools of the polluting producer behavior to find a well-designed policy in terms of a tax equivalent to the marginal cost of production of the firm or industry. So, this dissertation moves the theoretical argument forward from an academic view on this topic by linking the well-designed condition to a measurable concept of efficiency to get a policy instrument in terms of the Tax rate equal to the firm's marginal cost.

This study contributes to the existing literature in many ways:

1. It proposes a tax rate equal to the Marginal cost of the polluting industry, which allows air pollution control and promotes production simultaneously.
2. The air pollution control must be ex-ante rather than post-ante.
3. Previous studies on Porter's Hypothesis needed to be more accurate. These studies did not consider Porter's hypothesis prerequisite.
4. This study considers air pollution as a waste that has a cost in the production process. So, this cost is not different from the production cost.
5. This study gives economics meaning to the "well-designed regulation" concept. A well-designed regulation refers to regulation efficiency.

Limitations

The impetus for this research initially derived from the plan to research and create a first proposal for environmental regulation on the energy and transportation sector at the level of the State of Washington. After several contacts with the various state agencies, it turned out that the data necessary for developing such studies were unavailable. Some of the data was available only at the federal level.

- The first limitation of this research is at the data level. Data for conducting such research are hard to find available. The few data found at the Federal Reserve Bank of St. Louis (FRED) have all been expressed as an index. As is known, an index is a statistical tool that allows comparisons in time or space, in which the value of the variable to be compared and the value of the reference variable serving as the basis*100 are contrasted. The index is characterized by its base, which corresponds to a year. Index = (value of the variable to be compared/the value of the reference variable serving as the basis) *100. Finally, the index has no unit.

For this study, the index data were returned to their initial value to express them in monetary terms. Several manipulations were carried out for this purpose. It was necessary to know first:

1. What are the relationships between the three indicators?

- Between multiplier coefficient and rate of variation:
- The rate of change represents: [(End value – Start value) x 100]/Start value].
- The multiplier is equal to [(Rate of change/100) + 1].
- Between index and multiplier coefficient:

The index corresponds to (end value x 100)/start value, the value of the start year being chosen as the base, having the value 100. It is, therefore, equivalent to the multiplier coefficient multiplied by 100.

2. How do we find the other two indicators when there is only one?

From a rate of change:

- Index = [(rate of change/100) +1] x 100

- Multiplier = (rate of change/100) + 1

3. Based on a multiplier coefficient:

- index = multiplier coefficient x 100

- rate of change in % = (multiplier coefficient – 1) x 100

4. From the Index:

- multiplier coefficient = arrival period index/departure period index.

- percentage change rate = [(arrival index – departure index)/departure index] x 100.

- The second limit is at the level of the proposed environmental regulation policy.

Equation (17), $\mathbf{t^* = -C^1_q\ (x_1) = \ldots = -\ C^i_q\ (x_i) = \ldots = -\ C^n_q\ (x_n) = D_q\ (\sum q_i)}$. This equation shows that it suffices to set a tax with a rate t* equal to the n marginal costs of polluters and the marginal damage. This equation has three components: the tax rate, **n** marginal cost of polluters, and marginal damage. The notion of Social Damage $\mathbf{D_q\ (\sum q_i)}$ is challenging to identify and define by the legislator. This study was satisfied with only two components: the rate (**t***) and the industry's marginal cost $\mathbf{[-\ C^n_q\ (x_n)]}$ (Latzko, 2020).

The decision to use only the tax rate and the marginal cost of the industry in the study is pertinent due to the challenges legislators face in identifying the marginal damage caused by pollution. The following arguments support this perspective:

1. Complexity of Marginal Damage Assessment: Determining the exact marginal damage caused by an industry is complex. Marginal damage encompasses various environmental impacts, such as air and water pollution, habitat destruction, and resource depletion. Quantifying and valuing each of these impacts is challenging, requiring extensive scientific knowledge, data, and sophisticated modeling techniques. Legislators may need more expertise and resources to undertake such assessments comprehensively.

2. Uncertain and Long-Term Effects: The effects of environmental degradation often have long-term and cumulative consequences. It may take years or even decades for certain damages to manifest fully. Additionally, the interconnectedness of ecological systems can make it difficult to isolate and attribute specific damages to individual industries. Legislators face the challenge of predicting and evaluating the long-term impacts accurately.

3. Subjectivity and Valuation Issues: Assigning a monetary value to marginal damage involves subjective judgments and valuation methodologies that may need more consensus. Different stakeholders may have divergent views on the economic significance of various environmental impacts. For example, determining the monetary value of a lost species or the health costs associated with pollution requires making value judgments that can be contentious. Legislators may face criticism and challenges from stakeholders with differing views on their valuation methods.

4. Incomplete Data and Information: Legislators rely on available data and information to make informed decisions. However, comprehensive, and reliable data on environmental impacts may be lacking or incomplete. Gathering and analyzing data on all relevant environmental factors can be time-consuming and resource intensive. With adequate data, legislators can accurately estimate the marginal damage caused by industries.

Given these challenges, focusing on the tax rate and the marginal cost of the industry in the study offers a practical approach to assessing the relationship between environmental regulation and business outcomes. While it may not capture the extent of marginal damage, this approach provides meaningful insights into how environmental regulations affect innovation and productivity. Additionally, by examining the tax rate and industry costs, policymakers can still gain valuable information to inform their decision-making process while acknowledging the limitations in directly measuring marginal damage.

Recommendations for Future Research

The problems related to air pollution are better known in our modern societies both by the population and by our political leaders: these are becoming a public policy problem that must be addressed. As with any public policy problem, there is no easy solution. It takes compromise, sacrifice, and political will to arrive at a consensual solution.

This regulation aims to establish a fundamental balance between economic activities and the environment since it is central to natural ecosystems that humans can access the food and materials necessary to meet basic needs.

The recommendations within the framework of this research are simultaneously aimed both at the policymaker and at the polluting companies and secondarily at researchers in the field of environmental economics.

❖ Addressing policymakers, the recommendations are as follows:

1. We suggest adopting a tax on air pollution whose rate will equal the marginal cost of production and the marginal cost of damage. A tax meeting the criteria of Porter's hypothesis will act to promote economic activities and, at the same time, contribute to the improvement of air quality by reducing pollution.

2. The income from this tax must be directed to research likely to promote new technologies in the production process that are less polluting.

3. Identify all polluting industries by field of activity to ensure that no industry or form escapes this requirement.

4. Perfect knowledge of the markets in which these polluting companies operate. A market with perfect competition will be different from a monopoly or duopoly

- At the level of polluting companies and industries, it is possible to make the following recommendations:

1. Each polluting company or industry subject to this tax must facilitate the regulator's task by knowing its marginal production and damage costs. If the marginal damage rate seems difficult to calculate, the marginal cost of production of the company or industry is a metric in the company's accounting. It must be entered accurately because this metric will equal the tax rate.

2. On their initiative, firms, or industries subject to this tax must increase their research and development budget to set up new, less polluting production processes.

- Concerning researchers in this field, we make the following recommendations:

1. Agree on defining some critical variables on research related to development economics. The diversity of results in the context of the Porter hypothesis is partly due to the poor definition of variables and inadequate specification of the models.

2. Careful consideration should be given to the study data. As there are fewer surveys for data collection, most of the data used are second-hand and collected for other reasons, so their use should be done cautiously.

Summary

The last chapter of this research addresses questions related to the proposed solution to the central research question, solution implications, research limitations, and recommendations for future research. The research sets up a regulation proposal: a tax rate equal to the polluting firm's marginal production cost. This rate applies to the volume of pollution of the firm concerned. This proposed regulation contributes to environmental economics concerning the improvement of air quality and the desire to encourage the growth of economic activities. The research used data from the Federal Reserve to acquire the data used to verify the proposed regulations. The research experienced a size limitation concerning the data. The appropriate data was unavailable as the study is based on a different approach to what has been done so far. Finally, some recommendations were made to policymakers, polluting firms, and researchers in environmental economics.

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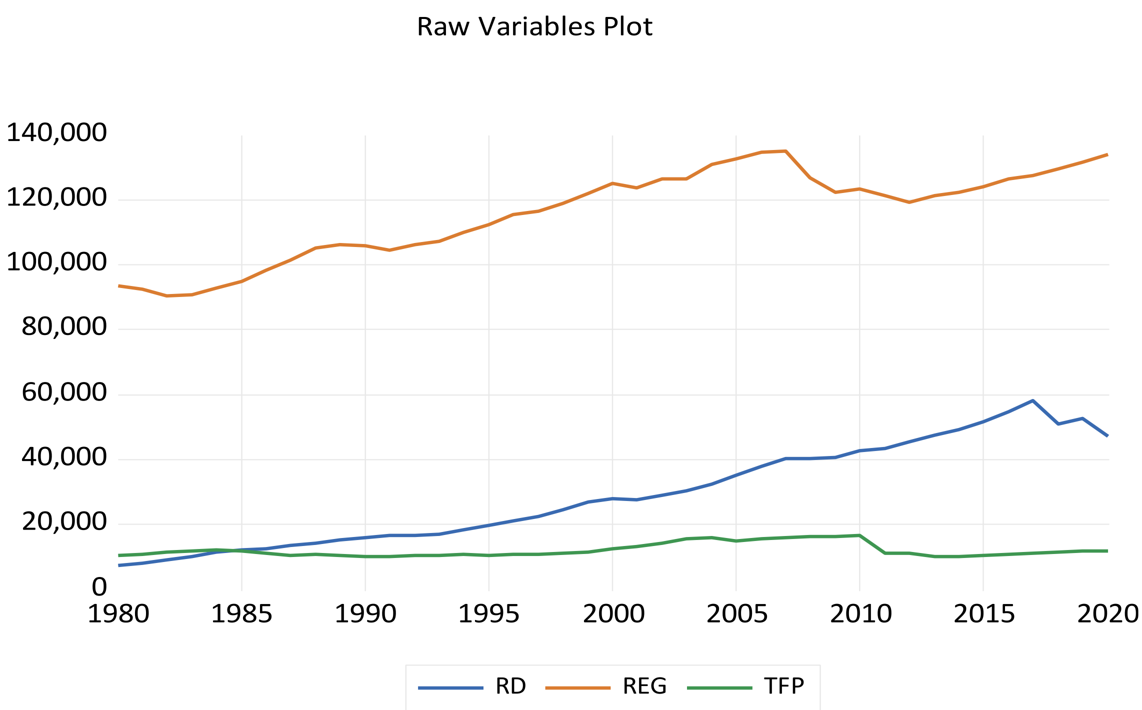
APPENDIX I: Raw Variables Plot

Graph 1.

Raw variables graph

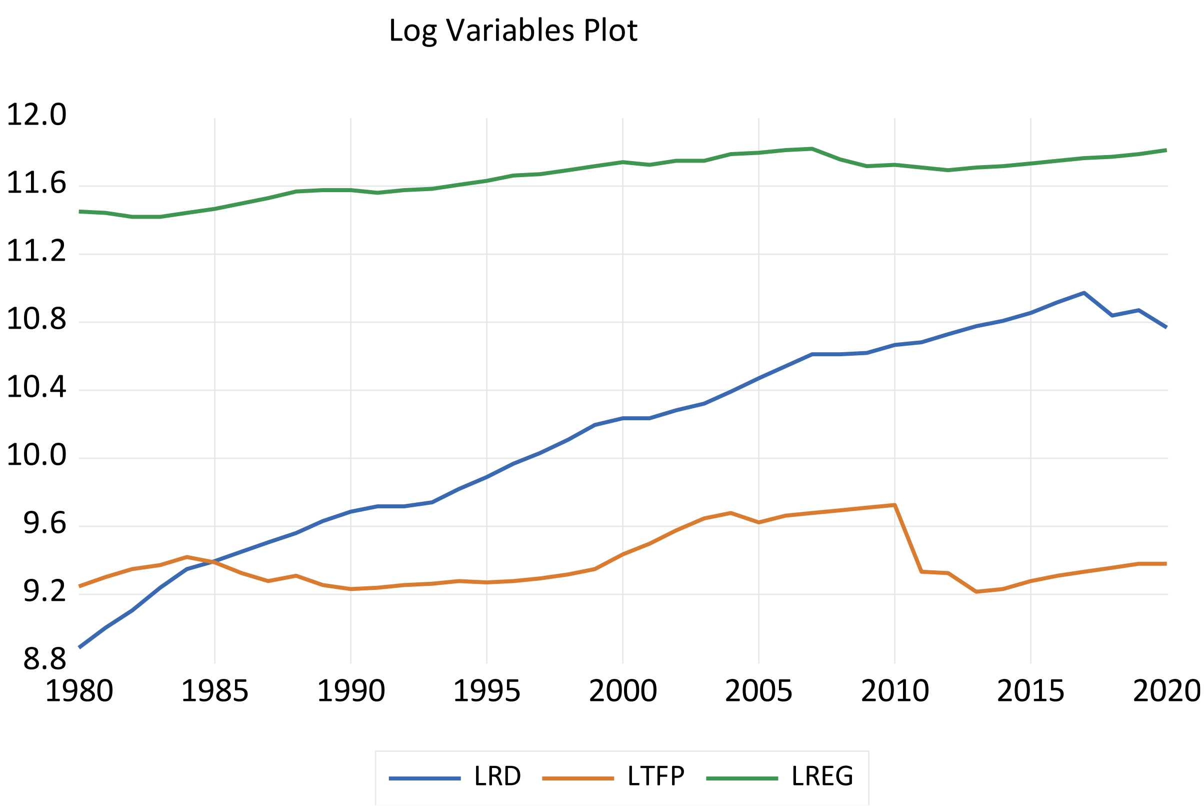


Note: The abscissa axis represents the rings, and the ordinate axis represents the monetary value in Millions of U.S. dollars.

APPENDIX II: Log Variables Plot

Graph 2.

Logarithm variables graph



Note: The horizontal axis represents the years, and the vertical axis represents the logarithm v value of variables.

APPENDIX III:

First model Estimation: The independent variable LER explains the dependent variable LRD.

Dependent Variable: LTFP
Method: Least Squares
Date: 02/16/23 Time: 16:47
Sample: 1980 2020
Included observations: 41

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.043879	2.112158	0.967673	0.3392
LREG	0.630294	0.181249	3.477493	0.0013

R-squared	0.236685	Mean dependent var	9.388497
Adjusted R-squared	0.217113	S.D. dependent var	0.159233
S.E. of regression	0.140890	Akaike info criterion	-1.034119
Sum squared resid	0.774154	Schwarz criterion	-0.950530
Log likelihood	23.19944	Hannan-Quinn criter.	-1.003681
F-statistic	12.09296	Durbin-Watson stat	0.287782
Prob(F-statistic)	0.001259		

APPENDIX IV:

Second model Estimation: The independent variable LER explains the dependent variable LTFP.

Dependent Variable: LRD
Method: Least Squares
Date: 02/16/23 Time: 16:52
Sample: 1980 2020
Included observations: 41

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-42.20582	3.546565	-11.90048	0.0000
LREG	4.490745	0.304339	14.75571	0.0000

R-squared	0.848090	Mean dependent var	10.12342
Adjusted R-squared	0.844195	S.D. dependent var	0.599338
S.E. of regression	0.236572	Akaike info criterion	0.002419
Sum squared resid	2.182679	Schwarz criterion	0.086008
Log likelihood	1.950407	Hannan-Quinn criter.	0.032858
F-statistic	217.7310	Durbin-Watson stat	0.171252
Prob(F-statistic)	0.000000		

APPENDIX V:

Written authorization to use two specific tables found the ATRI 2019 report.

RE: [EXTERNAL]

Carla Rose <crose@trucking.org>
to me

Tue, Sep 5, 6:09 AM (12 days ago)

Hi Emmanuel,

Thank you for checking with us. You have our permission to use any tables or charts from our report. We ask that you please use proper attribution when citing our work.

Thanks again,
Carla Rose

Carla S. Rose, Research Assistant
American Transportation Research Institute (ATRI)
2110 Powers Ferry Road, Suite 470, Atlanta, GA 30339
(770) 432-0628
crose@trucking.org
truckingresearch.org

ATRI American Transportation Research Institute

From: Emmanuel WANGI <wangis309@gmail.com>
Sent: Thursday, August 31, 2023 8:55 PM
To: ATRI <ATRI@trucking.org>
Subject: [EXTERNAL]

Dear Sir,

Dear Sir,

My name is Emmanuel Wangi, and I am currently researching for my dissertation titled: "*To What Extent Do Environmental Regulations Curb Air Pollution and Enhance Production, Productivity, and Innovation?*" I request your written authorization to use two specific pictures I found on the National Park Service (NPS) website.
The tables in question are related to "Marginal Cost." Specifically, I seek permission to use page 19 of the report "Table 9: Average Marginal Costs per Mile, 2010-2018" table and "Table 10: Average Marginal Costs per Hour, 2010-2018." These visuals contribute significantly to the clarity and effectiveness of my research, providing visual representations of the concepts being discussed.

I fully understand and respect these tables' copyright policies and intellectual property rights. Therefore, I would like to obtain written permission from the ATRI to include these tables in my dissertation and, potentially, in the subsequent publication of my work.

I assure you that the tables will be used solely for academic purposes, specifically in my dissertation and any related presentations or publications. Proper attribution will be provided, acknowledging the American Transportation Research Institute's source of these visuals.

Please review my request at your earliest convenience. If there are any specific guidelines or procedures I need to follow to obtain written authorization, please let me know, and I will be more than willing to comply.

Thank you very much for your attention to this matter. I greatly appreciate your assistance in helping me obtain the necessary authorization to enhance the quality and impact of my research. I look forward to your positive response.

Yours sincerely,

Emmanuel Wangi

APPENDIX VI:

Written Authorization to Use Images found on the EPA Website.

Gmail — Emmanuel WANGI <wangis309@gmail.com>

Request for Written Authorization for the Use Image found on the EPA website

3 messages

Emmanuel WANGI <wangis309@gmail.com> — Thu, Aug 31, 2023 at 6:40 PM
To: blackman.belinda@epa.gov

Dear Sir,

My name is Emmanuel Wangi, and I am currently researching for my dissertation titled: "*To What Extent Do Environmental Regulations Curb Air Pollution and Enhance Production, Productivity, and Innovation?*" I request your written authorization to use two specific pictures I found on the Environmental Protection Agency (EPA) website.

The images in question are related to "Sources of Greenhouse Gas Emissions." Specifically, I seek permission to use the Total U.S. Greenhouse Gas Emissions by Economic Sector in 2021 found at https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

These visuals contribute significantly to the clarity and effectiveness of my research, providing visual representations of the concepts being discussed.

I fully understand and respect these images' copyright policies and intellectual property rights. Therefore, I would like to obtain written permission from the EPA to include these tables in my dissertation and, potentially, in the subsequent publication of my work.

I assure you that the images will be used solely for academic purposes, specifically in my dissertation and any related presentations or publications. Proper attribution will be provided, acknowledging the EPA's source of these visuals.

Please review my request at your earliest convenience. If there are any specific guidelines or procedures, I need to follow to obtain written authorization, please let me know, and I will be more than willing to comply.

Thank you very much for your attention to this matter. I greatly appreciate your assistance in helping me obtain the necessary authorization to enhance the quality and impact of my research. I look forward to your positive response.

Yours sincerely,
Emmanuel Wangi

Ryan, Jini <Ryan.Jini@epa.gov> — Fri, Sep 1, 2023 at 6:50 AM
To: "wangis309@gmail.com" <wangis309@gmail.com>
Cc: "Stevens, Katherine" <stevens.katherine@epa.gov>, "Beck, Laura (she/her/hers)" <Beck.Laura@epa.gov>, "Deluca, Isabel" <DeLuca.Isabel@epa.gov>

Emmanuel,

Belinda forwarded your message to me. EPA's Office of Air will be able to assist you. I've copied their communications officers here. Thanks.

****

Ms. Jini Ryan
Director
Office of Multimedia (OM)
U.S. Environmental Protection Agency

202-564-0175 (Office)
703-589-6035 (Cell)
ryan.jini@epa.gov (Email)

Address:
1200 Pennsylvania Ave., NW
WJC-North, Room 6330H, MC 1703A

Washington, DC 20460

****
Office of Multimedia intranet site
https://work.epa.gov/multimedia
****

From: Blackman, Belinda <Blackman.Belinda@epa.gov>
Sent: Friday, September 1, 2023 7:06 AM
To: Ryan, Jini <Ryan.Jini@epa.gov>
Subject: FW: Request for Written Authorization for the Use Image found on the EPA website

See inquiry below. Thank you.

[Quoted text hidden]

Deluca, Isabel <DeLuca.Isabel@epa.gov> — Fri, Sep 1, 2023 at 6:57 AM
To: "Ryan, Jini" <Ryan.Jini@epa.gov>, "wangis309@gmail.com" <wangis309@gmail.com>
Cc: "Beck, Laura (she/her/hers)" <Beck.Laura@epa.gov>

Hi Emmanuel,

Thanks for your interest. The image that you would like to use is in the public domain and may be reproduced, with attribution.

Thanks!

Isabel

Isabel DeLuca

Deputy Communications Director

Office of Air and Radiation, US EPA
Phone 202-340-8190

[Quoted text hidden]