THE IMPACT OF US REGIONAL GREENHOUSE GAS INITIATIVE ON FIRM-LEVEL INNOVATION ACTIVITIES AND MARKET COMPETITIVENESS

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ABSTRACT

Climate change threatens the future of humanity, primarily driven by rapid industrialization and global competition. The challenge lies in balancing regulatory actions, which can raise costs against obligations to fight emissions, hinder productivity, and slow economic growth. The Emissions Trading Scheme (ETS) provides an effective solution for curbing global carbon emissions. Nevertheless, a prevailing view is that environmental regulations raise firm costs and prevent investment from clashing with expected innovation benefits. Recent observations challenge these notions and argue that well-structured regulations can encourage innovation and help stimulate firm performance. The Regional Greenhouse Gas Initiative (RGGI), active across ten northeastern US states since 2009 to reduce CO2 emissions from the power sector, yields paradoxical outcomes. However, emissions decline within RGGI states while neighboring regions witness the opposite. Moreover, rising temperatures and waning green initiatives underscore our failure to find effective remedies. RGGI's impact on firm-level innovation and market competitiveness remains unexplored, especially considering its fully auction-based ETS structure. This research examines RGGI's influence on firm innovation and market competitiveness, scrutinizing direct and policy-driven effects across regulated and unregulated sectors. Focusing on US-listed electric power sector companies (regulated) and Fortune 500 companies (non-regulated), the research spans 2000 to 2019 for patent timelines. Using a quasi-experimental approach consisting of 'difference-in-difference' and propensity score matching techniques, the investigation reveals the positive impact of RGGI on regulated sector innovation. However, policy spillover into the unregulated sector proves insignificant. Supporting the 'weak' Porter hypothesis (PH) in regulated sectors and negating it in the unregulated sector, RGGI's deployment lacks a statistically significant impact on green innovation in both spheres. Acknowledging the 'strong' PH variant, RGGI enhances market competitiveness in regulated sectors but counteracts this trend in the unregulated sector. Innovation and green innovation enhance US firm competitiveness, yet RGGI's implementation dampens the connection between firm-level innovation and market competitiveness. This study widens insights by disclosing RGGI's effects on innovation and competitiveness, delving into the link between innovation and market prowess among US firms. Contributions abound: empirical evidence emerges for the market-based nature of RGGI, distinguishing it from freely allocated policies like EU-ETS and CN-ETS. Furthermore, the study enriches the policy spillover literature by uncovering innovation spillover in non-regulated sectors. Notably, RGGI's fully auction-based approach significantly boosts market competitiveness among regulated firms, a novel finding in policy evaluation and spillover literature. Additionally, the study contributes to the 'innovation' and 'green innovation' discourse, showcasing empirical proof of US firms' high innovativeness. Intriguingly, RGGI moderates this connection negatively while bolstering it positively for innovative firms, holding implications for their market sustainability. Recommendations stemming from this study extend to RGGI authorities and industry stakeholders, illuminating the policy's implications.

Keywords: Regional Greenhouse Gas Initiative, Porter Hypothesis, Firm-level Innovation, Green Innovation, Market Competitiveness

IMPAK INISIATIF GAS RUMAH HIJAU SERANTAU A.S. TERHADAP AKTIVITI INOVASI PERINGKAT FIRMA DAN PERTANDINGAN PASARAN

ABSTRAK

Perubahan iklim mengancam masa depan umat manusia, utamanya dipicu oleh industrialisasi cepat dan persaingan global. Cabaran terletak dalam seimbangkan tindakan pengawalseliaan yang boleh meningkatkan kos dengan keperluan untuk melawan pelepasan, menghalang produktiviti, dan melambatkan pertumbuhan ekonomi. Skim Perdagangan Pelepasan (ETS) menyediakan penyelesaian berkesan bagi mengawal pelepasan karbon global. Namun, pandangan dominan ialah peraturan alam sekitar meningkatkan kos syarikat dan menghalang pelaburan, berbenturan dengan manfaat inovasi yang dijangka. Pemerhatian terkini mencabar pandangan ini dan menganggap peraturan yang tersusun dengan baik boleh merangsang inovasi dan membantu merangsang prestasi syarikat. Inisiatif Gas Rumah Hijau Wilayah (RGGI), yang aktif di sepuluh negeri timur laut Amerika Syarikat sejak tahun 2009 untuk mengurangkan pelepasan CO2 dari sektor tenaga, memberikan hasil yang paradoks. Namun begitu, pelepasan dalam negeri-negeri RGGI menurun sementara rantau-rantau jiran mengalami yang sebaliknya. Selain itu, peningkatan suhu dan inisiatif hijau yang semakin berkurang menonjolkan kegagalan kita dalam mencari penyelesaian yang berkesan. Kesan RGGI terhadap inovasi peringkat firma dan daya saing pasaran masih belum dijelajahi, terutamanya mempertimbangkan struktur ETS yang sepenuhnya berasaskan lelongan. Kajian ini mengkaji pengaruh RGGI terhadap inovasi firma dan daya saing pasaran, mengkritik kesan langsung dan berdasarkan dasar di sektor yang dikawal dan tidak dikawal. Tumpuan diberikan kepada syarikat sektor tenaga elektrik yang tersenarai di AS (dikawal) dan syarikat Fortune 500 (tidak dikawal), kajian ini meliputi tempoh 2000 hingga 2019 untuk jangka masa paten. Menerapkan pendekatan quasi-eksperimen yang terdiri daripada teknik 'difference-in-difference' dan penjodoh skor kecenderungan, penyiasatan ini mendedahkan impak positif RGGI terhadap inovasi sektor yang dikawal. Walau bagaimanapun, kesan aliran dasar ke sektor yang tidak dikawal adalah tidak signifikan. Menyokong hipotesis Porter (PH) yang 'lemah' di sektor yang dikawal dan menafikan hipotesis tersebut di sektor yang tidak dikawal, pelaksanaan RGGI tidak mempunyai kesan yang signifikan secara statistik terhadap inovasi hijau di kedua-dua bidang tersebut. Mengakui varian PH yang 'kuat', RGGI meningkatkan daya saing pasaran di sektor yang dikawal tetapi melawan trend ini di sektor yang tidak dikawal. Inovasi dan inovasi hijau meningkatkan daya saing syarikat-syarikat Amerika, namun pelaksanaan RGGI mengurangkan hubungan antara inovasi peringkat firma dan daya saing pasaran. Kajian ini meluaskan pandangan dengan mendedahkan kesan RGGI terhadap inovasi dan daya saing, menyelami hubungan antara inovasi dan kecemerlangan pasaran di kalangan syarikat-syarikat Amerika. Sumbangan kaya: bukti empirikal muncul bagi sifat berasaskan pasaran RGGI, membezakannya daripada dasar-dasar yang diperuntukkan secara bebas seperti EU-ETS dan CN-ETS. Selain itu, kajian ini memperkayakan literatur aliran dasar dasar dengan mendedahkan aliran dasar inovasi di sektor-sektor yang tidak dikawal. Menariknya, pendekatan RGGI yang berasaskan lelongan sepenuhnya secara signifikan meningkatkan daya saing pasaran di kalangan syarikat-syarikat yang dikawal, suatu penemuan baru dalam penilaian dasar dan literatur aliran dasar. Tambahan pula, kajian ini menyumbang kepada perbincangan tentang 'inovasi' dan 'inovasi hijau', mempamerkan bukti empirikal kecemerlangan tinggi syarikat-syarikat Amerika dalam inovasi. Menariknya, RGGI memoderatkan hubungan ini secara negatif sambil menguatkan hubungannya secara positif bagi syarikat-syarikat yang inovatif, yang mempunyai implikasi terhadap kelestarian pasaran mereka. Cadangan yang timbul daripada kajian ini merangkumi pihak berkuasa RGGI dan pihak berkepentingan industri, menerangi implikasi dasar tersebut.

Kata kunci: Inisiatif Gas Rumah Hijau Serantau, Hipotesis Porter, Inovasi peringkat Firma, Inovasi Hijau, Daya Saing Pasaran

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DEDICATION

To My Respected Father (late)

MD HAFIZUR RAHMAN

To My Respected Mother (late)

AYASHA AKTER

To My Respected Father-in-law (late)

MD SHAMSUL HOQUE

All of You are real World to me!

[Feels like I am living in a Virtual world without You….!]

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LIST OF SYMBOLS AND ABBREVIATIONS

ATE	:	Average Treatment Effect
CCH	:	Compliance Cost Hypothesis
CCR	:	Command-and-Control Regulation
CN-ETS	:	China's Emissions Trading Scheme
CO2	:	Carbon Dioxide
CPC	:	Cooperative Patent Classification
CV	:	Control Variable
DID	:	Difference-in-difference
DV	:	Dependent Variable
EPO	:	European Patent Office
ER	:	Environmental Regulation
EST	:	Environmentally Sound Technologies
ETS	:	Emission Trading System
EU-ETS	:	European Union's Emission Trading System
F500	:	US Fortune 500 companies
FGI	:	Firm-Level Green Innovation
GHG	:	Greenhouse gases
GI	:	Green Innovation
GPAT	:	Green Patent
IEA	:	International Energy Agency
IIH	:	Induced Innovation Hypothesis
IPC	:	International Patent Classification
IR	:	Integrated Review
MBR	:	Market-Based Environmental Regulation
MSPE	:	Mean Squared Prediction Error
NAICS	:	North American Industry Classification System
NNM	:	Nearest Neighbor Matching
NOx	:	Oxides of Nitrogen
OLS	:	Ordinary Least Squares
PACE	:	Pollution Abatement Costs and Expenditures
PH	:	Porter Hypothesis
POLS	:	pooled ordinary least squares
PPM	:	parts per million

PRISMA	:	Preferred Reporting Items for Systematic reviews and Meta-Analyses
PSM	:	Propensity Score Matching
PSM-DID	:	Propensity Score Matching-Based DID
RGGI	:	Regional Greenhouse Gas Initiative
R&D	:	Research and Development
SCM	:	Synthetic Control Model
SGMM	:	Two-Step System Generalized Method of Moments
SIC	:	Standard Industrial Classification
SO2	:	Sulfur Dioxide
TPAT	:	Total Patent
US	:	United States of America
USPTO	:	United States Patent and Trademark Office
WIPO	:	World Intellectual Property Organization
WOS	:	Web of Science

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Global leaders face the daunting challenges of global climate change, natural disasters, and environmental issues that threaten the existence of human life. Greenhouse gas emissions, mainly CO_2, have led to a 1.1°C rise in global temperatures since 1880, with a projected increase of 5°C by 2100 (NASA Goddard Institute for Space Studies, 2022; NOAA National Centers for Environmental Information, 2022a). Devastating events such as extreme temperatures, cyclones, floods, and wildfires have resulted in significant macroeconomic losses. Although natural factors contribute, the consensus points to human activity as the primary cause of global warming, driven by industrialized heat-trapping gases. As a result of climate-related risks, firms face increased physical and transitional risks (Walles et al., 2021). Physical risks include extreme weather events, while transformational risks associated with changes to sustainable economies due to government policies make conventional production methods obsolete.

Climate hazards have a direct and substantial impact on firm revenues (Hossain & Farooque, 2019). For example, urban high-rise developers face costs due to coastal or fluvial flooding, resulting in costs, reduced income, and loss of assets, thereby reducing net income and book value of assets (Ziff et al., 2022). Therefore, corporate strategies must adapt for resilience and improved risk management (Ziff et al., 2022). Governments have introduced Environmental Regulations (ER) to mitigate the industry's environmental impact and promote ecological awareness (Halvorssen, 2012; Hunter, 2022; Smirnova et al., 2021). International environmental law has evolved through distinct periods, from the pre-Stockholm era to the modern era following the 1972 Stockholm Conference (QC, 1995; Techera, 2012). The history of US environmental regulation is divided into six phases, including initiatives such as the Yellowstone Act of the 1970s and the modern environmental movement (Myers, 2013; Sine & Lee, 2009). Although global attention to environmental policy has increased since the Rio de Janeiro Conference in 1992, challenges have arisen due to the country's emphasis on economic stability, competitiveness, and globalization, which has hindered industrial directives (Lilliestam et al., 2021). Thus, climate-related risks exert a significant and immediate influence on firms' performance.

Governments in developed nations employ carbon pricing mechanisms such as carbon taxes or emission trading schemes (ETS) to incentivize energy efficiency and control CO2 emissions within specific sectors or regions (ICAP., 2021). Based on fossil fuel carbon content, carbon taxes entail financial transfers from enterprises to governments. Historically, European countries like Poland, Norway, Sweden, and the UK initiated carbon taxes in the early 1990s, primarily impacting fossil fuel use. Conversely, ETS directly imposes emission limits on facilities and allows them to trade emission permits. The Kyoto Protocol, in force since 2005, catalyzed global efforts to reduce greenhouse gas (GHG) emissions, compelling industrialized nations to curtail emissions in line with individual goals (United Nations Framework Convention on Climate Change, 1997). In response, various high GHG-emitting nations introduced emissions trading schemes, such as the European Union Emissions Trading System (EU-ETS), the US Regional Greenhouse Gas Initiative (RGGI), and China's Pilot Emissions Trading Scheme (CN-ETS), subsequently expanding with the Paris Agreement's enactment in 2016 (Paris Agreement, 2016). ETSs now span 80 jurisdictions and encompass 14% of global GHG emissions, significantly increasing from 5% in 2005 (ICAP., 2021). Despite these efforts, daily carbon emission trends continue to rise.

The United States (US) boasts a history of environmental law spanning over a century and is recognized as a trailblazer in environmental policy advancement (Myers, 2013). The US initiated environmental legislation like the Yellowstone Act (1872) and the Rivers and Harbors Act (1899) with an initial focus on resource preservation. The modern environmental movement, emerging in the 1950s, spurred increased attention toward climate change (EPA, 2017). Notable policies include the "Clean Air Act" (1970) and the "Energy Policy Act" (1992), enhancing the nation's climate resilience. Over the past two decades, both federal and state entities introduced greenhouse gas initiatives, like the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade (Yan, 2021). Multi-level regulations are underway to mitigate industrial impacts across the US.

Cap-and-trade is a market-driven environmental regulation strategy aimed at curtailing pollutants, including greenhouse gases, by imposing an emissions cap while establishing a tradeable permit market (Ellerman & Buchner, 2008). The government sets emission limits for specific sectors, requiring companies to possess permits equivalent to their emissions. Permit supplies decrease over time to achieve the cap, fostering emission reduction. Surplus permits from emission-cutting companies can be sold to those unable to reduce emissions, creating a financial incentive for emission reduction (Ellerman & Buchner, 2008). An example of a cap-and-trade application is the northeastern US's Regional Greenhouse Gas Initiative (RGGI), initiated in 2009, targeting GHG reductions from electricity. RGGI enforces a regional emissions ceiling through permit auctions, promoting energy efficiency, renewables, and greenhouse gas reduction programs (RGGI Inc., 2022b). While cap-and-trade mitigates emissions, exceeding allocated limits results in financial penalties or auctioned permit costs, possibly affecting company profits or consumer purchasing power (Ellerman & Buchner, 2008). Thus, the implementation of environmental regulation has become a serious concern for every stakeholder.

Environmental regulations encompass diverse categories based on formality and requirements, including formal, informal, mandatory, participatory, and voluntary regulations (Song et al., 2019). High-emitting nations such as China and the US have introduced varying ecological strategies; China's regulations include economic, legal, and supervised types (Liu et al., 2018). Although the effectiveness and terms of environmental regulations are debated, research shows that strict, mandatory regulations help control pollution, increase sustainability, stimulate green innovation, and increase market competition (Ning et al., 2022; Qiu et al., 2020a; Sun et al., 2019). However, Emissions Trading Systems (ETS), a flexible market-based regulation, have gained prominence for their effectiveness (Bel & Joseph, 2018; Y. Q. Liu et al., 2022; L. Zhang et al., 2019). Stringent regulations drive innovation by fostering cost reduction and competitive advantages (Lee et al., 2011; Popp, 2003), optimizing productivity and resource allocation (Xie et al., 2017), market competitiveness (Studeny et al., 2017), and compelling proactive environmental strategies (Brancati et al., 2021; Darnall et al., 2010). However, concerns exist that environmental protection might hinder business productivity and global competitiveness (Cai & Ye, 2020; Liu & Xie, 2020a; M. Peneder et al., 2022; H. L. Tang et al., 2020; Q. Z. Yang et al., 2020), allocating resources away from productive ventures and limiting technological choices (Liu & Xie, 2020a; M. Peneder et al., 2022). The traditional view posits compliance costs detract from competitiveness, necessitating innovative policies that balance environmental goals with flexible frameworks to curb negative business externalities (Cai & Ye, 2020; Liu & Xie, 2020a). Overall, the effectiveness of environmental regulations varies depending on the nature of the regulation.

In the environmental regulation (ER) case, ETS is seen as a strict but flexible strategy that offers much flexibility and effectiveness in reducing GHG emissions during production (Ramanathan et al., 2018). In addition to being flexible, the ETS is politically possible because it offers payment refunds, also called "carbon dividends," which pay for public benefits when GHG emission targets are met (Raymond, 2019). While environmental regulations help control serious pollution problems (Sun et al., 2019), market-based regulations, or "cap-and-trade," work well to manage intra-firm, internal, and external externalities directions. It helps firms become more environmentally aware by improving energy efficiency and developing new ways to use advanced technologies to make green products and processes (Chen, 2008; J. M. Zhang et al., 2020) . Then, taking part in auction trading (in ETS) and paying more than they need to for environmental compliance reduced profit, making it harder for the company to invest in green projects (X. Liu et al., 2022). As a result, a firm may lose its market share and hinder its green development initiatives. The exclusive focus of this study is to measure the effectiveness of the ETS in encouraging environmentally responsible practices among firms and enhancing their ability to compete in the marketplace.

Since the modern era of the environmental movement, many countries have enacted environmental laws and regulations to reduce GHG emissions, but recent global GHG emissions show the opposite trend. For example, global emissions in the so-called modern era increased by more than 240% from 9.39 billion metric tons in 1960 to 22.75 billion metric tons in 1990 (Tiseo, 2022). Since the 1990s, many governments have changed their environmental policies and adopted market-based regulations like carbon taxes and ETS, Sulphur or Carbon pricing, and some global efforts to deal with climate problems like the Kyoto Protocol or the Paris Climate Agreement. But recent emissions trends tell the opposite story. The global CO_2 emission trend reached 2.7 % in 2018 from 1.6% in 2017 (Roser, 2019). In 2021, global carbon dioxide emissions spiked to an all-time high (IEA., 2022). The IEA also noticed that global CO2 emissions fell due to last year's pandemic, but this year's increase has made up for about two billion tonnes. Even though renewable power production climbed the highest in 2021, the rise in energy consumption was driven by adverse conditions and changes in the energy market, particularly a spike in natural gas prices. It resulted in more coal combustion, which caused a 6% rise in CO2 emissions from energy worldwide in 2021, bringing the total to 36.3 billion tonnes (IEA., 2022). After the COVID-19 crisis, the global economy increased and depended significantly on coal. As a result, last year (2021) was recorded as the sixth warmest year (NOAA National Centers for Environmental Information, 2022b). From 2013 to 2021, nine years are among the ten hottest. Therefore, the increasing trend of GHG emissions indicates that more specific policy innovations are needed to address global environmental problems.

Meanwhile, US governments have supported and monitored state- and county-level GHG programs throughout the last two decades. They combine mandatory and voluntary policies to limit GHG emissions in the United States. A significant factor is the continuous and increasing production and consumption of fossil fuels such as coal, oil, and natural gas (Hao & Van Brown, 2019). As a result, industrial activities are the primary contributor to increased CO2 emissions, and business environmental stances are critical to the rise of hazardous gases. Still, the escalating trend of CO2 emission by the USA is quite like the global mean CO2 rising rate. The United States is still one of the largest carbon emitters, accounting for 15% of global carbon emissions. US emissions also increased by about 2.13% in 2018 (reaching 4.8 billion tons of CO2 in 2018 compared to 4.7 billion tons of CO2 in 2017)(Carr & Hodges, 2019). In 2021, economy-wide GHG emissions increased by 6.2% compared to 2020 (IEA., 2022). RGGI is a mandatory initiative for all participating states, which can effectively address external environmental pollution issues (Wu & Lin, 2022). Since the RGGI is a "cap-and-invest" program to reduce CO2 emissions and make US firms more competitive in the market through innovation activities, the results of this study can add a new dimension to and improve the existing research.

1.2 Statement of the problem

Environmental issues further complicate the United States' position as the world's largest economy and one of the high-emitting countries. The escalation of greenhouse gas (GHG) emissions in the US is driven primarily by rising fossil fuel production and industrial utilization (Hao & Van Brown, 2019). Notably, industrial activities and the environmental stances of organizations contribute significantly to CO2 emissions and hazardous gas accumulation. According to the US Environmental Protection Agency (EPA, 2022a), the US remains responsible for approximately 15% of global carbon emissions.

In 2021, the nation's GHG emissions surged by 6.2% compared to 2020 (IEA., 2022). In response, the US government has introduced numerous state and federal policies dating back to the initial 'Clean Air Act' in 1970. Market-based policies, including cap-and-trade programs, have emerged as effective tools for mitigating climate change while minimizing economic impact (Yan, 2021). Notably, cap-and-trade mechanisms gained prominence after the successful implementation of the US sulfur dioxide allowance-trading program in 1995. Subsequently, regional greenhouse gas initiatives (RGGI) were established for ten northeastern states in 2009, followed by California's cap-and-trade in 2013. The effectiveness of these environmental regulations remains a pressing concern for US policymakers.

In its most fundamental form, an Emissions Trading System (ETS) involves policymakers establishing a cap on allowable emissions and allocating allowances to emitters, the sum of which matches the cap. These allowances can be traded among firms within the market. However, firms must surrender an equivalent number of allowances for their emissions by the end of each year (Verde et al., 2021). The primary objective of an ETS is to curb the negative externalities of industrial activities while minimizing costs and safeguarding market competitiveness.

Central to the effectiveness of this policy is the encouragement of technological innovation. Technological innovation serves as a cornerstone for addressing long-term environmental challenges and fostering a sustainable environment (X. Yang et al., 2020). Moreover, it is pivotal in enhancing firms' productivity growth and competitiveness (Si et al., 2021; Zheng et al., 2020). This approach effectively places the responsibility for emissions reduction in the hands of polluters. Doing so establishes a dynamic where regulatory pressure and the lure of economic benefits push firms to adopt advanced technologies and optimize operations to align with environmental goals.

Additionally, the policy framework generates revenue through carbon credit auctions, directing these funds towards direct incentives for regulated companies. These incentives encompass technological advancements, transitioning to low-carbon practices, and offering utility bill assistance to citizens (Löschel et al., 2019; H. Tang et al., 2021; M. X. Wang et al., 2019). This multi-pronged strategy increases public environmental awareness and augments purchasing power (Perera et al., 2020). Thus, this study delves into the impact of a market-based ETS on firm innovation activities—a pivotal factor in realizing a mutually beneficial outcome for both environmental conservation and business prosperity.

However, it is often claimed that strict environmental regulations raise firms' costs to comply and force them to invest more in products and services that are less hazardous, making it harder for them to take advantage of other investment opportunities. On the other hand, environmental economists and business strategy experts like Professor Michael Porter and his colleagues have said that well-structured (strict but flexible) environmental policies encourage firms to come up with new ideas like innovation (Porter

& Van der Linde, 1995). They also claimed that innovations make the company more valuable by increasing sales, profits, and market share. This also gives the company a first-mover advantage by opening new markets through innovation. Also, innovations help to reduce costs by improving productivity and efficiency. Also, the company's continuous green innovation activities help improve non-financial assets like its green reputation, image, and quality of its products. It helps increase customer attention and satisfaction towards environmentally standardized products and services, which makes the company more competitive in the market.

In theory, an emissions trading program can create two sets of incentives that work against each other. On the one hand, the program lets firms meet their pollution-reduction obligations by buying allowances from other polluters, which may make them less likely to innovate when the innovation process is uncertain (Ragulina et al., 2021). Also, if a firm can control the risks of firm-level technology innovation in a timely way, it can keep its business from losing performance (Yang & Lu, 2016). On the other hand, the Porter Hypothesis argues that environmental regulations that are strict but flexible, like the ETS, may encourage technological change (Ren et al., 2020b). Later, the Porter hypothesis is divided into "weak" (i.e., the effect of ETS on innovation) and "strong" (i.e., the effect of ETS on firm-level market competition) versions (Jaffe & Palmer, 1997). In this way, ETS can create a 'double dividend' by creating a distributable fund so that regulators can use this fund to reduce the direct policy impact on citizens. In addition, it helps to create an investable fund in low-carbon technology by reducing the risk of innovation to achieve the carbon reduction goal, which makes ETS an economical solution for firm management and customers and a politically viable solution for the government.

Moreover, the ETS can incentivize sellers of permits to develop innovative approaches to lowering emissions, increasing their sales. This adaptability of ETS could improve firms' innovation activities, including green innovations, through the motivation of cost reduction (M. J. Yang et al., 2021), increase firms' profitability (Ahmad et al., 2019), and productivity by optimizing resource allocation and reconfiguring products and processes (D. Q. Shi et al., 2022; Si et al., 2021), and thus improve firms' financial performance (Canon-de-Francia & Garces-Ayerbe, 2019; Javeed et al., 2020; Xing et al., 2020). Consequently, it helps to promote a firm's competitiveness (Zheng et al., 2020) and ability to compete in the market (Ning et al., 2022). However, the overall effect of the ETS on firm-level innovation activities and market competitiveness in the US remains unidentified since most research has only examined the EU-ETS or the CN-ETS.

On the empirical evidence side, a vast body of literature has investigated the innovative effects of such a policy. Most studies have examined the eco-efficiency theory, more commonly known as the Porter hypothesis, by splitting it into "weak version" and "strong version" categories. Some studies suggest that the emissions trading program is a major driving force of technological innovation or green (low-carbon) innovation in the case of the 'weak version' (Borghesi et al., 2015; Calel, 2020; Calel & Dechezlepretre, 2016; Fang et al., 2021; Shen et al., 2021; L. Zhang et al., 2019). Albeit, other studies do not support this view (Z. F. Chen et al., 2021; M. G. Tang et al., 2021), and the results for the innovation effects of the policy tend to differ according to the design factors (Herman & Shenk, 2021; Xu et al., 2019). Moreover, these studies are mainly concentrated on the European Union Emission Trading System (Borghesi et al., 2015; Calel, 2020; Calel & Dechezlepretre, 2016; Parry, 2020; Verde et al., 2021) or Chinese Pilot Emission Trading Schemes (Z. F. Chen et al., 2021; Fang et al., 2021; Shen et al., 2021; M. G. Tang et al., 2021; L. Zhang et al., 2019). Unlike other market-based policies, the US RGGI is based on paid allocation (full auction-based policy), which has not yet been explored. Thus, these results can provide empirical evidence of the impact of RGGI (as paid or fully auction-based policy) on firm-level innovation activities and market competitiveness, which helps to minimize the present policy dilemma. Also, this research provides better insights for policymakers and practitioners.

Concerning the "strong version," some studies have shown that market-based carbon policies (or ETSs) make firms more productive, profitable, and competitive (Canon-de-Francia & Garces-Ayerbe, 2019; L. Zhang et al., 2019; Y. Zhang et al., 2022), whereas other studies do not support this argument (Chan et al., 2013a; Joltreau & Sommerfeld, 2019; Y. J. Luo et al., 2021; Marin et al., 2018; Shen et al., 2021). Nonetheless, most of these recent studies only investigate EU-ETS or CN-ETS. On the other hand, some studies used the Porter Hypothesis to examine US environmental policies' effects. But, they only considered command-and-control environmental regulations such as US Clean Water Act (Earnhart & Rassier, 2016; Rassier & Earnhart, 2010a, 2010b, 2011), US Environmental Protection Agency's Toxics Release Inventory (TRI) program (Tang, 2015), US Clean Air Act (Ryan, 2012), Carbon tax (Rivers & Schaufele, 2015). However, command-and-control regulation has some significant distinct features (M. Peneder et al., 2022), which lead to different impacts on firm-level innovation and market competitiveness (Yi et al., 2019; J. M. Zhang et al., 2020; J. X. Zhang et al., 2020). However, firm-level studies investigating the "strong version" of the Porter hypothesis have been overlocked by classifying market-based policy as purely auction-based carbon trading. Thus, this study fills this gap and can enrich the market-based environmental policy literature by revealing the impact of US market-based regulation on firms' innovation activity and market competitiveness.

The findings of this research significantly help policymakers and practitioners to find the best framework for market-based policies to motivate firm-level green innovation without sacrificing the ability to compete in the market. First, RGGI is similar to other market-oriented carbon pricing schemes, such as the EU ETS and CN-ETS. Like the EU

ETS and the CN-ETS, the RGGI has the following parts: coverage, setting a cap, allocating permits, trading allowances, monitoring, reporting, tracking, and ensuring the regulated facilities follow the rules. Despite the similarities, the US RGGI has specific features that can affect the firm's innovation activity and market competitiveness differently than other major ETS programs, EU-ETS and CN-ETS. Notab*ly,* the initial allocation of carbon transaction quotas is vital in constructing the carbon market (Álvarez & André, 2015; Wråke et al., 2010). These quota allocation mechanisms can be roughly divided into two categories: paid allocation and free allocation. For example, the RGGI differs from the EU-ETS in that it has a fully working auction, and the EU-ETS lets old emitters keep their allowances for free, called grandfathering (Borghesi & Montini, 2016; Haapala, 2017). Free allocation relieves companies of the expense of obtaining permits on the carbon market, which may assist in mitigating the possible negative effect on regulated facilities (Joltreau & Sommerfeld, 2019). Another issue is the substantial over-allocation of all three phases of the EU-ETS. It indicates that firms may raise their revenues by selling their surplus permits, even if they get these permits for free. Other firms may save by buying carbon permits on the carbon market when prices decrease due to an oversupply. Based on the "polluter pays" or "auction and invest" principle, the main goal of the RGGI is to set up the state's carbon markets to ensure costs are spread out correctly and encourage investment to keep the system stable and working well.

In summary, global leaders confront dual challenges. Firstly, industrial expansion harms the environment and jeopardizes human civilization's future. Secondly, environmental regulations escalate compliance costs, impeding investment utilization and hampering long-term economic growth. The government faces a dilemma, selecting a potent policy framework to reconcile these opposing challenges. The Emissions Trading System (ETS) offers hope, an adaptive, economically viable market mechanism to combat emissions globally.

Conversely, firms' innovation enhances efficiency, cost-cutting, and competitiveness. However, realities contrast with optimism; CO_2 emissions decline within participating states but the surge in neighboring states (Fell & Maniloff, 2018). Few inventions are 'green', especially post-2010. The Porter hypothesis asserts that well-managed environmental rules foster innovation, bolstering performance and competitiveness. Scholarly testing of this hypothesis yields mixed results. Most studies focus on free allocation-based schemes, criticizing ETS for inconclusive outcomes due to over-allocated carbon allowances. Remarkably, scant evidence exists for paid or fully auction-based schemes. To address this gap, our study assesses the impact of the US RGGI, a fully auction-based cap-and-trade program, on firms' innovation and market competitiveness. This research surpasses measuring regulations' effects on firm-level innovation activities and evaluating how firms' innovation influences their competitive stance.

1.3 Research question

The relationship between the implementation of environmental regulation and firms' innovation activities has been explained in the original argument of the Eco-efficiency theory or the Porter Hypothesis. However, the authors examined the extended relationship between the market-based regulation or the ETS and the firm's green innovations. One possible reason may be the nature of market-based regulation, as it is also performance-based regulation, meaning that a firm must buy or participate in the auction trading permits if they exceed their cap limit and vice versa. Also, green innovation helped them to keep their emission low or within the boundary of the upper limit. Another possible reason may be the reimbursement of auction proceeds, where authorities provide direct or indirect incentives for green innovations in the regulated regions. Therefore, this study first measured the impact of the RGGI's deployment on firm-level innovation, then narrowing down to firm-level green innovations. As a result, this study called it the firm-level innovation activities (firm's total innovations and green innovations). This study aims to answer the following research questions:

1. What impact does the US Regional Greenhouse Gas Initiative (RGGI) have on firm-level innovation activities?
2. How does the US Regional Greenhouse Gas Initiative (RGGI) affect firms' market competitiveness?
3. How do innovation activities affect market competitiveness?
4. Does innovation and RGGI implementation moderate the relationship between innovation activities and market competitiveness?

1.4 Objectives of the study

As mentioned earlier, this study aims to measure the impact of US RGGI on firm-level innovation activities (including green innovation) and market competitiveness. Thus, all key variables are considered at a firm-level, especially for US-listed firms. Based on research questions led by research problems, research objectives are formulated as follows:

1. To examine the impact of the US RGGI implementation on innovation.

1a. To examine the impact of the US RGGI implementation on green innovation.

2. To evaluate the impact of the US RGGI on the market competitiveness.
3. To measure the relationship between innovations and market competitiveness.

3a. To measure the relationship between green innovations and market competitiveness.

1.5 Scope of the study

In the last few decades, and especially after the Kyoto Protocol, many countries and regions have passed different environmental laws to deal with the growing problems caused by climate change. The classifications of these rules include mandatory or voluntary, command-and-control or market-based, formal or informal, single or hybrid policies, etc. Market-based approaches have a political advantage over other forms of regulations and are widely accepted by many constituents because they can pay "double dividends". This generates chances to redistribute carbon revenue among citizens and stimulates investment in low-carbon technologies. It makes it easier to meet climate change or emissions targets.

The market-based policy is flexible because it gets money from auctions and gives direct and indirect incentives to regulated facilities for green projects that help meet environmental goals without hurting their ability to compete in the market. But market-based policies can be divided into free and paid allocation or auction-based policies. Free allocations like the EU-ETS and CN-ETS are based on grandfathering and benchmarking, which leads to overallocation. Even though these rules can help reduce the adverse effects of competition in the market, critics claim that they do not do enough to encourage firms to invest in the environment and develop green technologies.

On the other hand, policies based on paid allocations or full auctions (i.e., regional greenhouse gas initiatives) are simple and make it easy to set up quotas. Still, they are criticized for having higher operational costs and allowing carbon leakage. This research examines only the US Regional Greenhouse Gas Initiative (RGGI) as an auction-based carbon reduction program. Environmental regulations have a different dimensional effect. However, this study only evaluated the impact of RGGI on firm-level innovation activities and market competitiveness. The US RGGI has been introduced in 10 northeastern states of the US to control carbon emissions from the electric power sector. Thus, this study selected the 'Electric Power Generation, Transmission and Distribution (NAICS 2211)', and 'Natural Gas Distribution (NAICS 2212)' as regulated firms. This analysis solely analyses publicly traded companies (major U.S. stock exchanges) for more data similarity and reliability.

Innovation is expensive since it requires new ideas and patent filings. As a result, a company's financial health and ability to pursue innovation are closely linked. Meanwhile, more than 35% of the global top 100 innovating companies are US-originated, and most of these companies are ranked in the US F500 (Derwent-Index, 2019). Hence, choosing F500 companies is a good way to cover high-performing companies (based on total revenue) and patent activities. Therefore, this study considers the US Fortune 500 listed companies to investigate the policy spillover effects in non-regulated sectors. A company's patent registration is valid for 20 years, and it is essential to look at the balance before and after the RGGI comes into effect since the RGGI was introduced in 2009. This study considers the year 2000 to 2019 as the study period.

Different proxies have been used in the research to determine how ETS affects innovation activities at the firm level. However, each proxy has some advantages and disadvantages. For example, some studies used patent citations to measure firm-level innovation or innovation adoption (J. Hu et al., 2020; Nemet, 2012; Patel & Ward, 2011; Popp, 2002; Rong et al., 2017; D. Y. Zhang et al., 2019). Zhuge et al. (2020) recommended that invention patents are a true innovation. Also, most researchers used patent citations to measure innovation quality (Conti et al., 2018; J. Hu et al., 2020; Rong et al., 2017; D. Y. Zhang et al., 2019). This study considers the total number of yearly registered patents as a measure of a firm's innovation quantity. Then, it separates green patents, as defined by the World Intellectual Property Organization (WIPO), as a measure of green innovation at the firm level. Also, regulatory, and technological "push-pull" effects force a company to invest more in technological progress. It fails to take advantage of prospective investment possibilities, which may result in a decline in the company's productivity, sales, and market share. From this point of view, many studies have examined how the ETS affects a company's efficiency, total factor productivity, financial performance, and ability to compete in the market. Both financial performance and competitiveness have been criticized for being too broad and inadequate to measure a company's success. Hence, this study examines how RGGI affects the market competitiveness of a company in both regulated and unregulated sectors.

Companies must continue to improve their creative or innovative ability to succeed and remain competitive in the market. The market has acknowledged the value of technological innovation. Also, innovation helps the firm improve energy efficiency, which influences the firm’s competitiveness. Green innovation is also expensive for the company, making it harder to invest in new opportunities. On the other hand, a successful green innovation improves the quality of a product or process and makes a company more efficient. It gives the company a reputation for being green and a green image. In addition, green initiatives help firms show better concern for the environment (producing fewer hazardous products and services), social (raising public awareness of the environment), and economic benefits. As a result, it helps increase demand in the market and makes it easier for a firm to compete. From this point of view, this study also examines how innovation activities at the firm level (including green innovation initiatives) and market competitiveness are related. Many factors can influence the relationship between innovation activities and market competition. But this study only considers the technological lag effect, how innovative a firm is, and the effect of RGGI. These three things may significantly impact how innovation at the firm level affects market competitiveness.

1.6 Research hypothesis

In the late 1990s, Professor Porter and his colleagues argued that the costs of environmental regulation (ER). The Porter Hypothesis (PH) central focus is that proper implementation of ER requires a dynamic nature of strategy but supports improving business performance. More explicitly, an adequately designed environmental regulation may spur innovation ('weak' version), and flexible regulatory policies give firms greater incentives to innovate and thus are better than strict regulation ('narrow' version). Many authors empirically investigated the PH and concluded with supportive and unsupportive indications. However, PH testing in flexible ER like RGGI is not yet explored.

The central notion is that if the ER is flexible and strict (i.e., adequately designed and implemented), it can promote firms' innovation activities. Based on this notion, this study sets the first hypothesis (H_1) to examine the relationship between the RGGI deployment and firms' innovation activities (H_1-for regulated sector and H_{1a}-for non-regulated sector). In the recent literature, many scholars emphasize green or low-carbon innovation after EU-ETS implementation in 2005 and CN-ETS (pilot in 2013-14) as EU-ETS and CN-ETS are induced in market-based nature with a specific focus on green innovation. Similarly, the US RGGI has designed a market-based scheme and redistributed carbon auction proceeds to improve low-carbon or green innovation. Thus, this study considers the second hypothesis (H_2 for the regulated sector and H_{2a} for the non-regulated sector) to investigate the relationship between the RGGI deployment and the firm's green innovation activities.

Moreover, Porter's Hypothesis states that environmental regulation can increase firm competitiveness, also known as the 'strong' version. From this theoretical perspective, this study considers another hypothesis (H_3) to examine the impact of the US RGGI on firms' market competitiveness in the regulated sector. Also, it is evident in the empirical literature that a firm's proactive nature to adopt less hazardous environmental measures helps manage the upcoming regulatory push well and helps to get a first-mover advantage which assists in winning over competitors' rivalry. Thus, this study also investigates the impact of RGGI on firms' market competitiveness in the non-regulated sectors through another hypothesis (H_{3a}).

According to the Schumpeterian hypotheses, a positive relationship exists between market concentration and innovative activity, known as the 'Schumpeterian effect'. However, more recent works claim the relation between innovation and competition follows an inverted u-shape, also known as the 'Competition escape effect'. The 'Competition escape effect' dominates for low levels, and the 'Schumpeterian effect' for high levels of competition; an intermediate degree of competition maximizes incentives for innovation. To resolve these inconsistent findings, researchers have called for a contingency approach. The goal of this approach would be to allow for factors that moderate the relationship between competition and innovation. Based on the overall theoretical discussion, it is evident that firms' innovation activities significantly impact firms' Thus, this study aims to examine the extended relationship between firms' innovation and market competitiveness in H_4. This study also explores the relationship between firms' green innovation and market competitiveness in H_5.

According to a recent literature survey, it is evident that regulatory push significantly and separately influences a firm's innovation or green innovation activities and its ability to compete in the market. However, very few studies have emphasized the moderating role of market-based carbon reduction initiatives between innovation or green innovation and market competitiveness. From this perspective, this study intends to examine the moderating influence of RGGI between the firm's innovation activities and market competitiveness exhibited by H_6 and the firms' green innovation activities and market competitiveness shown by H_7. Leading to the research questions and objectives, this study underlined the following hypotheses as follows:

H1: The RGGI has a significant and positive impact on innovation in the regulated sector

H1a: RGGI has an impact on innovation in the non-regulated sectors

H2: The RGGI has a positive and significant impact on green innovation in the regulated sector

H2a: The RGGI has an impact on green innovation in non-regulated sectors

H3: The RGGI positively affects the market competitiveness in the regulated sector

H3a: The RGGI has an impact on the market competitiveness in non-regulated sectors

H4: Firm-level innovation promotes the market competitiveness of US firms

H5: Firm-level green innovation promotes the market competitiveness of US firms

H6: RGGI moderates the relationship between innovation and market competitiveness of US firms

H7: RGGI measures the relationship between green innovation and market competitiveness of US firms

1.7 Contribution of the study

This study advances existing literature by examining market-based regulations' impact on innovation activities including green innovation. The 'weak' Porter Hypothesis asserts that strict yet flexible environmental rules foster innovation; although some studies support this, others do not, often focusing on programs with free allocation (W. Mbanyele & F. Wang, 2022; Michael Peneder et al., 2022). In contrast, the US RGGI operates via paid or auction-based allocation. While RGGI effects have been studied in various domains, including emissions and health benefits, its influence on firm-level innovation, especially green innovation, remains unexplored. Based on the findings, this study contributes in the following ways:

1. Compare to freely allocated policies such as EU-ETS and CN-ETS, this study investigates the relationship between the implementation of RGGI (a full auction-based environmental policy) and firm-level innovation activities. Thus, the results of this study provide empirical evidence of market-based environmental policies.
2. This study also explores the impact of RGGI implementation on regulated and non-regulated sectors, measuring both direct and indirect effects. Previous research has studied regulatory effects on various sectors and areas (Hao & Li, 2020; Li et al., 2021; Lyu et al., 2020; Qu et al., 2022). Limited conclusive evidence exists about ETS effects on firms' green initiatives, warranting comprehensive exploration. Environmental regulations' spillover effects extend to non-regulated sectors (Heras-Saizarbitoria et al., 2015), while heavily polluting firms proactively adopt voluntary compliance for industry legitimacy (Ramanathan et al., 2017; Skjærseth, 2013; Skjærseth & Skodvin, 2018). This study enriches policy spillover literature, illustrating RGGI's influence on innovation and green practices in the unregulated sector.

This study's second objective examines the influence of RGGI on firms' market competitiveness. It delves into the effects within both regulated and unregulated sectors. While past research has investigated ETS impact on competitiveness, this study expands the concept to include a wider spectrum of competitive factors, focusing on a firm's ability to innovate and outperform rivals (Cui et al., 2021; El Amrani et al., 2021). By exploring these dimensions, the research enhances understanding of RGGI's direct impact on regulated sector competition and its spillover effects in the non-regulated sector. Most major ETS systems are criticized for free permit allocation or over-allocation that leads no or insignificant effects on market competitiveness.

3. This study evidenced that fully auction-based carbon trading policy has a positive and significant effect on the market competitiveness of firms in the regulated sector, which is a new addition to the market-based policy evaluation literature.
4. Also, the present study also revealed policy spillover effects in the non-regulated sector, enriching the policy spillover literature of market-based environmental policy.

In the third objective, this study measures the relationship between innovation activities and market competitiveness. Additionally, this study examines the moderating effects of RGGI implementation and a firm's innovativeness on the relationship between firms' innovation activities and their ability to compete in the market. The findings contribute to understanding the impact of innovation at the firm level, assisting management in maintaining their market position with novel and green innovations in the following ways.

5. The results of this study contribute to the literature on 'innovation' and 'green innovation' by revealing empirical evidence of highly innovative firms in the US (as F500 firms are mostly among the top 100 innovative firms listed in the 'Dervent Innovation Index').
6. This study examines how RGGI moderates the relationship between firm innovation activity and market competitiveness. The statistically significant negative moderating effect indicates that RGGI weakens firms' market competitiveness through innovation, providing evidence of a fully auction-based policy.
7. This study also examines the moderating effects of 'Innovativeness' and found statistically significant positive effect, indicating that innovative firms retain

existing market opportunities more than less-innovative firms. Thus, this is also an exciting contribution to the current literature.

Furthermore, methodologically, this study employs the 'Synthetic Control Method (SCM)' to explore the connection between RGGI deployment and firms' market competitiveness. SCM is valuable when utilizing a composite of regions rather than a single one, providing a more realistic intervention assessment (Abadie et al., 2010). This non-parametric approach extends conventional Difference-in-Differences (DID) by using objective data for control group weighting, defining their contribution to the counterfactual state, and preventing excessive extrapolation. While SCM has been utilized to assess regional environmental regulations' outcomes, often at macro-levels (Kim & Kim, 2016; Lee & Melstrom, 2018; Maguire & Munasib, 2016, 2018; Wen et al., 2021; Xiang & Lawley, 2019), this study uniquely applies SCM to measure the micro-level impacts of market-based regulation on firms' market competitiveness, contributing to the literature.

1.8 Chapter conclusions and thesis outlines

This chapter mainly initiated the study by illustrating the topic, background, problem statement, research questions and objectives, the scope of the study, and the significant or potential contributions to the body of knowledge and their implications. The following chapter discusses the recent literature by emphasizing the theoretical background and hypothesis development. Finally, this chapter states the organization of the whole thesis. The literature review is explained in Chapter two, followed by methodology in Chapter three, analysis of results in Chapter four, discussion of findings in Chapter five, and conclusion and policy implication in Chapter six.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter contains several sections to provide a comprehensive literature overview of this research. There are many well-known ways to do a literature review, like the "bibliometric," "scientometric," "meta-analysis," "systematic literature review," and "integrated literature review" methods. This study considers the 'Integrated Review (IR)' to construct a literature review. The current section used a ten-step Priority Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method to select publication records to organize a literature review of these studies. The PRISMA flowchart for the integrated literature review is portrayed in Appendix A. An integrative review (IR) takes a broad approach and considers diverse samples with mutually exclusive empirical, theoretical, or both literature (Cooper, 1984). IR offers a more comprehensive synthesis of empirical research and methodological and academic contexts literature (Whittemore et al., 2014). This study looked at the specific keywords from the research questions for the literature search. The keywords chosen for this literature review are listed in Appendix B. Also, this study follows the eligibility criteria illustrated in Appendix C, including the exclusion and inclusion process guided by Turin et al. (2020).

There are two specific reasons to consider for this integrative review process in this study. First, this study used a comprehensive literature review process to clarify conceptual interchangeability issues and theoretical literature related to environmental policy impact analysis works. According to Whittemore and Knafl (2005), an integrated review is best designed to review experimental and non-experimental research at the same time, which aims to specifically define concepts, review theories, review evidence, point out gaps in the literature, and analyze methodological issues. Second, to compare market-based policies such as CN-ETS, EU-ETS and RGGI, this study uses some "grey" literature (unpublished theses or research papers; conference presentations and online documents) to reveal specific characteristics. Oermann and Knafl (2021) recommended the use of integrative review processes when the literature deserves to be considered 'grey' documents. Moreover, the use of integrative review is essential when the researcher wants to examine the literature evaluating both qualitative and quantitative research to reach his conclusions (Dhollande et al., 2021). Therefore, this study decided to use the integrative review method to define some topics and ensure the comprehensiveness of the literature to reveal the theoretical background of this study.

In the second section of this chapter, each objective is described in terms of its theoretical foundation. After that, hypotheses have been developed based on a summary statement of evidence from recent research. Each section contains subsections, such as key variable definitions, conceptual differences in variables and their relevance to environmental regulations, control characteristics, firm-level innovation, green innovation, and market competitiveness. Then in the third section, 'Research Framework' is presented and explained. This chapter concludes with the 'Summary and Conclusion' section.

2.2 Relevant theories of environmental policy, innovation, and competitiveness

This section briefly presents the theoretical basis of this study. The section explains the main theoretical foundations of this study. Further, the study highlights the essence of the under-listed theories in achieving the study's objectives. Additionally, this study briefly explains the theoretical rationale before discussing the empirical findings of previous research on each objective.

Traditionally, environmental protection has been considered an additional cost for companies that can reduce competitiveness. Also, it forces firms to put some resources (labor and capital) toward reducing pollution, which is less productive for businesses, even if it helps the environment or public health. Technical standards limit the selection of technologies or inputs for the manufacturing process. Specifically, taxes and tradeable permits penalize businesses for pollutant emissions, a traditionally free consequence of the industrial process. These fees drain funds away from profitable investments.

Professor Michael Eugene Porter questioned the traditional view of how environmental regulations affect businesses. He argued that well-designed regulations could make businesses more competitive. Porter states, "Strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it" (Porter, 1991a, p. 168). Mostly based on case studies, they claimed that pollution is often a waste of resources and that reducing pollution can help better use resources. They also claim that adequately designed environmental regulations (like carbon pricing) can "trigger innovation [broadly defined] that may partially or [in some instances] more than fully offset the costs of complying with them" (Porter & Van der Linde, 1995, p. 98). Admittedly, for-profit businesses would take advantage of pollution-cutting possibilities if they existed. Several papers have been discussed over the last three decades regarding what is now referred to as the Porter Hypothesis (PH). Even now, many academics misinterpret what PH means and do not mean, and they explain many inconclusive ideas and findings.

Nevertheless, Porter was not the first person to dispute what most economists thought about the cost of regulating the environment. There have been calls for stricter regulations on polluting industries since at least the nineteenth century (Desrochers & Haight, 2014). In the 1980s, many academics started examining whether or not ER could encourage technological innovation without hurting competitiveness (Ashford, 1993). John Hick's "Induced Innovation Hypothesis" (IIH) says that technological change is a process that can be affected by economic policy. It is based on the idea that pricing carbon through a carbon tax or emissions trading can lead to new low-carbon technologies. The IIH argued that when the price of a production factor goes up, people are more likely to come up with ways to use it less (Hicks, 1932). However, The IIH's application goes beyond market-based strategies and environmental policy.

Moreover, the British-American economist Ronald Coase developed the "Coase theorem" in 1960. It was not a formal regulatory structure but opened the way for market-based or incentive-driven frameworks later. It proposes that environmental problems are the result of environmental externalities created by economic progress and that environmental problems can only be remedied fundamentally by internalizing external costs (Coase, 1960). This concept has given the theoretical groundwork for the adoption of emissions trading (Y. J. Luo et al., 2021). Unfortunately, since the basic assumption of the Coase theorem, "costless discussion", often falls short, the theory is generally not applicable as a real-world solution (Naegele, 2018). However, academics have evaluated environmental issues from diverse perspectives, such as Pigou's "externality" (Pigou, 1920), Coase's "transaction cost" (Coase, 1960), Arrow's "information asymmetry" (K. Arrow, 1962), and North's "free rider" (North, 1981), all of which presented novel viewpoints but overlooked the influence of technology or technical advancement.

Furthermore, although they did not consider the impact of technological innovation, some authors introduced emission pricing or trading to reduce environmental pollution cost-effectively. The origin of emissions trading was stated by Demsetz (1967), who argued that externalities should be internalized by allocating property rights. Subsequently, Crocker (1966) and Dale (1968) are credited as being the first to suggest emissions trading as "cap-and-trade." Montgomery (1972) was the first to prove that it was cost-effective.

In contrast, the central focus of the Porter Hypothesis (PH) is that proper implementation of ER requires a dynamic nature strategy but helps improve business performance (Porter, 1991c). Followed by Porter and Van der Linde (1995, pp. 99-100) exert six channels that ER can serve i) *signaling* for resource inefficiency and potential for technological improvement, ii) enhancing *corporate awareness* that helps to improve corporate environmental responsibility, iii) *reducing in uncertainty* which ensures more investment, iv) increase innovation pressure, v) *leveling* the transitional *playing field*, and vi) *improve environmental quality*. Jaffe and Palmer (1997) explained the PH by separating it into three versions: weak, strong, and narrow.

- *"**Weak** version"- properly designed environmental regulation may spur innovation.*
- *"**Strong** version"-environmental regulation can lead to an increase in firm competitiveness.*
- *"**Narrow** version"- flexible regulatory policies give firms more significant incentives to innovate and thus are better than authoritarian forms of regulation.*

Porter (1991b) urges policymakers to assess the anticipated effects of their actions and choose those regulatory tools, especially economic instruments, that will support productivity and competitiveness. Lanoie et al. (2011) also supported the "narrow" version of the PH, which is very impressive. This shows that laws that are more flexible and based on the market may work better than traditional command-and-control. Therefore, the "narrow version" reiterates the economist's desire for market mechanism over command-and-control measures (Ambec et al., 2013).

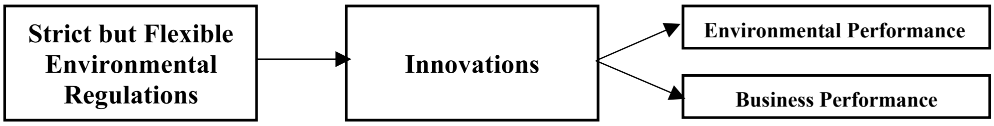

Figure 2.1: Schematic representation of the Porter Hypothesis

[Source: (Ambec et al., 2013)]

Alternatively, voluntary environmental regulation positively affects firm performance, supporting the Porter hypothesis's narrow version (Wang & Lin, 2022). Voluntary regulation benefits the actual firm performance in two ways: firms get the flexibility to avoid unnecessary compliance costs and could significantly encourage innovation, and innovation promotes firm performance (Bu et al., 2020). Additionally, voluntary regulation enhances investors' expectations for the performance of the company by strengthening its reputation (Wang & Lin, 2022). However, voluntary environmental regulation creates the free rider problem and immediately hurts the company's market share (Chandra et al., 2010). Standing on the bottom line, like the "narrow" and "weak" version that ER stimulates innovation, this study also intends to measure the effects of the US RGGI on firm-level green innovation.

Porter and Van der Linde (1995) explained that ER can stimulate "innovation offsets" if adequately designed. As a result, innovation offsets can simultaneously improve ecological performance and partially or fully offset the extra cost of compliance, leading to better business performance. They also argued that the "narrow" version should be focused on strict but flexible regulations. The interlink among all three versions of PH was first presented in Figure 2.1 by Ambec et al. (2013). However, the Porter Hypothesis was emphasized more in the climate economics literature after market-based regulation had become more popular, especially in the last five years.

2.2.1 Recent extension of the Porter Hypothesis

Experimental testing of the PH has increased significantly in the last decade. The publication trends of full-length articles (published in the Web of Science database) emphasizing the Porter hypothesis are illustrated in Appendix E. The keywords 'innovation' and 'competitiveness' were combined with the Porter hypothesis to improve the consistency of the comprehensive literature review of published records. This study chooses a few recently published papers summarized in Appendix F to test the Porter hypothesis and show how environmental regulations affect innovation and competitiveness.

2.2.1.1 Extension of the "weak" version of the Porter Hypothesis in recent literature

Numerous studies examine the "weak version" of the PH, which states that well-crafted environmental legislation can stimulate innovation (the relationship between the first two steps in Figure 2.1). The expanded Porter hypothesis diagram shows that the environmental regulation and innovation categories are expanding. In practice, innovation is usually measured by the amount spent on research and development (the input) or the number of registered patents for innovations and the total number of green patents for innovations that are good for the environment (the output of Research and Development investment). As Porter and Van der Linde (1995, p. 98) highlight, innovation is wider than only technological change. It can appear in many forms, including "a product's or service's design, the segments it serves, how it is produced, how it is marketed, and how it is supported."

Some recent studies have evaluated innovation through R&D expenditures or the number of patents (Bu et al., 2020; Z. F. Chen et al., 2021; Javeed et al., 2021; Ning et al., 2022; Ouyang et al., 2020; Q. Z. Yang et al., 2020). However, in the early days of testing the Porter hypothesis, authors used proxies to quantify the influence of environmental regulations on innovation activity or behavior at the firm level. Most recent studies used panel treatment effect models (such as DID, PSM-DID, SCM, 2SLS, or System GMM) to separate the treatment and control groups via the policy interaction variable (a dichotomous variable). In addition, total registered green patents were used to measure firms' green innovation. However, in some cases, authors misinterpreted the empirical results concerning the Porter Hypothesis; they usually overlocked data, methodology, timing, and firm, industry, and environmental characteristics that may influence the firm's innovation behavior and productivity or competitiveness (Ambec et al., 2013; OECD, 2010).

For instance, G. Q. Hu et al. (2021) examined the impact of Chinese green credit guidelines on the green innovation of heavily polluting enterprises and found supporting evidence for the "weak" version of the Porter Hypothesis. Also, Fang et al. (2021) found similar results in the case Chinese Environmental Protection Law on corporate green innovation of Chinese listed firms. However, the "weak" version of the PH was not supported in the case of Chinese pilot emissions trading schemes and innovation (M. G. Tang et al., 2021) and green innovation (Z. F. Chen et al., 2021). Concerning the relationship between environmental regulations and city or provincial technological innovations, most of the evidence from China supports the "weak" version of the Porter Hypothesis (Chen et al., 2022; Dou & Han, 2019; Fan et al., 2021; Nie et al., 2022; Wang & Liu, 2020). In the case of country comparison, Martinez-Zarzoso et al. (2019) and Guarini (2020) investigated the 14 OECD and 23 European countries, respectively, and found supporting the conclusion of the "weak" version of the Porter Hypothesis. Therefore, based on recent global testing evidence of the Porter Hypothesis, it found the supporting stance that environmental regulations promote innovations.

2.2.1.2 Extension of “strong” version of PH (Firm-Level Performance)

The "strong version," often assessed by a company's performance or productivity, is evaluated without examining the source of variance in business performance (i.e., whether it is related to innovation or other causes). In the recent literature, the ‘strong’ version of the PH was tested in terms of competitiveness (Zheng et al., 2020), market competition, profitability (Ahmad et al., 2019; Naso et al., 2020), total factor productivity (Ghosal et al., 2019; D. Q. Shi et al., 2022; H. L. Tang et al., 2020), market competitiveness, efficiency (Feng & Li, 2020), and economic and financial performance (Gu et al., 2022; Javeed et al., 2020; X. T. Liu et al., 2022; Xing et al., 2020).

The majority of research indicated that the "strong" version of the PH is supported, i.e., environmental restrictions enhance company performance. However, H. L. Tang et al. (2020) investigated the effect of command-and-control regulation on the total factor productivity of businesses using the DID method. They found that the "strong" version of the PH was not supported. In other words, they concluded that CCR significantly impeded the growth of Chinese manufacturing firms' total factor productivity from 1998 to 2007 and that this was a persistent issue. Another study by Naso et al. (2020) found a similar result. They also considered the study period from 1998 to 2007, but they investigated Chinese industrial enterprises, unlike the previous study. Unfortunately, these two studies do not consider any other issues linked to productivity. However, one recent study by D. Shi et al. (2022) investigated the effect of CCR on a firm’s productivity with DID method and found a positive relation. They consider the period from 2003 to 2012, unlike the previous two studies (from 1998 to 2007), indicating that some other cause may influence negative findings. Therefore, based on the results of recent studies, this study can assume that environmental regulation helps improve business performance.

2.2.1.3 Extension of "narrow" version of PH in the recent literature

Environmental laws and regulations require three significant stages, environmental rules as goals in flexible methods (Porter & Van der Linde, 1995, p. 110). Followed by Jaffe and Palmer (1997, p. 610) stated that "the "narrow" version of the hypothesis is that certain types of environmental regulation stimulate innovation… almost all existing US environmental regulations are not of this type…". Meanwhile, the first environmental regulation, Clean Air Act, was introduced in 1970 to curb US air emissions. However, the US RGGI is the first mandatory market-based regional regulation implemented in 2009 in regulated states to reduce GHGs from the electricity sector in the US, relying entirely on auctions to distribute emission allowances. RGGI is designed as a cap-and-trade program, which refers to establishing a limit or 'cap' or 'upper limit' on GHG emissions. Ambec et al. (2013) provided the most straightforward understanding of the "narrow version" of the PH. They said that policies with flexible rules give companies a lot of reasons to come up with new ideas and are, therefore, better than policies with strict regulation*s.* Indeed, Porter (1991b) urges regulators to think about the likely effects of their actions and choose those regulatory tools, especially economic ones, that will encourage innovation and competition. Consequently, the "narrow version" of the PH restates the economist's choice for market-based regulation over command-and-control measures.

2.2.2 Summary of the extension of Porter Hypothesis

This study extends from Figure 2.1 to Figure 2.2, as Ambec et al. (2013) suggest, to illustrate versions of the Porter hypothesis. Figure 2.2 summarizes the main new causal links in all three 'versions' of the PH. According to the Web of Science database, the recent trend of publications emphasizing the PH is presented in Appendix E. Based on recent research, and this study restates the "narrow version" by using the dotted line in

Figure 2.2 to link market-based environmental regulation, innovation, and firm performance. Recent research has highlighted the "narrow version" as market-based, performance-based, and hybrid environmental regulations have become increasingly popular and politically acceptable. In the broader literature, authors have explored "narrow versions" focusing on macro or micro levels. For instance, Bel and Joseph (2018) found that EU-ETS has no significant impact on the low-carbon patents in the 28 European countries' energy sector. Another study by Ajayi and Reiner (2020) revealed no effects on technological innovation while comparing the energy-intensive and less-energy-intensive industries of 17 EU countries. Lin et al. (2019) found a significant positive effect when comparing ETS countries and non-ETS countries in the pulp-and-paper industry of 42 countries. In addition, Saether (2021) also confirmed the positive impact in the power sector of OECD and BRICS countries, and Zhang and Wang (2021) verified the significant effect in the aviation sector. In addition, Y. Q. Liu et al. (2022) also found the supported "narrow" version of the Porter Hypothesis while examining the CN-ETS in a Chinese provincial study. For firm- or facility-level cases (exclusively for Japanese regional ETS), most studies have concluded in favor of a "narrow version," as reported in Appendix F.

Some studies have examined multiple versions of PH at the same time, like combinations of "weak," "strong," and "narrow," according to Appendix F. Some papers also used more than one model to figure out how the policy affected issues, such as treatment effect models, static panel regression, and dynamic panel regression. The findings of the Porter hypothesis test are further affected by examining regulation in the context of several industries or sectors across different research periods. Therefore, this research summarizes the results of a current literature review in Appendix F and recommends considering all relevant aspects when assessing whether or not Porter's hypothesis is validated. Based on the above discussion of recent literature, this study provides strong evidence that environmental regulations, especially market- and performance-based (strict but flexible) regulations, encourage innovation, green innovation, business performance, productivity, and market competitiveness significantly.

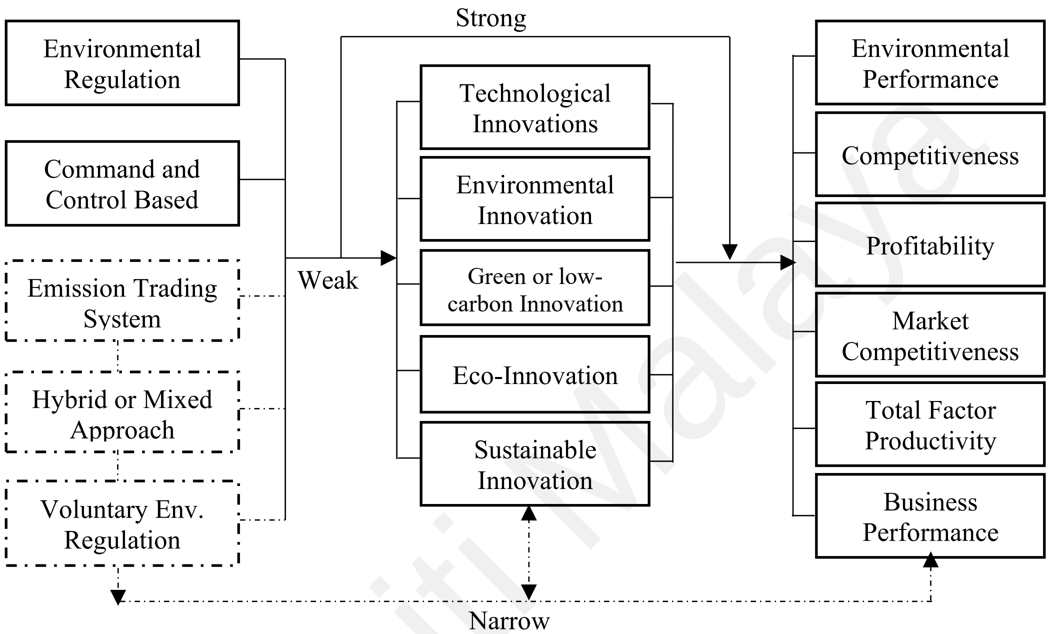

Figure 2. 2: New schematic representation of the Porter Hypothesis

Note:
Solid Boxes (left-hand side) denote comparatively more strict regulation than dotted boxes.
'Weak'-ER can spur innovations
'Strong'- ER can lead to enhance firm competitiveness
'Narrow'- Flexible policies give firms better incentives and foster innovation and competitiveness.

Like Figure 2.1, Figure 2.2 also states the "weak" version in the first two parts. This study distinguishes between types of regulation, such as command-and-control regulation (the solid line box on the left side of Figure 2.2) and flexible regulation (the dotted line box), and their impact on different types of innovation. In terms of the "strong version," Figure 2.1 only depicts environmental and business performance, but recent literature has expanded on many of the issues described in Figure 2.2. The line with dots at the bottom of Figure 2.2 shows the "narrow version" of the Porter hypothesis.

2.3 Related empirical findings of prior studies

This section explains the recent literature based on each relationship, examining each objective separately. Also, the statement of hypothesis development based on the results of previous empirical research is explained in this section.

2.3.1 Relationship between market-based environmental regulation and innovation activity

This section reviews key concepts for determining how the “Market-Based Environmental Regulations (MBR)”, such as US RGGI, EU ETS, CN-ETS, and other comparable systems, affect innovation at the firm level. This section outlines a combination of four sub-sections. The first section explains the conceptual differences between invention, innovation, and adoption. Next, the distinction between command-and-control and market-based regulation is presented in the second section, as they affect firm-level innovation differently. In the third and fourth sections, this study describes the theoretical relationship between MBR and innovation at the firm level, as well as recent empirical evidence and the development of hypotheses.

2.3.1.1 Interchangeability issue of innovation

In the extended technological innovation literature, "innovation" has somewhat different characteristics than invention and adoption. Notably, the characterization of ‘invention’ and ‘innovation’ was discussed in the IRI-1970 annual meeting (Roberts, 2007). In the end, they came up with the well-known definition that innovation is the combination of two activities that happen in order: (i) coming up with a new idea or invention and (ii) turning that new idea or invention into a business or other good use. Schumpeter (1934) elucidated that invention creates technological feasibility, which requires appearing and ensuring its transaction in the marketplace before it can be treated as an innovation.

Roberts (1988) stated "innovation" has two parts: "invention" and "exploitation." He described "invention" as a multi-step process that focuses on making a new idea work. In the same way, "exploitation" has many steps that focus on commercial development, application, idea transfer, and putting the new product or process on the market. In the economic sense of 'invention and innovation,' a business entity engages in systems when an invention is forwarded or introduced to the customer or market.

However, the phrase "adoption" is new to the acquiring company ("new-to-firm") but not to the rest of the world ("new-to-market") (Kemp, 2010; Kemp & Pontoglio, 2011). Therefore, invention, innovation, and adoption happen at different stages of the innovation process. For example, invention is creating a new idea, innovation is developing a new idea or idea for commercialization, and adoption is when other firms accept the innovation (more definitions are in Appendix D). In this study, innovation is defined quantitatively as patenting activities at the firm level that are recorded in well-known patent databases like the USPTO and EPO.

2.3.1.2 Environmental regulation vs market-based environmental regulation

Since 1970, many governments have passed environmental laws and regulations to reduce the negative effects of businesses on the environment and make them more environmentally aware. Many experts believe ER is the most important legal tool to stop environmental damage. For example, Frondel et al. (2007) said that government environmental policy is the primary factor in ecological innovation. Environmental regulation should improve environmental quality and efficiency, minimizing regulatory enforcement costs (Ribeiro & Kruglianskas, 2015). Recently, Sun et al. (2019) stated that environmental regulation mitigates severe pollution problems. In the context of carbon neutrality, Wu and Lin (2022) considered ER as a double-edged sword that is a key tool for achieving sustainable economic and social development.

Many governments have enacted ER to control ecological risks in the last few decades, especially after the Kyoto Protocol and the Paris Climate Agreement. Scholars classified these regulations into various dimensions. In a broader sense, these can be classified as mandatory and voluntary environmental regulations (Ren et al., 2018; Wang & Lin, 2022; Y. Zhu et al., 2019). The term "mandatory regulation" is used to describe the system of laws, regulations, and standards put in place by governments to compel businesses to reduce their environmental impact or face penalties such as fines or even shutdown (Wang & Lin, 2022; D. You et al., 2019). In contrast, voluntary regulation comes from top managers caring about protecting the environment (Lim & Prakash, 2014) and giving incentives, but not rules, for controlling pollution (Jiang et al., 2020).

These policies are divided into formal and informal (Song et al., 2019). Others are categorized according to their legal status, such as mandatory, participatory, and voluntary. A few authors also classified "mandatory regulation" (i.e., "environmental regulation," "command and control-based," "market-based emission scheme or cap-and-trade mechanism or emission trading schemes," and so on), "participatory regulation" (i.e., "R&D subsidies," "pollution incentives," and "voluntary regulation" (Y. S. Luo et al., 2021; Qu et al., 2022; Reichardt et al., 2017; Shen et al., 2020; P. Wang et al., 2021). Many scholars classified mandatory regulation into command-and-control, market-based, and hybrid environmental regulation (Gimenez & Rodriguez, 2010). Moreover, many developed and developing countries have enacted some combined regulatory strategies. For example, China induced three kinds of environmental rules: economic, legal, and regulatory policies (Liu et al., 2018). Environmental policies have been put in place at the federal, state, county, and city levels in the United States. These policies combine command-and-control, market-based trade, and voluntary regulation.

A "command-and-control rule" (CCR) is a statutory environmental policy that controls pollution by regulating the manufacturing process, employing resources, or other commercial actions that influence the environment at a certain time or location (K. Tang et al., 2020). On the other hand, Popp (2019) argued that CCR directs a specific performance level. As opposed to this, "market-based regulation (MBR)" provides a monetary value to emissions by the imposition of taxes or levies, such as a carbon tax, or through the allocation of tradable allowances between businesses entities (Popp, 2019), such as EU-ETS, RGGI, and CN-ETS. Likewise, A MBR is a similar mechanism the government uses to incentivize pollutant reduction among firms using market signals (Cheng et al., 2017). To coordinate the environmental behavior of firms, the government may either create a market (emission trading) or use an already existing market (through pollutant discharge fees and environmental taxes) (K. Tang et al., 2020).

Experts have claimed that market-based regulations offer more significant incentives for innovation. Fundamentally, this practice meets three of the five features the authors said were necessary for emissions trading. These are flexibility, frequency, and depth. "Flexibility" means if the policy encourages people to come up with new ways to reduce pollution, "incidence" means how closely the policy targets pollution, and "depth" means if the policy gives people a reason to keep coming up with better ways to reduce pollution. The opposite is true for the last two features: stringency and predictability. The stringency and predictability of an ETS rely on its particular design (Teixido et al., 2019). The carbon ETS, which allows firms to buy CO2 emission credits to get permits for GHG emissions, effectively cuts down on GHG emissions, especially global CO2 emissions (Liao et al., 2015; Liu et al., 2015). This study considers market-based regulation as economical, formal, flexible, and mandatory.

2.3.1.3 Properties of RGGI as market-based regulation

In January 2009, 10 northeastern states[1] agreed to use a cap-and-trade program called the RGGI to cut GHG emissions from the power sector. The goal was to encourage regulated firms to cut CO2 emissions through market mechanisms and cut costs even more. The RGGI was formed in 2009 from unique CO2 budget trading programs in each member state and associated management measures to establish an institutional foundation for executing the CO2 ETS (RGGI Inc., 2022a). Like the EU ETS and the CN-ETS, the RGGI has the following parts: coverage, setting a cap, allocating permits, trading allowances, monitoring, reporting, tracking, and making sure people follow the rules. However, RGGI started with a fully functioning auction compared to freely grandfathering allowances in EU-ETS (Borghesi & Montini, 2016). Hence, the RGGI caused a significant change in the power sector, making it easier for regulated firms to switch to cleaner technologies, push the power sector more efficiently, and turn it into a low-carbon industry through market mechanisms.

Based on the "polluter pays" or "auction and invest" principle, the main goal of the RGGI is to set up the state's carbon markets to make sure costs are spread out correctly and encourage investment to keep the system stable and functioning well. The market initially limits the aggregate quantity of GHG emissions (such as CO2, SO2, and NOx), gradually reducing over time (Lamb et al., 2021). Most of the time, these credits are used when a regulated entity manages and releases CO2. This is called "banking allowances." Credits were given out using a controlled auction and direct allocation for large companies or other entities needing stability. The main prerequisites for the market's

[1] Originally, ten states were listed: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont, and New Jersey, but New Jersey was dropped and returned in 2019. *Now, the participating states have become 11 as* Virginia became a participating state on January 1, 2021.

effectiveness, which the electricity industry meets, are various sources and emissions intensity. The market gives credit to the places where these emissions come from. This lets them release a certain amount of these gases per credit, often based on how much they have previously released. Credits issued by these sources may be traded on the open or secondary market (Luca et al., 2020). This market-based system promotes the most efficient businesses to utilize credits and penalizes those who emit them excessively. This technique enables the market to determine the most cost-effective strategies to reduce emissions. Eventually, it provides a sense of stability to market participants, stimulating long-term clean energy investments to improve the physical and social environment.

The RGGI CO2 cap establishes a statewide CO2 quota for the power sector. Initially, the RGGI cap was set at 188 million allowances for ten participating states in the first compliance period from 2009 to 2011. Recently, the RGGI authority increased the present CO2 emission ceiling to 116.11 million metric tons in 2022 from 119.77 million in 2021 for the eleven member states (RGGI Inc., 2022a). They also steadily cut the state's yearly CO_2 emission budget by 86.9 million metric tons by 2030 (RGGI Inc., 2022a). This continued cap reduction affects the permit clearing price, which has increased from $3.07 in the initial year to $13.50 in 2021. So, RGGI met its goal of cutting CO2 emissions from the electric power sector below 2005 levels by 2020, and it is expected to cut emissions by another 30% in participating states by 2030 (RGGI Inc., 2022a). According to the EIA, RGGI lowered CO_2 emissions from the electric power sector by around 50% in 2021 compared to 2005 (RGGI Inc., 2022a). However, this reduction in emissions could result from cheap natural gas prices, reduced consumption, or improved renewable energy capacity (Huang & Zhou, 2019).

The RGGI held 55 successful auctions and made $4.95 billion from the sale of 1.21 billion carbon dioxide permits (RGGI Inc., 2022a). They have committed to allocating all auction revenues to reduce GHG emissions through energy efficiency, renewable power generation, direct utility bill support, agricultural and household technology innovation, and other programs (RGGI Inc., 2022a). Energy efficiency, for example, accounted for 40% of RGGI spending in 2019 and 54% of total investment. More than 250,000 households and 1,400 companies in the area are estimated to save $553 million in energy costs over their lifetimes, preventing more than 1.5 million metric tons of CO2. From the 2019 auction revenue, they have spent 18% on developing renewable energy, 15% on projects to reduce greenhouse gas emissions, and 19% on helping people pay their bills directly. Because of these investments in technology and direct bill support, more than 2.51 million short tons of CO2 were not released in the states that took part. Therefore, this shows that RGGI, through the market mechanism, is creating favorable conditions for environmentally good technologies.

2.3.2 Relationship between market-based environmental regulation and green innovation

This section outlines some key concepts regarding the impact of MBR on low-carbon technological change. This section focuses on a) a conceptual explanation of green innovation, b) key features of an ETS that help it encourage low-carbon technological change, and c) recent empirical findings on the relationship between market-based carbon ETS and firm green innovation activities based on the Porter hypothesis.

2.3.2.1 Interchangeability issues of green innovation

The term "green innovation" is used interchangeably with "technological innovation" and other types of innovation, such as "eco-innovation," "sustainable innovation," etc., in the scientific literature about technological innovation and climate change. Developing a new idea or invention that can be turned into a business or other useful thing that can generate revenue for the inventor is known as innovation. "Green innovation," on the other hand, is usually defined as new products and processes that meet customer needs and increase business value while having a low impact on the environment (Fussler & James, 1996). Followed by some scholars defined the term GI exclusively concerning the environmental aspects (Driessen & Hillebrand, 2002). Likewise, green innovation should assist firms in complying with environmental standards through energy conservation, pollution prevention, waste recycling, green product designing, and organizational environmental management (Chen et al., 2006). Moreover, Bernauer et al. (2007) argued that GI might include new or modified products, processes, and more environmentally sustainable techniques throughout the product's life cycle (i.e., manufacturing process to residual disposal).

Green innovation, in general, is an innovation that mitigates adverse environmental effects. Several authors believe GI is synonymous with ecological, eco-innovation, low-carbon, and sustainable innovation. Many academics defined FGI as minimizing negative environmental consequences, generating economic gains, and distinguishing itself from other types of innovation. For instance, Environmental innovation is when new or better products, processes, techniques, and systems are made or changed to keep the environment safe (Horbach, 2008; Kemp & Pearson, 2007). Some researchers conceptualized eco-innovation by emphasizing environmental improvements and business or economic aspects (Hojnik & Ruzzier, 2016; Reid & Miedzinski, 2008). Others extend the coverage with social benefits (Kuo & Smith, 2018; Santos et al., 2019). Most scholars highlight environmental, economic, and social benefits to define sustainable innovation. Still, others added ethical issues, i.e., sustainable innovation should consider ethical aspects where economic, socio-cultural, and environmental aspects are balanced (Blok et al., 2015). As a result, the so-called interchangeability issue has no bearing on any innovation because they all have unique coverage features.

An invention is patented if it is economically feasible and deemed innovative. Many experts, however, believe that the economic benefits of pollution prevention measures are just as significant as the environmental benefits. According to Lee and Kim (2011), "green innovation" integrates manufacturer and supplier innovation activities that improve environmental regulatory compliance and achieve target economic success. Green innovation is a distinctive firm's invention that promotes new or improved products and processes, including technological, administrative, organizational, and marketing innovations, boosting the firm's environmentally conscious attitude, reducing environmental damage, and generating economic benefits.

In practice, firms cannot invest in options that do not offer value to the organization. For innovation to be worth investing in, it must provide a significant benefit. Management expects green innovation to earn financial rewards. Based on this perception, most firms have combined green innovation strategies to maximize the firm's economic performance and environmental constitutionality (F. Wang et al., 2020; Z. C. Zhang et al., 2019). Some authors define green innovation based on many other factors, as Appendix D illustrates.

Several proxies have been used in the past to quantify the firm's green initiatives. Decades back, many academics relied on the Pollution Abatement Costs and Expenditures (PACE) study to evaluate the environmental awareness of corporations. Inadequate data quality is to blame for PACE's inability to accurately reflect a company's green initiatives (Jaffe & Palmer, 1997). Appendix H shows the recent literature overview on measuring proxies for green innovation, low-carbon technological innovation, and eco-innovation activities. Some authors used green patents by separating them from the total patents through 'green keywords' to measure firm-level green innovation (FGI) (D. Y. Li et al., 2019; L. Zhang et al., 2019). But this proxy could be inappropriate for two reasons: first, a few words are insufficient to establish green identification. Second, it's more important to use the international patent classification (IPC), which the WIPO and OCED pushed for in 2010 and 2015. To avoid controversy, like Ghisetti and Quatraro (2017) and Z. Yang et al. (2020), this study quantified by counting the annual total green patent applications of each sample firm defined in WIPO's green inventory or IPC list for Environmentally Sound Technologies (ESTs).

2.3.2.2 Relationship between market-based carbon ETS and firm green innovation

In principle, ETS creates two competing streams for firm-level green innovation. Although the program does provide a means for firms to meet their pollution reduction targets, doing so by the purchase of allowances from other polluters reduces the incentive for these firms to pursue green innovation generally (Riehl et al., 2022). However, according to the PH, incentives for broad technical progress (Cohen & Tubb, 2018) and low-carbon technological change (Y. Q. Liu et al., 2022) are found in rigorous and flexible regulations, like the ETS. Furthermore, the ETS incentivizes allowance sellers to develop low-carbon technologies that lessen emissions and let them sell extra allowances in the market. Therefore, as shown in figure 2.2 (in the dotted line), the "narrow version " of PH says that flexible but strict regulatory policies offer firms better support and encourage green innovation and competitiveness.

Most of the time, the ETS is a flexible but mandatory policy that gives regulators and polluters certain benefits, such as cost-effectiveness, efficiency in reducing emissions, political acceptance, incentives for low-carbon energy and technology, harmonization with other similar regulatory frameworks, and the possibility of going global (EPA, 2022b; Jiang et al., 2016; Lyu et al., 2020). The EU was the first to create a carbon-only ETS, called the EU-ETS, which has since been used worldwide to reduce CO2 emissions. Followed by EU-ETS, the largest regional ETS in the US, called RGGI, started in 2009. Though its coverage is still limited, it is the first cap-and-trade system for carbon in the US (Luca et al., 2020). As previously discussed, the ETS works by giving CO2 a price, selling CO2 emission rights, and letting emitters trade reduction obligations.

Climate change policy talks are increasingly emphasising innovation, especially green innovation, as a way to cut carbon emissions (Metz et al., 2007). Green innovations reduce waste and pollution by making manufacturing more efficient and companies more sustainable (Qu et al., 2022; Suki et al., 2022). The 1990s were the start of research on "green innovation," which mostly means "green technological innovation." Many researchers defined green innovation by covering different aspects, which is reported in Appendix D. However, the present research defines "green innovation" as new or improved products and processes, such as technical, managerial, and organizational innovations that contribute to environmental sustainability (H. H. Weng et al., 2015). According to empirical research, green innovation successfully realizes the "win-win" of high-quality economic growth and environmental conservation (Yang, 2022). When properly configured, the ETS may employ price signals to facilitate a better match between technology and funding and to stimulate investment in low-carbon technologies.

Most ETSs implemented so far are pilot programs for specific regions of the country or sector(s) of the economy. As mentioned earlier, all ETSs have similarities, and policy experts also revealed distinct characteristics. According to floor auction reserve pricing, the major ETS programs, including the EU-ETS, RGGI, California and Quebec cap-and-trade, and CN-ETS, are comparable (Flachsland et al., 2020). But Quebec is different because of its ‘bilateral linkage’ with Californian cap-and-trade (Borghesi & Montini, 2016). Also, Korea's Emission Trading Scheme (KETS) and New Zealand's Emission Trading Scheme (NZ ETS) have some distinguishable features, such as extended coverage and the nature of distributing proceeds (ICAP., 2020). Hence, though many laws have been implemented globally in recent decades, each has diverse influences based on its goal, coverage, and path settings.

Researchers are particularly interested in market-based ERs due to their fast-growing nature and effectiveness in GHG emissions reduction. Also, the polluter-pays structure of ETS and the direct distribution of proceeds help people pay their energy bills and encourage companies to improve their green technology. This makes ETS politically viable (Ai et al., 2021). Scholars focused on environmental and economic concerns' direct and indirect implications to better understand the consequences. Researchers have empathized with GHG emissions (CO2, SO2, NOx), carbon leakage, energy efficiency, and fuel switching (Erdogan et al., 2020; Huang & Zhou, 2019; Ren et al., 2020a; Wang & Wang, 2020). Economic issues such as research and development expenditures, financial performance, and competitiveness are emphasized (Li & Lv, 2021; Qiu et al., 2020c). Still, the relationship between ETS regimes and firms' green innovations is less prioritized.

Few studies have examined how ETS regimes affect environmental or green performance at the firm level by comparing regulated and unregulated industries. Hence, several authors investigated how the implementation of regulations affected regulated and non-regulated sectors, cities, states, provinces, or countries (Hao & Li, 2020; Li et al., 2021; Lyu et al., 2020; Qu et al., 2022). However, this study does not try to broaden the scope of the literature review to include the effects of policies on the whole economy. Instead, it looks at the effects of market-based regulation on green innovation at the firm level. For example, the EU-ETS does not significantly reduce CO2 emissions in Lithuania (Jaraite & Di Maria, 2016) or improve the investment behavior of firms to adopt low-carbon technologies compared to non-ETS firms in regulated firms in Sweden (Lofgren et al., 2014).

In contrast, EU-ETS helps regulated firms improve efficiency, bringing positive economic benefits (Löschel et al., 2019). Compared to EU-ETS, energy efficiency was negatively pretentious to CN-ETS and varied based on industrial structure and techno-innovation (Liu, Ma, et al., 2020). Firms' green innovation was positively linked with CN-ETS implementation (L. Zhang et al., 2019). CN-ETS produced a considerable decline in enterprise innovation trends in environmental firms compared to non-environmental firms (Feng et al., 2017). There is still not enough conclusive evidence on how ETSs affect firms' green or environmental activities, so it is important to study the effects of different ETS regimes in different ways.

2.3.3 Relationship between market-based environmental regulation and market competitiveness

This section mainly discusses the relationship between market-based environmental regulation and the market competition of firms, including five different sections. Conceptual and measurement dilemmas between 'competitiveness' and 'market competitiveness' are discussed in the first sub-section. Followed by how the characteristics of ETS and RGGI relate to firm-level market competitiveness, hypothesis development statements are explained.

2.3.3.1 Measurement debate between competitiveness and market competitiveness

The terms ' competitiveness', 'competitive advantage', and 'market competitiveness' are used interchangeably in the literature. However, 'competitiveness' refers to the ability of a firm, individual, or economy to produce goods and services that meet the quality standards of the market and to do so at a lower cost than its competitors, thereby achieving a comparative advantage. It encompasses various factors such as efficiency, innovation, quality, and cost-effectiveness. 'Competitive advantage', on the other hand, refers to a specific aspect of a company's operations that allows it to produce goods and services more efficiently or at a higher quality than its competitors. This can include access to unique resources, proprietary technology, economies of scale, a strong brand, or superior management. Competitive advantage provides a company with a relative edge over its competitors and contributes to its overall competitiveness.

On the other hand, market competitiveness refers to a firm's ability to compete in a particular market. It is concerned with a firm's relative position in a market in terms of its ability to attract customers, generate sales, and achieve profitability. Market competitiveness is influenced by price, quality, brand image, product features, and distribution channels. It is a narrower concept that focuses on a firm's performance in a specific market rather than its overall competitiveness in the global economy.

Over the past 30 years, many researchers have investigated environmental regulations and their impact on competitiveness, but a clear definition has yet to be developed. Many researchers have used the term 'competitiveness' in their research but have not defined it (Dechezleprêtre & Sato, 2017; Demailly & Quirion, 2008). Measuring 'competition' is also controversial in economics (Meleo, 2014) and very complex to measure. This issue becomes more ambiguous when a study attempts to identify the impacts of ER and green innovation on competitiveness, especially when the authors consider the effects of regulation at the country, sector, and firm levels. Back in 2000, the understanding of 'Competitiveness' was straightforward: a country, a productive sector, and an individual firm's ability to sell its goods and services in the local and global markets (Barker & Köhler, 1998; OECD, 1993; Stewart, 1992).

Competitiveness at the firm level, various authors endeavored to explain firm-level competitiveness in different ways. According to Balassa (1962), a firm's competitiveness is the ability to sell its output in foreign and domestic markets. However, Jaffe et al. (1995) stated that the actual scenario of firms' competitiveness was impossible to measure because of poor data quality or insufficient data. They attempted to measure the competitiveness by the cost of environmental regulation, productivity, net export, and direct foreign investment but failed to provide an acceptable definition. Baron (1997) measured competitiveness by combining "micro" factors (like "cost structure," "product quality," "trademark, service, and logistical networks," and "employment") with "macro" factors (like "exchange rates" and "trade regimes."). Baranzini et al. (2000) defined competitiveness as the capabilities of a firm to maintain or enhance both global and domestic market shares and profitability.

Later in 2000, some studies focused not only on the definition but also linked various aspects of the firms' competitiveness and attempted to measure it differently. Previous literature used 'productivity', 'innovation', and 'international trade' as the competitiveness, which also sufficiently distracts to reveal the actual definition of competitiveness. For instance, Anger and Oberndorfer (2008) measured firm-level competitiveness using firm revenue and employment. Abrell et al. (2011) and Branger et al. (2013) worked on the impact of EU-ETS on competitiveness, where they calculated competitiveness by firms' added value, employment, and profit margin. Moreover, Chan et al. (2013b) determined the components of competitiveness through the combination of unit material cost, employment, turnover, and market share. Productivity and export intensity were used to calculate firm competitiveness by Stoever and Weche (2018), and Dechezleprêtre and Sato (2017) measured competitiveness with the combination of 05 variables, namely net trade, industry location, employment, productivity, and innovation.

In recent studies, authors measured a firm's competitiveness by covering many issues such as productivity (Rubashkina et al., 2015; Stoever & Weche, 2018), profitability (Joltreau & Sommerfeld, 2019), employment (Zhang & Duan, 2020), export performance (Liu & Xie, 2020b; Stoever & Weche, 2018), gross investment in tangible goods (Agovino et al., 2020), and market performance and intangible performance (Carmen Paola Padilla-Lozano & Pablo Collazzo, 2022). Based on the above discussion, competitiveness is a broader competitive shape at the macro and micro levels.

In contrast, few authors explained market competitiveness based on their measurement method. For instance, Jones and Sasser (1995) suggested measuring market competitiveness by providing alternative products, services, and benefit plans. However, Jia et al. (2011) used net profit margin to measure a firm's market competitiveness, representing the firm's efficiency and ability of internal resource utilization. In contrast, Jang et al. (2019) and Li and Wang (2019) measured market competitiveness by the firm's market share, indicating its ability to do business with its competitors. El Amrani et al. (2021) that a company's market competitiveness is determined by its ability to make products and services that are more innovative and better than those of its competitors. Likewise, Cui et al. (2021) defined the market competitiveness goal as reaching market goals, such as increasing market advantage, market share, market position, and profits. This study does not intend to prolong the conceptual discussion. Still, additional definitions are presented in Appendix D. Compared to competitiveness, and market competitiveness is a firm's ability to manage its resources well to maintain or surpass the competitor's performance.

Moreover, the authors recently focused on competitiveness, market competition, and market competitiveness in various sectors. They used common proxies like Herfindahl–Hirschman Index (HHI), Export growth, Sales Growth, Lerner Index, Employment, and PACE. Appendix I contains a table with information about recent studies and how they measured competitiveness, market competition, and market competitiveness. Following the previous studies by Fresard (2010), J. Hu et al. (2021), and Nguyen et al. (2021), this study considers that market competitiveness is a firm's ability to business activities within a market context considering the demands of products and services rendered to the market by complying with additional environmental compliance costs due to the implementation of the RGGI.

2.3.3.2 Properties ETS, RGGI, and Market Competitiveness

ETS is the fastest growing compared to command-and-control regulation. About 9% of the world's emissions are now covered by 23 ETSs in more than 80 jurisdictions (Luca et al., 2020). Through selling permits, the ETS essentially sets a price on GHG emissions. The regulated entities can get their emission permits in one of three ways: a) for free, through grandfathering, benchmarking, or output-based allocation; b) through auctions; or c) a combination of these two ways. Under "grandfathering", permits are granted in proportionality to past emissions. When using "benchmarking", permits are assigned based on measurable outcomes. Benchmarks (regarding emissions per production unit) are multiplied by current output levels to arrive at allocations. The "output-based allocation system" distributes permits in line with the quantity produced. Thus, the amount of production of the regulated entities directly affects how ETS is adopted. The economic reason for using free allocation is to minimize the risk of losing market share to cross boarder competitors (all the unregulated entities, either local or international) and to minimize the risk of carbon leakage. "Carbon leakage" refers to the dispersion of greenhouse gas emissions because of climate mitigation policy intensity variations. Hence, the properties of ETS are vital to promoting green innovation so that a firm can minimize the threat of losing market competitiveness and emissions leakage.

Additionally, ETS regimes reduce emissions reduction costs while increasing market liquidity through tradable CO2 permits, generating revenue from carbon allowances, and incentivizing green innovation, which all benefit the firm's operations

(Zeng et al., 2019). On the other hand, regulatory and technological pull-push effects help the firm improve product quality, specifically the environmental fitness of the product through pollution abatement efficiency or pollution emissions efficacy. This environmentally advanced product also enhances the consumers' demand thresholds and preferences, ultimately influencing the firm's market share and sales volume.

2.3.3.3 Distinction of RGGI from other concurrent ETS programs

As mentioned earlier, RGGI started in 2009 in 10 northeastern states to cut down on GHG emissions from the electric power industry, the most significant source of CO2 emissions in the US for the last 40 years. RGGI recognizes a cap-and-invest mechanism for establishing an enforceable regional ceiling on CO2 allowances generated by the power sector. Each RGGI state distributes most CO2 permits through quarterly regional CO2 allowance auctions. The concept of "cap-and-trade" is often used to describe a formal and mandatory regulatory scheme to limit the total amount of CO2 emitted by industrial activities. Firms that exceed the emission limit must purchase their CO2 allowances via an auction to avoid penalties.

As a result, doing so entails a financial burden in the form of lost revenue. Even while businesses do not give up earnings, it suffices to say that the cost of the pollution permit is passed on to the customer, which reduces the consumer's buying power or reduces market demand. Also, most of the auction proceeds are spent on energy efficiency, clean and renewable energy development, GHG abatement programs, and direct bill help. CO2 emissions in regulated areas are decreasing because of these initiatives, leading to better air quality in the same region. As a result, it has a significant impact on things like infant mortality (Lee & Park, 2019), child health benefits (Perera et al., 2020), and even overall health benefits (H. Yang et al., 2021). Also, these could help develop an understanding of green things or make people more likely to buy them, which could help reduce the risk of firm-level green innovation. Hence, the RGGI is vital to minimize the damage to the physical environment and plays an essential role in creating consumer environmental awareness and helping to ensure social wealth, including health benefits.

The RGGI is different from the EU-ETS in that it has a fully working auction, while the EU-ETS lets old emitters keep their allowances for free (Borghesi & Montini, 2016; Haapala, 2017). In addition, experts criticize free allowances because they would diminish financing for the development of low-carbon technology (Commission, 2014). Most of the emission permits regulated producers get under the existing EU ETS are free; therefore, passing down the opportunity costs of these allowances boosts their profitability (Chen et al., 2008). In turn, the combination of cost pass-through and free allocation led to gains that were not expected (Joltreau & Sommerfeld, 2019). Firms do not have to pay for their permits on the carbon market if they get them for free. This could help reduce the negative effects on regulated entities (Joltreau & Sommerfeld, 2019). "Overallocation" is a problem as well, and in the case of EU-ETS, it's a big one across all three stages. This implies that companies given free permits may still make money by selling their surplus permits to other companies. Because of oversupply, prices have declined, meaning other businesses can benefit from cheap permits. Also, the lower price of emission permits limits the number of possible ways to reduce pollution. Thus, it is evident that the over-allocation free allowance leads to the insignificant effect of the EU ETS on firms' competitiveness (Joltreau & Sommerfeld, 2019). Hence, the fully auction-based RGGI is free from grandfathering-based free allocation of allowances or over-allocation of allowance, which may lead to different dimensions of market competitiveness, especially in regulated sources.

The Chinese Pilot emission trading scheme has recently been highlighted among academics. However, the CN-ETS also has some noticeable differences from the US RGGI. First, like EU-ETS, but unlike US RGGI, the CN-ETS also suffers free allowance or over-allocation. For instance, the Chinese pilot ETS has been induced in the seven provinces but considered grandfathering allowance allocation except in Shenzhen and Chongqing, significantly influencing firms to maximize current profits (Zhang et al., 2015). Likewise, Wang et al. (2018) found that carbon quotas are positively correlated with the optimum production level and maximizing profits of an enterprise. From this perspective, experts like Liu and Wang (2017) and Wang et al. (2018) recommended that CN-ETS authorities further restrict free allowance allocation techniques and cut allowance supply to stabilize market carbon prices and maintain the price-setting ability of carbon markets. Another similar recommendation proposed by H. J. Zhang et al. (2019) is that to encourage the development of innovative low-carbon technology and the reduction of carbon intensity in China's industrial sectors, officials there should make it more difficult to hand out free permits.

Another noticeable distinction is 'banking and borrowing of allowance'. Banking is widely seen as an important way to reduce the effects of price changes caused by temporary changes in supply and demand (Chevallier, 2013). Specifically, EU-ETS allowed both banking and borrowing allowance (though limited to the compliance period). There is some ambiguity in the case of CN-ETS, such as they allowed banking of carbon allowance but no specific indication for borrowing in Hubei and Shanghai pilot ETS (Borghesi & Montini, 2016). To stabilize secondary market prices and ensure liquidity, ETS systems often implement allowance storage, new trading registries, carbon offset accounting, international linkages, revenue management, and other measures (ICAP, 2016; Schmalensee & Stavins, 2017). RGGI is also separated from other ETS for a "cost containment reserve" and an "emission containment reserve".

Furthermore, CN-ETS has been chastised for insufficient reporting, a lack of a legislative framework to enforce compliance, and lenient punishments, cited as some of the seven pilots' most significant challenges (Yu & Lo, 2015). A survey of Chinese companies in 2015 found that the carbon price did not "stimulate companies to upgrade mitigation technologies" and that most companies only joined the ETS pilots to get closer to the government and build a good reputation in the community (Yang et al., 2016). Thus, these findings can create a new dimension and enrich the current literature as the RGGI is a cap-and-invest-based program to control CO2 emissions.

2.3.3.4 Relationship between Market-based regulation-RGGI and Market Competitiveness

The impact of environmental policy adoption, especially market-based carbon reduction programs, on firms' performance and market competitiveness has been the focus of recent scholarly work. However, there is a controversy between the "Compliance Cost Hypothesis" (CCH) (Barbera & McConnell, 1990; Gray, 1987) and the "Porter Hypothesis" (Porter, 1991a; Porter & Van der Linde, 1995). Based on neoclassical economic theory, the CCH says ER makes it more expensive for firms to protect the environment. The costs are very high beyond the capital investment that can be used for technological advancements. This slows down technological progress and makes production less efficient. Some studies also found empirical evidence in favor of CCH (Albrizio et al., 2017; Alpay et al., 2002; Jaffe & Palmer, 1997; Zhao & Sun, 2016). They concluded that environmental control regulations lowered the output of inefficient enterprises and drove them out of business. However, this study does not prolong this discussion here, as we aim to investigate the effects of market-based, flexible, and mandatory ER.

In contrast, the Porter Hypothesis states that because of the costs of following environmental regulations, companies would be forced to develop new ideas and change how they run their businesses (Porter & Van der Linde, 1995). They also said that well-designed rules create an "innovation compensation effect" that makes up for the extra costs of following the rules. Due to technological advancement, a firm can minimize the cost of pollution remediation over time. Environmental regulation that works can make production more efficient and make a company more competitive (Ambec et al., 2013; Jaffe et al., 2002). From the perspective of environmental regulation, many scholars supported the PH (Brunnermeier & Cohen, 2003; Domazlicky & Weber, 2004; Qiang et al., 2022). In the last twenty years, many scholars supported the PH regarding environmental regulation, especially flexible or market-based environmental regulation (Canon-de-Francia & Garces-Ayerbe, 2019; Liu, Zhou, et al., 2020). However, some studies also reject the existence of PH (Hille & Mobius, 2019; Shen et al., 2021), and some concluded with inconclusive results (X. T. Liu et al., 2022; Wu & Lin, 2022). These controversial findings indicate that further empirical testing of PH is needed to provide more evidence to policymakers and practitioners.

In the recent literature survey, this study found evidence based on market-based environmental regulation for a “strong version” of the PH. For instance, Zhang et al. (2021) applied the DID model to examine the link between market-based environmental regulation and green development efficiency. They confirmed the presence of PH by showing that CN-ETS increased green development efficiency in test regions. De Santis et al. (2021) also demonstrated the validity of the Porter Hypothesis. In 18 OECD countries, they found that different rules about the environment, like green taxes, had different but positive effects on the growth of the labor force and productivity. Some studies emphasize firm-level research, such as Canon-de-Francia and Garces-Ayerbe (2019), which concluded that firms’ environmental investment brings positive financial performance while investigating the impact of EU-ETS on Spanish industrial companies. Likewise, few studies concentrated on the firm-level effects of CN-ETS with panel data and found supportive conclusions for the "strong" version of the Porter Hypothesis (Shen et al., 2021; L. Zhang et al., 2019). In the case of province or city level, similar findings were also reported in studies done by (Liu, Zhou, et al., 2020; Si et al., 2021; Wu & Lin, 2022). All these studies either focus on EU-ETS or CN-ETS. To the best of the researcher's limited knowledge, there is not that examines the impact of the US cap-and-trade carbon reduction program, namely RGGI, on the firm-level market competitiveness.

2.3.4 Relationship between innovation activities and market competitiveness

This section mainly illustrates the relationship between firm-level innovation activities (including green innovation) and market competitiveness. This study states some relevant theories related to innovation activities and market competitiveness in the first sub-section. In the second and third subsections, this study illustrates previous empirical findings. Also, the moderating effects of RGGI implementation and firm innovativeness are explained in the fourth and fifth sub-sections.

2.3.4.1 Relevant theories of innovation and competitiveness

The relationship between a firm's ability to compete in a market and innovative behavior has recently been of great concern to economists and policymakers. At the micro (company) level, competitiveness is generally understood to refer to the ability of a firm to increase in size, market share, and profitability (Clark & Guy, 1998). According to the Schumpeterian hypothesis, concentration of the market encourages new ideas and innovation (Schumpeter, 1942). The possibility that the innovator can control the market gives them a reason to make the necessary investment. In the early days, several theoretical approaches were used to reconcile the Schumpeterian paradigm with the evidence provided in the empirical works. For instance, researchers have devised and found that R&D and concentration have distinct but complimentary impacts (Dasgupta & Stiglitz, 1980; Nickell, 1996). Indeed, empirical work generally finds an inverted U-shaped relationship because competition can increase innovation profits for firms near the technological frontier (Aghion et al., 2005).

Nevertheless, intense competition can also reduce the incentive to innovate for laggards (Escrihuela-Villar & Guillen, 2014). For instance, they used panel data for the UK over the period 1973–1994 and the Lerner Index as an indicator of product market competition. In contrast, K. J. Arrow (1962) shows that the benefit of innovation to a single firm with R&D capabilities is higher under perfect competition than under a monopoly.

To integrate both lines of argument, more recent works claim the relation between innovation and competition follows an inverted U-shape (Aghion et al., 2005). The 'Competition escape effect' dominates for low levels, and the 'Schumpeterian effect' for high levels of competition; an intermediate degree of competition maximizes incentives for innovation. While theoretical arguments favor different relationships between competition and innovation, empirical investigations contribute little to reducing this ambiguity or sorting out competing accounts. The empirical literature offers evidence supporting any of the hypothesized relationships (Hecker & Ganter, 2013). To resolve these inconsistent findings, researchers have called for a contingency approach. The goal of this approach would be to allow for factors that moderate the relationship between competition and innovation and, therefore, could account for prima facie contradictory results (Scott, 2009; Tang, 2006).

In particular, Auh and Menguc (2005), for instance, suggested that as market competition intensifies, a firm's performance is heavily influenced by the actions undertaken by competitors. Under such a condition where predictability diminishes, and uncertainty increases, firms must collaborate to acquire information, reduce competitive uncertainty, and lower risk (Ang, 2008). Also, they conclude that intense competition motivates a firm to adopt a cooperative strategy because it helps the firm grasp knowledge of timely new technologies and market changes and enhances organizational efficiency. In summary, the early literature developed to analyze the different aspects of the relationship between innovation and micro-level competition does not provide clear conclusions.

However, Clark and Guy (1998) proposed two different models, namely the 'Linear Model of Innovation' and the 'Interactive Model of Innovation'. In a linear model, they said that "technology push" (technological development through basic science helps improve the manufacturing process, which leads to higher sales) and "demand pull" (the market needs to be forced to improve the manufacturing process, which leads to higher sales) make a strong link between a firm's innovation and its competitiveness. Along with an interactive model for innovation, they also mentioned the necessity of close synergy between parts of a firm's R&D system, between that system and the rest of the firm's production system, between the firm and other firms, and between the firm and other private and public institutions. Another study by Chen and Wang (2017) constructs a relational framework between innovation and firm performance. Based on a neo-Schumpeterian simulation model containing firms' production, pricing, pollution abatement investment, (environmental) R&D, entry & exit decision-making, and consumer choice behavior, they established a significant relationship between a firm's innovation and sales growth. Based on the overall theoretical discussion, it is evident that a firm's innovation activities significantly impact the firm's ability to compete in the market. However, the detailed empirical evidence is yet to be unexplored in this section but will be presented in the next section.

To sum up, theoretically, the "Porter Hypothesis" states that flexible but strict and well-managed policy stimulates innovation activities, which increase performance and ability to compete in the market. Many scholars have tested this hypothesis empirically, but the results are inconclusive. Previous firm-level studies mainly examined the EU-ETS, and CN-ETS, which are free allocation-based schemes, and criticized for being inconclusive due to free or over-allocated carbon allowances. Surprisingly, there is no evidence of paid-based or fully auction-based schemes devoid of overallocation complaints. To fill this gap, this study aims to determine how the US RGGI, a fully auction-based Carbon Emission Trading System, affects US firms' innovations and ability to compete in the market.

2.4 Hypothesis development

2.4.1 Relationship between the implementation of US RGGI and Firm-level Innovation

As previously stated, this research aims to assess the impact of US RGGI, a market-based trading scheme, on firm-level innovation activities. Consequently, this research presents empirical evidence about fully auction-based, market-based environmental policies and innovation. An overview of the literature emphasizing the relationship between flexible or market-based environmental regulation and innovation is illustrated in Appendix G. Some authors used survey data to reveal the relationship between flexible/market-based regulations such as EU-ETS (Rogge & Hoffmann, 2010; Rogge et al., 2011), institutional incentives (Y. L. Tang et al., 2020), and energy-saving policies (J. Zhang et al., 2020) and a positive impact on firms' innovation. As flexible environmental regulation, few scholars investigated the relationship between voluntary environmental regulation and its effect on firms' innovation and found significant positive relation (Bu et al., 2020; Jiang et al., 2020; Lim & Prakash, 2014; Y. F. Zhu et al., 2019). These studies are different from the current one because the current one only looked at required regulations and not voluntary ones.

In terms of market-based regulation, the authors focus on macro and micro (firm-level), but most of the evidence is from China. For instance, Pan et al. (2019) found a positive relationship between Chinese market incentive-based environmental regulation and provincial innovation. However, two other provincial and city levels were conducted by Shi et al. (2018) and Liu, Ma, et al. (2020), and they found that the CN-ETS effect negatively on the regulated provinces and cities. Only a few studies focus on the micro-level; two papers investigate market-based regulation, but the regulation is only for SO2 emissions. Although they found a positive relationship, the current system is looking for market-based regulation to curb CO2 emissions. Some researchers looked at the CN-ETS for CO2 emissions in firm-level innovations using panel data and DID as a treatment effect model. They found both positive and negative relationships. For instance, M. G. Tang et al. (2021) concluded that the CN-ETS negatively impacts firms' innovation in the Chinese industrial sector. However, this study did not separate the regulated and non-regulated firms. Another similar study found a positive relationship between CN-ETS and the innovation of Chinese-regulated industrial firms compared to non-regulated firms. Moreover, two recent similar studies highlighted the CN-ETS and the innovation activities of Chinese listed firms and found positive relations (Qi & Cheng, 2022; Shen et al., 2021). Based on theoretical discussions and the results of some recent studies of firms, this study found that market-based regulations encourage firm-level innovation.

As per the 'weak version' of the PH, all flexible but strict environmental regulations (e.g., well-structured regulations) should encourage innovation. The US RGGI, on the other hand, operates on the "cap and invest" approach, which means that the RGGI redistributes revenue from carbon auctions in a manner that benefits citizens and makes it simpler for participating states to invest in low-carbon technology to reach emissions reduction goals. Also, the RGGI was formulated, like all major ETS, to help with energy efficiency, renewable power, low-carbon innovation, helping people pay their utility bills, and other ways to reduce GHG emissions. Thus, RGGI must significantly change regulated sectors such as power generation and transmission. Even though different studies have come to different conclusions about the relationship between market-based regulation and firm-level innovation, there is still a research gap. Additionally, unlike other ETS programs, RGGI's functionality is unique, especially for fully auction-based regulations. No studies measure the impact of US market-based carbon trading regulation on firm-level innovation activities. Therefore, this study proposed a hypothesis as follows:

H_1: The RGGI has a significant and positive impact on innovation in the regulated sector

A firm's environmental initiatives or actions are classified into two broad categories: reactive and proactive initiatives (Chen et al., 2012). The implementation of regulation forced the firm to take measures or initiatives to comply with the legislative pressure, commonly known as a reactive measure to comply with the regulation. In contrast, a firm that acts or is aware of the upcoming regulatory push before induced regulation knows a proactive initiative. Though it is not limited to the only polluting industry, according to Heras-Saizarbitoria et al. (2015), heavily polluting firms were more proactive about voluntary compliance to maintain the legitimacy of their industry. For example, Shell (a Dutch-British derived oil company) adopted a proactive climate strategy, and Exxon (a US oil and gas company) adopted a reactive strategy before the ETS in Europe (Skjærseth, 2013; Skjærseth & Skodvin, 2018). The ETS influenced Shell's decision to take a proactive stance on climate change, a policy partly influenced by the company's home environment. As a result of its "climate-friendly" focus and bold goals in renewable energy, the corporation is in a prime position to reap the advantages of the ETS (Skjærseth, 2013).

Organizations that can creatively adapt to environmental regulations and proactively manage their environmental performance often see greater personal benefits from sustainability (Ramanathan et al., 2017). On the other hand, even though large firms are getting into the rising renewables market and facing a clash of cultures within their own companies, most of their investments are still going to traditional technologies. Therefore, it's not clear if the giant companies are moving quickly and proactively enough to help the power sector eliminate carbon emissions, which is necessary. In this perspective, Rogge et al. (2011) argued that keeping markets open and attracting new, dynamic, and innovative entrants is vital. In the states that are part of RGGI, the RGGI authority spends more than 85% of the revenue from carbon auctions on developing renewable energy, making energy use more efficient, and even helping people pay their utility bills directly, which makes people more aware of environmental damage. Thus, it is essential to consider the firms' proactive or spillover effect of the RGGI on the non-regulated sectors. This study considers another hypothesis in this perception:

H_{1a}: RGGI has an impact on innovation in the non-regulated sectors

2.4.2 Relationship between the implementation of US RGGI and Firm-level Green Innovation

Many studies have found significant GHG emission reductions in participating states in the context of the US carbon ETS, namely RGGI (Chan & Morrow, 2019; H. Yang et al., 2021; Zhou & Huang, 2021). However, there are numerous reasons to reduce CO_2 emissions in member states. First, when RGGI went into effect in 2009, it led to more "electricity imports" from neighboring states and a rise in power production and

CO2 emissions in the non-RGGI states (Lee & Melstrom, 2018). Second, when it comes to "fuel switching" from coal to natural gas, Kim and Kim (2016) demonstrated that the RGGI significantly increased fuel switching. However, Huang and Zhou (2019) asserted that reducing coal imports and emission leakage instead of switching to natural gas can help reduce emissions. Third, 'energy-efficiency improvement' could be the output of efficient electrical appliances development, not the implementation of RGGI (Huang & Zhou, 2019). Forth, "Emission leakage" is the process of moving manufacturing operations to places where they are not regulated. This is the main way emissions are reduced in the RGGI States (Huang & Zhou, 2019). Fifth, 'economic downturn'- in a recession, demand for carbon allowances is affected by changes in economic activity, which influences the price of CO_2 (Luca et al., 2020). Overall, CO_2 emissions reductions are not just due to the RGGI's adoption but are cohesive for multiple reasons.

Counterintuitively, many studies have investigated how RGGI affects Sulphur dioxide emissions, nitrous oxide emissions, social welfare benefits, carbon leakage, and merging opportunities. According to Chen (2009), RGGI could generate economic incentives and move long-term production toward a mix of low-carbon technologies and short-term decarbonization. On the other hand, the market for tradable emission permits encourages mergers between firms (Creti & Sanin, 2017). Like the rest of the ETSs, RGGI creates a 'double dividend' scope, i.e., reallocating carbon revenue, which benefits citizens and improves the participating states' ability to invest in low-carbon technologies to achieve emission goals (Raymond, 2019). Technology and market-driven forces also drive a firm's innovation in low-carbon technology, which reduces ecological compliance costs and improves its potential to mitigate environmental damage and penetrate the market in the long run (García-Pozo, 2019; Kula & Unlu, 2019). Effective ETSs mainly encourage a firm's green innovation (Lyu et al., 2020; Ren et al., 2020a). The theory of innovation economics suggests that the regulatory push is as necessary as the market and technology pull-push factors for firm-level green innovation. Therefore, government agencies should keep strengthening environmental supervision to make the policy well-functioning to promote GI (Tan & Shang, 2018). This study developed a research question: "to what extent is the US RGGI promoting the firm's green innovation initiatives?" This study examined the RGGI's impact on the green innovation of regulated and non-regulated companies, which could add to the body of knowledge (especially the "narrow" version of the Porter Hypothesis, reported in Figure 2.2) on the relationship between market-based carbon regulations and a firm's green innovation.

All ETS programs (apart from Tokyo and Saitama ETS) addressed the power sector to limit GHG emissions during the generation and electric power distribution. Simultaneously, to reduce the use of fossil fuels, improve low-carbon energy production, encourage renewable energy, and promote low-carbon technologies (ICAP., 2020; Samant et al., 2020). Generally, the cost of carbon allowances generates numerous incentives for the power industry, including financing less carbon-intensive energy sources, cutting energy demand, and transitioning to a low-carbon power transmission infrastructure (Luca et al., 2020). Hence, the RGGI, like all major ETSs, was designed to facilitate energy efficiency, renewable power, low-carbon innovation, utility bill support for households, and other GHG alleviation measures.

Moreover, green technical innovation encompasses inventions linked to renewable energy, energy efficiency, low-carbon energy generation and distribution, and WIPO's Green Inventory IPC classification (WIPO., 2020). This study considered all the 'IPC green inventory' classifications as a proxy for the firm green innovation. In addition, RGGI authorities are continuously trying to encourage corporate green initiatives by distributing carbon revenue to low-carbon projects and directing bill support to citizens. As a result, the current research anticipates that implementing RGGI will directly impact the firm-level green innovation that operates with participating states. Along with Porter Hypothesis, the empirical literature has also established a connection between ETS implementation and firm-level green innovation. Finally, this study assumes that the RGGI will impact the green patenting efforts of the US firms in the participating states. Thus, the second hypothesis is provided based on the prior study.

H_2: The RGGI has a positive and significant impact on green innovation in the regulated sector

Environmental regulation can force the firm to promote its green innovation activities. Meanwhile, green innovation positively affects firm performance. By using these processes, companies can improve their financial performance (for example, by growing their market share and sales) and their image in the market. However, Weng (2015) suggests that "going green" is not just a way for companies to comply with government rules. Instead, by developing green technologies, businesses can alter their strategies and improve their performance, providing managers with a game-changing new strategic weapon. They also argued that strengthening a company's green innovation capacity can provide a new strategic weapon for managers.

Moreover, Firms that proactively promote environmental performance could improve their benefits by cutting costs and doing better in the market (Ramanathan et al., 2017). This also supports the "strong version" of the Porter Hypothesis. A proactive company tries to change how the process works to avoid paying to clean up pollution at the end of the pipe (Quatraro, 2019). This strategy will likely make a company more competitive by lowering operating costs and boosting its reputation as a leader in green marketing (Hart, 1995). Furthermore, consumer demand for green creates market pressures encouraging firms to be proactive in green innovation (Dai et al., 2018). As a result, the proactive reactions of companies to environmental concerns provide greater returns (Thoumy &

Vachon, 2012). Therefore, a firm's green innovation, whether spurred by the regulatory push or a firm's proactive response to the regulation, is beneficial.

Green innovation also strives to reduce the environmental impact of products and manufacturing processes and ensure that economic and environmental effects are considered equally (T. Y. Chiou et al., 2011). Green innovation has the same positive "spillover effects" as other innovations. It has "double externalities," or two benefits that come from it. Also, green innovation creates positive externalities by lowering costs and reducing negative externalities (Rennings, 2000). The costs of environmental regulations can be offset by green innovation, which offers firms "innovation offsets" and "first mover advantage" (Pan et al., 2021). Thus, firms' green innovation initiatives should not be limited to the regulated sector, but other non-regulated sectors should emphasize for many reasons.

In parallel to the impact analysis of ETS on GHG emissions, ongoing research has also focused on the spillover effects, like revenue-generating ability (profit), growth, energy prices, lower energy consumption, air quality, and child mortality. Environmentally less hazardous innovation must be viewed as a proactive strategy for firms to maintain a competitive advantage and higher performance rather than a reactive behavior levied by the government (de Burgos-Jiménez et al., 2013). Thus, managers should be concerned, build awareness among their team about the benefits of green innovation, incorporate it into their company's overall strategy, and be encouraged to implement it. It can inspire green initiatives and improve the performance of the firm. Therefore, if the RGGI has any expansion tendency or firms from the non-regulated sector feel any pressure or threat to face ETS soon. Then, the non-regulated firms might have a proactive measure for less environmentally hazardous production processes or green innovation initiatives to improve their energy efficiency through advanced production processes. From this perspective, this study considers another hypothesis as follows:

H_{2a}: The RGGI has an impact on green innovation in non-regulated sectors

2.4.3 Relationship between the implementation of US RGGI and Firms' market competitiveness

Each cap-and-trade or ETS program has distinct properties, leading to firm-level performance (Narassimhan et al., 2018). RGGI has unique properties, such as a fully auction-based allocation of carbon allowance (compared to free grandfathering in EU-ETS, CN-ETS) and 'banking carbon credit' but not a borrowing option in case of excess emission. In addition, unlike other ETS schemes, the RGGI authorities are reimbursing more than 85% of their auction revenue to energy efficiency, clean & renewable energy, and greenhouse gas abatement efforts. Also, they committed to allocate at least 25% of revenue for 'consumer benefit'– no explicit low-income provisions. It may offer double benefits to the regulated sources, such as developing green initiatives and direct customer benefits that can enhance consumer green awareness and help to ensure a higher ability to compete in the market by reducing the innovation risk. Thus, this study can provide new evidence in the climate economic literature. Based on the theoretical relationship between the "strong version" of the PH and the analysis of the empirical findings, this study sets the first hypothesis as follows:

H_3: The RGGI positively affects the market competitiveness in the regulated sector

A competitive perspective suggests a close connection between competition and innovation, where a firm's innovation activities are driven by market competition (Bonanno & Haworth, 1998; Czarnitzki et al., 2014; Shaked & Sutton, 1982). However, green innovation, including product and process innovation (Huang & Li, 2017), is a proactive action aiming to address increasing pressure to focus on environmental sustainability rather than market competition (Dangelico, 2016). Noting that many firms initiate green innovation programs for more reasons than just regulatory pressure (Chang, 2011), it is vital to investigate how firm performance is affected by green innovation. For instance, the technology spillover effect is noticeable and significantly promotes green innovation technology (TAO & Zhou, 2016). Firms can acquire higher market competitiveness by proactively taking actions to meet the increasing demands for green consumption (Sueyoshi & Wang, 2014), creating a green brand image and thus gaining consumer trust (Eiadat et al., 2008). Such a proactive approach can help enterprises control and minimize the risks of green innovation (Barforoush et al., 2021). Proactive smaller firms may have profiles similar to large ones, considering that product EI can boost their competitive advantage (Klewitz & Hansen, 2014). As discussed in the previous sections, proactive technological development or regulatory spillover effects influence firms' innovation activities in the non-regulation sectors. Thus, this technological and legislative spillover effect can help non-regulated firms enhance their ability to compete in the market. Therefore, this study also considers another hypothesis as follows:

H_{3a}: The RGGI has an impact on the market competitiveness in non-regulated sectors

2.4.4 Relationship between firm-level innovation and market competitiveness

Innovation is a key driver of a firm's competitiveness in the market. It can lead to the development of new products, processes, and business models that can give a company a competitive advantage over its rivals. Additionally, a company that can continuously innovate may be able to stay ahead of market trends and changes, allowing it to maintain its competitive position over the long term. On the other hand, a lack of innovation can make a company less competitive, as it may struggle to keep up with its rivals and cannot offer as many unique products or services. Overall, innovation is an important factor in determining a firm's competitiveness in the market.

Apart from the regulatory pull-push effect, the relationship between innovation and competitiveness is also rising in the recent literature. This literature is divided into macro and micro levels. For instance, Davydova et al. (2016) used innovation and competitiveness indexes to study innovative investment development in BRICS countries at the macro-level. Another study by Cinicioglu et al. (2017) applied Bayesian Networks to evaluate the simultaneous interaction of competitiveness indicators in 148 countries and their innovative performance. Yordanova and Stoimenova (2021) analyzed the linkage between innovation on a country level and the competitiveness of universities. Another similar country-level study conducted by de Miranda et al. (2021) suggested that global competitiveness influences the innovativeness of nations significantly and positively.

Moreover, innovation significantly reduced labor costs in Finland, which leads country's competitiveness (Kaitila, 2019). Another study emphasized Slovakia by Hudakova and Maros (2019) and showed a strong and positive relationship between the regional competitiveness index and innovation performance. Traditionally, innovation is started with the invention (generation of a new idea), innovation (commercialization of invention), adoption (accepted by the firm, which is new to them but not new in the market), and diffusion (accepted by every stakeholder). Thus, innovation and firm-level involvement are also vital.

In recent studies, innovation has been adjacent to firms' competitiveness, market competition, and market competitiveness. For instance, recent empirical studies have found mixed results on how innovation responds to intensifying Chinese competition, with Bloom et al. (2016) documenting positive innovation responses to Chinese competition in Europe, while Autor et al. (2020) find that the US publicly traded firms systematically reduced innovation. Likewise, Cao et al. (2020) revealed that market competition and firm scale have positive and significant effects on the efficiency of two-stage innovation in China's high-tech industries. However, Mulkay (2019) found a negative impact of competition on innovation in most French firms, meaning that more competitors in the industry or a small market share harm the propensity to innovate, either in products or processes. They also found a more substantial effect on the product than on process innovation. According to Jin et al. (2021), technology imports and indigenous innovation can reduce the costs of technology imports and indigenous innovation. They also revealed that firms can enhance their market competitiveness only by indigenous innovation based on technology imports.

Moreover, innovation helps the firm improve energy efficiency, which influences the firm's competitiveness (M. Peneder et al., 2022). However, they focused on the self-reported impacts of adopting "green" energy-saving and related technologies. The current study differs because of market-based measures of a firm's competitiveness. Another similar study found a strong, positive link between firm innovations and competitiveness (Sukumar et al., 2020). They only focused on 216 UK IT firms though they used panel data from 2000 to 2016 but used the R&D expenditure for innovation proxies representing innovation input; as discussed earlier, innovation should be measured based on output such as patents registration. Theoretical literature argues that ER can lead to technological innovations that improve production efficiency, thus reducing production costs while improving product quality, ultimately improving firms' profitability and competitiveness (Porter & Van der Linde, 1995). Still, the relationship between technological innovation and firms' market competitiveness is unexplored. Thus, based on Schumpeterian hypotheses, this study considers another hypothesis as follows:

H_4: Firm-level innovation promotes the market competitiveness of US firms

2.4.5 Relationship between firm-level green innovation and market competitiveness

The relationship between firm-level green innovation and market competitiveness is positive. Green innovation can improve a firm's competitiveness by reducing costs, improving brand image, and attracting customers who prioritize sustainability. Additionally, government policies and consumer demand for environmentally friendly products can create new market opportunities for firms that invest in green innovation. However, the relationship is not always straightforward and depends on various factors, including the stage of market development, the level of consumer awareness and demand, the level of competition, and government policies.

As previously discussed, researchers are equally intrigued by two prominent concepts concerning the impact of firm-level innovation. These include the "Schumpeterian view" or "Schumpeterian Effect," which posits that sizable firms operating within concentrated markets exhibit greater capacity and motivation for innovation (Mulkay, 2019). The second concept is the "Arrowian view" or "Escape-Competition Effect," which asserts that heightened competition fosters increased innovation among firms, driven by the necessity to differentiate themselves from competitors (Mulkay, 2019; Wang & Sun, 2022).

Schumpeter (1934) argued that more competition in a market harms innovation. Large firms innovate more because they are more stable, have more internal funds to invest in innovation, and can easily protect their innovations. The inverse argument that competition is better for innovation was first presented by K. J. Arrow (1962). A monopoly has less incentive to innovate because it gains only the increment in its monopoly rents if it introduces a new product or technology. Conversely, a competitor benefits from all the new profits from its innovation. Based on what motivates industrial firms to innovate, the literature focuses on the appropriability of innovations, the size of innovations, the obsolescence of old products, or the uncertainty of innovation outcomes. Some firms want to keep a market advantage by continuously proposing new products to consumers. Other firms want to improve the production process to save inputs, time, or labor, reducing the cost of goods.

As discussed earlier, green innovation has some distinguishable features from conventional innovation. Green innovation is the improvement of products and processes by using technology to save energy, stop pollution, recycle waste, design eco-friendly products, use eco-friendly packaging, and manage a company's impact on the environment (Chen et al., 2006). From this point, it is clear that conventional and environmentally friendly innovations are different. The latter is motivated by ecological concerns in the market or government legislation (Qu et al., 2022). Innovation is generally considered a significant determinant of a firm’s performance and, consequently, a country's growth. Generally, innovation creates value by improving efficiency, productivity, or performance (C. P. Padilla-Lozano & P. Collazzo, 2022). Also, innovations improve a firm’s profitability by lowering its production costs and giving it a market advantage over its competitors (Guo et al., 2022).

Conversely, green technology offers value by creating products and processes that solve environmental concerns for the government, market, and customers (Albort-Morant et al., 2017). Nonetheless, the study of green innovation is still relatively new, and most of the literature has been about defining and theorizing about it (Fanny Hermundsdottir & Arild Aspelund, 2021). Therefore, more studies are required on innovation activities by separating the distinguishing features of innovations.

Among the various studies that have addressed the background of firm-level green innovation, many perspectives have been considered: competitive advantage (Barforoush et al., 2021; Chen et al., 2006; Juo & Wang, 2022; Sellitto et al., 2020; Waqas et al., 2021); the reduction of costs (Horbach et al., 2012); firm performance (Chen & Liu, 2019; Huang & Li, 2017), firm sustainability (Asadi et al., 2020; Qiu et al., 2020b; Zhang, 2018); firm's environmental and economic performance (Duque-Grisales et al., 2020; Raza, 2020; H.-H. Weng et al., 2015); firm growth (Leoncini et al., 2019; X. E. Zhang et al., 2022); the benefits of the market (Dangelico & Pujari, 2010; Lambertini, 2017); the opportunities to create innovations and increase product quality (Chen & Wang, 2017); labor productivity (Woo et al., 2014).

Numerous studies have shown that investing in green innovation makes businesses more competitive. This study aims to find out whether this is true as a foundation for green innovation in businesses. Appendix J shows the literature survey on the relationship between green innovation and its impact on a firm's competitiveness, market competition, and market competitiveness. For instance, Apak and Atay (2015) concluded in their research that green innovation and technologies are necessary for companies seeking international competitiveness in global markets. However, they focused on the macro level, i.e., cross-country comparisons with cross-sectional data. Still, this study is different due to panel data from 2000 to 2019 with micro-level evidence, which is vital to understanding the relationship between firms' green initiatives and their ability to enhance market competitiveness.

Moreover, some recent studies revealed a positive and statistically significant relationship between the firm's green innovation and competitiveness (C. P. Padilla-Lozano & P. Collazzo, 2022), green product competitiveness (Nuryakin & Maryati, 2020), firm environmental, economic, and financial performance and growth (Huang &

Li, 2017; Leal-Rodriguez et al., 2018; Raza, 2020; H.-H. Weng et al., 2015; Xue, 2019; X. E. Zhang et al., 2022). However, all these studies used survey data and measured green innovation as the firm's green attitude or behavior. Thus, the researcher believes this study can provide different scenarios with accurate measures for a firm's green innovation with the outcome of the firm's green attitude and behavior. Few authors investigated the impact of green innovation on financial competitiveness (S. Liu et al., 2021), international competitiveness (Y. H. Hu et al., 2021), competitiveness, and firm sustainability (G. P. Li et al., 2019; Qiu et al., 2020b). Although these studies used firm-level panel data, they only focused on Chinese firms. Also, most Chinese authors measured the firm's green innovation using the so-called 'Green Key words' approach, for example, work done by G. P. Li et al. (2019) and Y. Zhang et al. (2020). However, the so-called green keywords approach is criticized because a few green words are insufficient for the patent's identity.

Another recent study by Y. Q. Liu et al. (2022) found a positive influence of green innovation and market competition with panel data, but they emphasized the province level. One more study by Duque-Grisales et al. (2020) found a significant positive effect of a firm's green innovation on the performance of Latin American firms. They covered the study period from 2013 to 2017 with panel data, but they measured the firm's green innovation by ISO 14001 certification and green R&D expenditures, which is the input of green innovation. Specifically, innovation is an output of R&D expenditure. Thus, it is necessary to measure firm-level by a firm's registered patent activities (Lin et al., 2019). Therefore, this study used the firm's total registered patents for innovation and green patents for green innovation, which help to provide an actual impact of the firm's green innovation on the firm's market competitiveness. To the limited knowledge of the researcher, the relationship between a firm's green innovation and market competitiveness for US firms is yet to be unexplored. Following this line of reasoning, this study proposes the following hypothesis:

H_5: Firm-level green innovation promotes the market competitiveness of US firms

2.4.6 Moderating effects of RGGI between innovation activities and market competitiveness

The conventional neoclassical notion is that environmental regulation hinders firm performance. In contrast, according to Porter's Hypotheses, flexible but strict environmental regulation promotes business performance through innovation activities. In the empirical literature, this study found that scholars have investigated many moderating issues between the relationship between environmental regulation and innovation or green innovation activities and found a diverse conclusion. For instance, regulation has dual effects, such as increasing compliance costs in the short run and improving technological development through innovation activities that promote business performance in the long run. However, very few studies examine the moderating effects of regulation. This study investigates the moderating role of RGGI between the firm's innovation or green innovation activities and the firm's market competitiveness. Therefore, this study proposes another two hypotheses as follows:

H_6: RGGI moderates the relationship between innovation and market competitiveness of US firms

H_7: RGGI measures the relationship between green innovation and market competitiveness of US firms

2.4.7 Moderating role of firm's innovativeness between innovation activities and market competitiveness

Generally, innovation is conceptualized as an outcome of a firm's activity at a business level (Chang, 2011) that is measured by firms' patent activities. However, extended literature conceptualized a firm's innovativeness in various aspects, which are also essential determinants for business performance (Nishant et al., 2017). For instance, A firm's innovativeness is considered an important determinant of its consumer adoption rate (Holak & Lehmann, 1990) and new product success (Montoya-Weiss & Calantone, 1994). Innovativeness is a firm's ability to innovate in market orientation (Dewett & Jones, 2001). Likewise, Eisingerich and Rubera (2010) defined innovativeness as a firm's capacity to be open to new ideas and work on new solutions. They also define green brand innovativeness as 'the extent to which consumers perceive brands as able to provide new and useful solutions to their green needs'. Innovativeness is a characteristic of economic entities or economies, which means being able to create, implement, and use innovations and absorb them (Sobczak et al., 2022). It means actively participating in innovative processes and taking the proper steps. It also means actively getting firms' resources and skills to participate in innovative strategies (Sobczak et al., 2022). Therefore, a firm's innovativeness is its ability to create and implement innovation on a continuous basis.

Firms can reduce their cash flow vulnerability by staying ahead of the competition through innovation. Investors who are interested in cash flow, especially the possibility of higher and faster cash flows in the future, may see these innovations as platforms for introducing new products in the future and as signs that the company is doing well in the innovation process itself (Srinivasan et al., 2009). Innovations that are responsive to customer needs can result in substantial revenue increases. In turn, potential improvement in financial performance will positively affect a firm's stock price (Ba et al., 2013). In addition, Pujari (2006) argues that the market success of the green product is still uncertain Signalers, as the critical signaling theory actors determine signal strength (Arthurs et al., 2009) and interpretation (Connelly et al., 2011).

Furthermore, firm innovativeness affects market returns from new product announcements (Lee & Chen, 2009; Nishant et al., 2017). Moreover, green brand innovativeness is directly associated with brand loyalty (Lin, 2017). For technological innovation, the inverse u-shape of the relationship between the intensity of competition and a firm’s innovativeness (Aghion et al., 2005). In contrast, flexible regulations enhance creativity and innovativeness (Ramanathan et al., 2017). The interaction between market orientation, which is aligned with the organisation's overall functioning, and innovativeness was shown to be positively moderated by green management attitudes and environmental policy (Dibrell et al., 2011a; Dibrell et al., 2011b). Therefore, this study sets another two hypotheses as follows:

H_8: The firm’s innovativeness moderates the relationship between innovation and market competitiveness

H_9: The firm’s green innovativeness moderates the relationship between green innovation and market competitiveness

2.5 Summary of literature survey

In 1932, regarding technological change as a process that can be influenced by economic policy, John Hick's induced innovation hypothesis (IIH) underpinned the idea that carbon pricing, whether in the form of carbon taxation or emissions trading, can spur novel low-carbon technologies. The IHH postulates that an increase in the relative price of a production factor stimulates inventions aimed at reducing its use. Considering carbon as a production factor, the IIH applies to carbon pricing. However, the applicability of the IIH is general, beyond market-based policies and the environmental policy domain.

Later in the 1990s, Professor Porter and his colleagues challenged mainstream economic views about environmental regulation (ER) costs. The Porter Hypothesis (PH) central focus is that proper implementation of ER requires a dynamic nature of strategy but is supportive of improving business performance. More explicitly, an adequately designed environmental regulation may spur innovation ('weak' version), and flexible regulatory policies give firms greater incentives to innovate and thus are better than strict regulation ('narrow' version). Many authors empirically investigated the PH and concluded with supportive and unsupportive indications. However, PH testing in flexible ER like RGGI is not yet explored.

The central notion is that if the ER is flexible and strict (i.e., adequately designed and implemented), it can promote firms' innovation activities. Based on this notion, this study sets the first hypothesis (H_1) shown in figure 2.3a to examine the relationship between the RGGI deployment and firms' innovation activities (H_1-for regulated sector and H_{1a}-for non-regulated sector). In the recent literature, many scholars emphasise green or low-carbon innovation after the implementation of EU-ETS in 2005 and CN-ETS (pilot in 2013-14) as EU-ETS and CN-ETS are induced in market-based nature with a specific focus on green innovation. Similarly, the US RGGI has designed a market-based scheme and redistributed carbon auction proceeds to improve low-carbon or green innovation. Thus, this study considers the second hypothesis (H_2) in figure 2.3b ((H_2 for the regulated sector and H_{2a} for the non-regulated sector) to investigate the relationship between the RGGI deployment and the firm's green innovation activities.

According to the Porter Hypothesis, environmental regulation can increase firm competitiveness, also known as the 'strong' version. From this theoretical perspective, this study considers another hypothesis (H_3) to examine the impact of the US RGGI on firms' market competitiveness in the regulated sector. Also, it is evident in the empirical literature that a firm's proactive nature to adopt less hazardous environmental measures helps manage the upcoming regulatory push well and helps to get a first-mover advantage which assists in winning over competitors' rivalry. Thus, this study also investigates the impact of RGGI on firms' market competitiveness in the non-regulated sectors through another hypothesis (H_{3a}).

According to the Schumpeterian hypotheses, a positive relationship exists between market concentration and innovative activity, known as the 'Schumpeterian effect'. However, more recent works claim the relation between innovation and competition follows an inverted u-shape, also known as the 'Competition escape effect'. The 'Competition escape effect' dominates for low levels, and the 'Schumpeterian effect' for high levels of competition; an intermediate degree of competition maximizes incentives for innovation. To resolve these inconsistent findings, researchers have called for a contingency approach. The goal of this approach would be to allow for factors that moderate the relationship between competition and innovation. Based on the overall theoretical discussion, it is evident that firms' innovation activities significantly impact firms' Thus, this study aims to examine the extended relationship between firms' innovation and market competitiveness in H_4 in figure 2.3a. Also, exploring the relationship between firms' green innovation and market competitiveness in H_5 is exhibited in figure 2.3b.

According to a recent literature survey, it is evident that regulatory push significantly and separately influences a firm's innovation or green innovation activities and its ability to compete in the market. However, very few studies have emphasized the moderating role of market-based carbon reduction initiatives between innovation or green innovation and market competitiveness. From this perspective, this study intends to examine the moderating influence of RGGI between the firm's innovation activities and market competitiveness exhibited by H_6 in figure 2.3a and firms' green innovation activities and market competitiveness shown by H_7 in figure 2.3b.

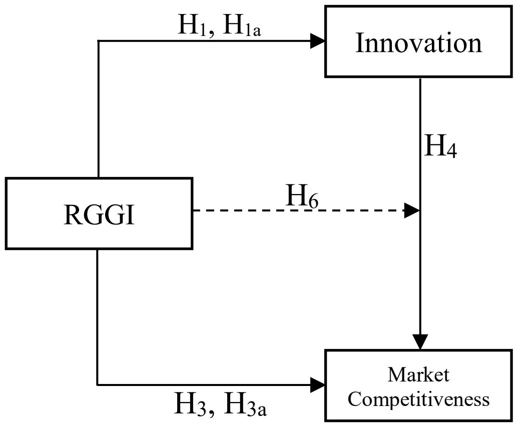

Figure 2. 3a: Research Framework

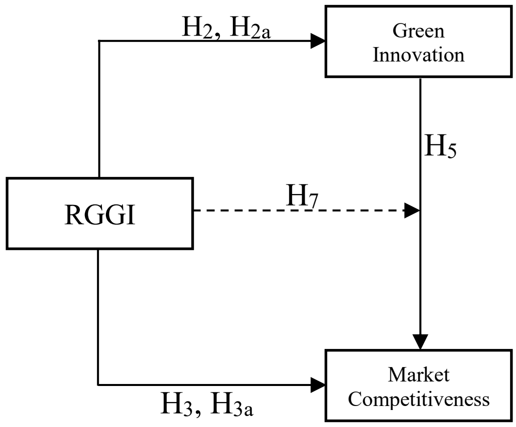

Figure 2.3b: Research Framework

Note:
H1: The RGGI has a significant and positive impact on innovation in the regulated sector
H1a: RGGI has an impact on innovation in the non-regulated sectors
H2: The RGGI has a positive and significant impact on green innovation in the regulated sector
H2a: The RGGI has an impact on green innovation in non-regulated sectors
H3: The RGGI positively affects the market competitiveness in the regulated sector
H3a: The RGGI has an impact on the market competitiveness in non-regulated sectors
H4: Firm-level innovation promotes the market competitiveness of US firms
H5: Firm-level green innovation promotes the market competitiveness of US firms
H6: RGGI moderates the relationship between innovation and market competitiveness of US firms
H7: RGGI measures the relationship between green innovation and market competitiveness of US firms

2.6 Chapter conclusions

This chapter provides a comprehensive literature review and summary of the previous studies on the impact of environmental regulation, specifically market-based carbon-reducing schemes, on firms' innovation, green innovation, and market competitiveness. First, this study explains the distinction of similar key variables' definitions which helps to understand the key variable used in this study and other similar variables used interchangeably. Second, this study provides a comprehensive theoretical background for each objective, clarifying each objective's theoretical stands. This section comprehensively explains how different versions of Porter's Hypotheses explain each objective's relation. Third, this chapter describes the features of the ETS and RGGI, which show how they are different from environmental regulations and ETS programs. It also explained how the RGGI is formed and how the ETS is linked to innovation, green innovation, and market competitiveness in firms. Fourth, based on the integrated literature approach, this section explains the recent empirical findings of the literature, which helps to develop the hypotheses under each objective. Fifth, this section described how the company's proactive steps to adopt less dangerous technologies helped it get first-mover advantages and how environmental regulations had spillover effects in sectors that were not regulated. Sixth, this section develops a research framework after integrating all the theoretical discussions, previous empirical findings, and proposed hypotheses.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter explains the research methodology of this study, including model estimation for benchmarks and robustness testing. It has multiple sections to demonstrate the entire procedure and the overall treatment effects of US RGGI. For instance, Section 3.2 portrayed the flowchart of research design, Section 3.3 explains the philosophical stance and research approach, and Section 3.4 describes the three benchmark models for each objective of this study. In Section 3.5, estimation techniques for robustness testing are specified. Section 3.6 explains the summary of this chapter.

3.2 Philosophical stance and research approach

This study selects a high GHG emitting country like the USA and its market-based regulation, namely RGGI, to compare its impact on firm-level innovation activities and market competitiveness between the regulated and non-regulated sectors. In particular, this study undertook the positivist approach based on the suggestions by Burrell and Morgan (1979). The positivist paradigm suits cause-and-effect linkages and statistical and linear analysis (Latham et al., 2005). Positivists describe the real-world situation involving the problem statement, observation, and deriving several hypotheses to test the relationship (Inanga & Schneider, 2005). So far, most positivist research has been focused on finding the most critical factors that lead to success or failure (Van Cauter et al., 2016). However, several researchers have found fault with the positivist method. According to Cecez-Kecmanovic et al. (2014), this paradigm has a constrained mission and provides a moderate contribution.

Most scholars strongly recommend using the scientific method in conducting empirical research as that researcher can avoid subjective interpretations. On the contrary, a positivist approach helps reinforce the researcher's independence and eliminates bias in exploring the orientations (Van Cauter et al., 2016). Therefore, the following section discusses the research approach.

There are two research approaches, which are deductive and inductive (Bell et al., 2022; Saunders et al., 2009). Guided by the positivist approach, this study employed a deductive approach. In particular, the deductive approach employs scientific principles, progresses from theory to data, requires an explanation of the causal relationships between variables, gathers quantitative data, and employs controls to ensure data accuracy. In addition, this approach aids in operationalizing ideas to offer clarity of definitions, a highly organized methodology, the researcher's independence from what is being investigated, and the need to identify adequate samples to generalize the results (Saunders et al., 2009, p. 127). For this reason, the deductive approach starts with a theory, develops hypotheses from that theory, and then collects and analyzes data to test those hypotheses.

This study uses quantitative methods using secondary data from US firms listed on major US stock exchanges. This study intends to investigate the impact of policy on firm-level innovation activities and market competitiveness. This research has to compare before and after the policy intervention and between the regulated and non-regulated firms to reveal the actual effects of policy implementation. Note that this study selects the US RGGI as the policy implemented in 2009; thus, multiple selections of firms and at least one year before and after the policy intervention are mandatory. Therefore, it is suitable for this study, which is panel data. This study with panel data is designed to collect data to answer the research question.

3.3 Flowchart of research design

This study follows a structured approach to proposed policy implications and recommendations from research problem identification as shown in Figure 3.1.

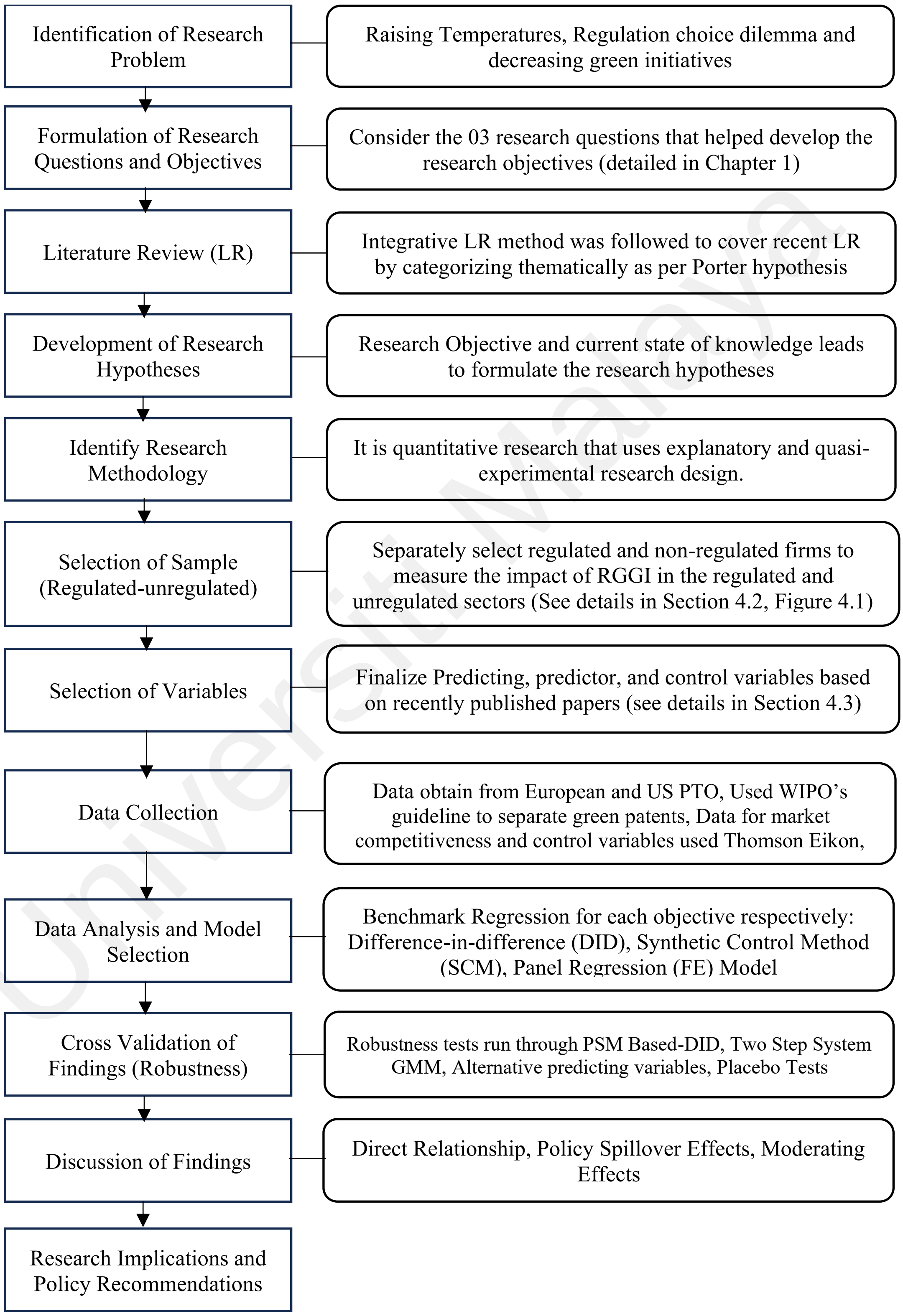

Figure 3. 1: Flowchart of Research Design

3.4 Estimation techniques for benchmark models

This study employed three benchmark empirical models for each of the three different objectives. First, this study used "difference-in-difference (DID)" as a treatment effect model to measure the impact of the RGGI on a firm's innovation in regulated and non-regulated sectors. Second, the "Synthetic Control Method (SCM)" was used to figure out how the RGGI affects a firm's ability to compete in the market. Third, the panel regression (fixed-effect model) was used to analyze the relationship between a firm's innovation activities and market competitiveness. The Eco-efficiency theoretical framework (Porter Hypothesis) and the conceptual model presented so far serve as the basis for all three empirical models.

3.4.1 The Difference-in-Difference estimation

The DID methodology is frequently used in the policy impact analysis literature and elsewhere to compare a treatment group to a control group before and after treatment. Specifically, the DID technique is widely used to determine the results of a policy or any measures. In other words, DID techniques are basic panel-data approaches used to find the mean of a set of groups when only some groups are affected by the variable of interest. It allows for creating a "treatment" and a "control" group to be kept apart. For ETS research, the treatment group usually consists of firms covered by carbon trading restrictions and subject to incentives for environmental initiatives, and the control group consists of other firms not covered by the ETS program. Each group has a time-intermediate dichotomous variable to differentiate between pre- and post-policy shift periods. It allows us to use a DID research design to compare the results of different groups. The DID evaluation of matched data can result in a more conservative estimate since it takes into consideration other characteristics that can often vary by jurisdiction and examines disparities between firms within the same region or state (O'Neill et al., 2016). Therefore, the panel-based DID explicitly helps researchers to measure the actual impact of treatment or policy by "double difference", i.e., the difference between the treatment and control groups before and after the policy effect.

Despite DID's popularity, Besley and Case (2000) cautioned against endogeneity problems in a policy or treatment and advised an examination of the policy equation to identify effective tools. Additionally, Bertrand et al. (2004) demonstrated DID inference problems involving "clustering/grouping" observations which are associated with each other by having shared the individual index 'i' (i.e., on the same individual), the time index 't', or something else such as the firm's age or size. Another inferential problem arises when a treatment varies at the aggregate level, not the individual level. This study verified and confirmed that the policy endogeneity issue is not addressed but is not unique to DID. To keep this section short, this study does not discuss the DID inference issues; interested readers could refer to Lee (2016), Brewer et al. (2018), and Wooldridge (2021), where the key message appears to be "use at least a panel generalized least squares estimator with a clustered variance estimator to account for serial correlations and others."

The states that are part of RGGI can use the revenue from the quarterly auctions to support renewable energy sources. This helps to promote energy efficiency, switching fuels, technological advancement, and real savings for consumers in the form of lower energy bills. Also, green innovation helps companies care more about the environment, improving energy efficiency and reducing pollution. RGGI, on the other hand, reduces emissions of CO2 inside the states that participate. Consequently, the RGGI should increase the firm's green innovation. Thus, implementing RGGI and its effects on firms' green innovation is a quasi-natural experimental method.

In this view, the study sets 'Total Patents (TPAT)' and 'Green Patent (GPAT)' as random variables of firm-level innovation and green innovation, respectively. Only companies regulated within states with regulatory frameworks are impacted. There is now a connection between the RGGI and the regulatory status of both regulated and non-regulated firms. Now, using the "difference-in-difference" concept, it is possible to figure out how RGGI has affected US firms' ability to come up with innovation activities, including green innovation. This is done by separating the "treatment group" from the "control group."

Mainly, RGGI (regulated) = 1 and RGGI (unregulated) = 0 show the companies whose headquarters are in RGGI-covered states (also called a treatment group) and those that are not covered (called a control group). In other words, RGGI=1 means the firm headquarters is in the regulated state (treatment group). Conversely, RGGI=0 implies the firm headquarters is unregulated (control group). Here, the idea is that RGGI only affects treated or regulated firms, which means that only firms in regulated states are affected and treated as regulated firms. Consequently, the effect of RGGI on the firm's innovation and green innovation is *E(Green Patent|Regulated = 1)* in the treatment group and *E(Green Patent|Unregulated = 0)* in the control group. Thus, the analysis establishes the causal relationship of the RGGI on the regulated firms. Thus, the real effect of RGGI on the firm-level innovation activities (i.e., innovations and green innovation) of the treatment group is well-defined as follows:

$$Y = E(TPAT \ or \ GPAT | Regulated = 1) - E(TPAT \ or \ GPAT \ | Unregulated = 0) \ldots\ldots (3.1)$$

Based on the quasi-natural experiment of the RGGI, a CO_2 emission regulation was induced in January 2009 in the ten northeastern states of the US. According to the study's labelling, the years 2000–2008 are considered "pre-treated," the years 2009–2019 are considered "post-treated" after the successful implementation of RGGI, and the years 2000–2008 and 2009–2019 are considered "pre-control" and "post-control," respectively, in the treatment group and the control group. In Eq. (3.2), the term ‘PAT’ defines as a firm's annual accepted patent applications. Then, the pure effects of RGGI on innovation (TPAT) and green innovation (GPAT) of selected enterprises were calculated by comparing the change between the treatment and control groups before and after the adoption of the RGGI-based difference-in-difference concept.

$$(PAT_{Post\ Treated} - PAT_{Pre\ Treated}) - (PAT_{Post\ control} - PAT_{Pre\ control})\text{......(3.2)}$$

This study ran the DID benchmark regression suggested by Brewer et al. (2018) and Wooldridge (2021), which helped this study avoid the serial correlation or other statistical issues of the panel-based treatment effect model. Equation 3.3 specified the DID model as follows:

$$Y_{n,s,t} = \propto + \beta_1 RGGI_{nt} + \beta_2 YD_{nt} + \beta_3\, RGGI_{nt} \times YD_t + \beta_4 X_{nt} + \gamma_n + \delta_t + \varepsilon_{nt}\text{.......(3.3)}$$

In Eqn. (3.3), Y_{nst} denotes the firm's total patents in case of innovation and the firm's green patents for green innovation in respective jurisdiction 'n', sector 's' in year 't'. The $RGGI_{nt}$ is an indicator for policy intervention, 1 for regulated states and '0' for non-regulated states. YD_t is the indicator for the time of RGGI deployment, 1 if the time is greater or equal to 2009, and "0" otherwise. The interaction term "$RGGI_{nt} \times Year\ Dummy_t$" is a multiplication of regulation and year indicators, i.e., $RGGI_{nt} \times Year\ Dummy_t = (RGGI \times YD)$, for instance, 1×1=1, and 1×0=0. Moreover, X_{nt} representing vector of covariates, γ_n and δ_t represent time and sector-specific factors. The coefficient β_3 the consequence of policy intervention and a firm's green innovations for regulated and non-regulated firms.

3.4.2 The Synthetic control model estimation

Based on the "strong version" of PH, this study investigates the effects of RGGI deployments on the market competitiveness of U.S. companies from regulated and unregulated sectors between 2000 and 2019. Thus, this study intends to measure the direct impact of policy on the regulated sector and the policy spillover effect on the non-regulated sectors. Most of the recent studies tested the "strong version" of PH based on panel data, but they used Tobit regression (Wu & Lin, 2022), panel data regression (Lei et al., 2022; Naso et al., 2020; Y. Zhang et al., 2022), and the Difference-in-difference (DID) (Liu, Zhou, et al., 2020; D. Q. Shi et al., 2022; H. L. Tang et al., 2020; Y. L. Yang et al., 2021). Among them, DID method becomes the most widely used individual method in causal inference to measure treatment effects in the last decade (Lee & Sawada, 2020). Despite DID's popularity, Besley and Case (2000) cautioned against endogeneity issues in a policy or treatment and urged exploring the policy equation to identify feasible instruments.

However, in the treatment effect model, a vital step in conducting impact research is identifying a plausible control group that is comparable to the treated group besides the treatment. This study accomplished this goal through the use of a data-driven process known as the synthetic control method (SCM), which was initially introduced by Abadie and Gardeazabal (2003) and has since been widely employed in impact analysis (Abadie et al., 2010, 2015). Based on observed measurable attributes, SCM can be used to create a counterfactual treatment-free outcome for the treated unit based on control unit outcomes. With this approach, researchers can select weights that can be used to construct a control group that has outcomes and covariates similar in time to the treated unit, thus reducing the amount of discretion in choosing control groups as well as allowing unobserved factors to change over time in the pre-treatment period (Liu, 2015). Comparative case studies rely heavily on properly selecting control groups (regions), which might be difficult (Abadie et al., 2010). If the comparison regions are not close enough to the states that represent the case under study, any difference in outcomes between treatment and control regions may be due to differences in characteristics (Abadie et al., 2015; Wen et al., 2021). The SCM aims to provide a more realistic assessment of the intervention area, mainly when the study uses a composite of regions rather than just one (Abadie et al., 2010).

Regarding the applicability of the statistical method, the bottom-line understanding is that no method is universally applicable, and all statistical methods are based on some maintained hypotheses. However, in the case panel-based treatment effect model, SCM offers specific benefits over the panel data approach or DID method. For example, SCM is better than the panel data approach when more preintervention periods and covariates are available (Wan et al., 2018). There are further benefits to SCM, including first, it is a non-parametric approach that broadens the scope of the classic DID, and second, the control group weight is based on facts rather than subjective opinion. Third, each control group's part in making the counterfactual state is clearly stated. The counterfactual state is the weighted average of each control group's part. The weights are positive and add up to 1, preventing too much extrapolation. Fourth, before the event, the predictor variables are used to figure out how similar the control and treatment groups are. This avoids the error that comes from comparing areas that are so different. These advantages motivate us to examine the implications of RGGI deployment on market competitiveness using the panel data-driven SCM. This study could employ SCM to ascertain the consequences of the policy intervention. RGGI implementation significantly impacts a region's market competitiveness, represented by the market share of the firms in that region.

Researchers use SCM to determine how the same outcome would change for a group of unaffected areas (Abadie et al., 2010). For instance, Kim and Kim (2016) investigated the impact of RGGI adoption ("policy intervention") on fuel switching ("aggregate outcome") using the SCM. Competitiveness refers to an enterprise's capacity to maintain and increase market share (Nguyen et al., 2021). The scholars addressed the

HHI index, commonly used to assess a firm's or industry's competitiveness. As a result, the HHI is an incredibly robust indicator for determining industrial competitiveness. Higher values indicate that the industry's market share is more concentrated on a few enterprises, meaning less market competition (Moeinaddin et al., 2013).

Moreover, SCM uses panel data to construct a weighted average of untreated areas that most closely match the characteristics of the treated area over time before the intervention (Lee & Sawada, 2020). The intervention's impact is assessed by comparing the results of treated and synthetic areas. The treated area may consist of a single or many regions. This research initially combines data from the intervention areas (Abadie et al., 2010), as recommended by Kim and Kim (2016), where numerous regions, such as the RGGI region, were aggregated with composite RGGI for the case studies. However, Kim and Kim (2016) emphasized a regional-level study. Then this study also found some other firm-level studies where authors can use SCM and composite case studies (Acemoglu et al., 2016; Connelly et al., 2020; Sun et al., 2021; Zou et al., 2020). This study used several steps to measure the impact of US RGGI on a firm's market competitiveness.

Following Abadie et al. (2010, 2015) and Kim and Kim (2016), this study separates firms based on the firm headquarters location. Suppose the observed regions $i = 0, 1, \cdots, N$ where *i=0* is the firms from RGGI regulated states, and $i = 1, \cdots, N$ are firms from controls (unregulated states). The periodical panel setting is $t = 1, \cdots, T$ and separated prior to intervention $t = 1, \cdots, t_0$ and after intervention $t = t_0 + 1, \cdots, T$. Let y_{it}^{N} is the outcome that observed for state *i* at time *t* in the absence of the intervention, for states $i = 1, \cdots, N$ and time periods $t = 1, \cdots, T$. Under no intervention, the result is shown with a superscript *N*. Let y_{it}^{I} is the result that has been consider for state *i* at time *t,* assuming that state *i* is subject to the intervention for the course of time intervals t_0+1 to *T*. It is the effect of the treatment, as indicated by the superscript 'i'. This study is based on the premise that the treatment has no impact on the outcome prior to the RGGI deployment, so for *t*∈*[1, ⋯, t₀]* and *i*∈*[1, ⋯, N]*, and have $y_{it}^{I} = y_{it}^{N}$.

Assume that $\propto_{it} = y_{it}^{I} - y_{it}^{N}$ is the impact of RGGI on the firms from regulated state *i* at time *t* and further assume that d_{it} is an indicator that considers value 1 if state *i* is the subject to RGGI implementation at time *t* and 0 otherwise. The observed outcome for regulated state *i* at time *t* is

$$y_{it} = y_{t}^{N} + \propto_{it} d_{it} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(3.4)$$

The intervention is restricted to the first region (*i=0*) and occurs only after the period t_0, this study has that.

$$d_{it} = \begin{cases} 1 & if\ i = 0\ and\ t > t_0 \\ 0 & other\ wise \end{cases} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3.5)$$

This study aims to estimate $\propto_0 = (\propto_{0.t_0+1}, \propto_{0.t_0+2}, \dots.\propto_{0.T})'$. For $t>t_0$

$$\propto_0 = y_{0t}^{I} - y_{0t}^{N} = y_{0t} - y_{0t}^{N} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3.6)$$

Because y_{0t}^{I} is observed to estimate $\propto_{0t}$. This study required to measure y_{0t}^{N}. Presume that y_{it}^{N} is driven by a factor model.

$$y_{it}^{N} = \delta_t + \theta_t z_i + \boldsymbol{\lambda}_t \mu_i + \varepsilon_{it} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3.7)$$

where δ_t is an unidentified mutual time effect, z_i is a $r \times 1$ vector of observed covariates (unaffected due to RGGI intervention), μ_i are variables that remain unobserved over time, θ_t and $\boldsymbol{\lambda}_t$ are unspecified parameters, and ε_{it} are unobserved error terms with zero mean. Consider an N×1 vector of weights, w = $(w_1, \cdots, w_N)' \in [0\ 1]^N$, adding to 1, to reduce the gap between treated firms and the weighted mean of their control counterparts in their baseline characteristics. The posttreatment impact is calculated by subtracting the two variables, in other words,

$$\hat{\alpha}_{0t} = y_{0t} - \sum_{i=1}^{N} w_i y_{i,t} \, for \ t = t_0 + 1, t_0 + 2, \cdots, T \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

Then, this study chooses the vector $w^* = (w_1^*, \cdots, w_N^*)'$ satisfying

$$\sum_{i=1}^{N} w_i^* z_i = z_0, \quad \sum_{i=1}^{N} w_i^* y_{i,1} = y_{0,1}, \cdots, \sum_{i=1}^{N} w_i^* y_{i,t_0} = y_{i,t_0} \cdots\cdots\cdots\cdots\cdots\cdots (3.9)$$

The vector w* is selected to reduce the outcome variable's mean squared prediction error (MSPE) prior to intervention. The MSPE is the total of the squared deviations between “actual RGGI” and “synthetic RGGI” firms for all pre-RGGI eras, MSPE = $E[\sum_{t=1}^{t=t_0}(y_{1,t} - \sum w_i^* y_{i,t})^2]$ for the outcome variable.

In other words, the vector w^* is adopted to reduce the disparity between the treated and synthetic control units in observed and unobserved confounders, i.e., $\|X_1 - X_0W\|$. This study measured the distinction through the distance metric $\|X_1 - X_0W\|$ v = $\sqrt{[(X_1 - X_0W)' V (X_1 - X_0W)]}$, where X_1 is a (k × 1) vector that considers the covariates and pre-treated outcomes for the regulated firms, and X_0 is a (k × I) matrix consider for unregulated firms. V is a (k × k)-dimensional symmetric and positive semidefinite matrix that reflects the relative priority assigned to the *k*th variable in this study. There are numerous options for selecting V; however, Abadie et al. (2010) advocate choosing V and W concurrently to reduce the root mean square prediction. Abadie et al. (2010) demonstrated that if the weighted values of the predictor variables (such as covariates and pre-treatment outcomes) for the control pool are equitable to those of the RGGI firms in Eq. (3.8) and Eq. (3.9). Also, the outcome is a linear function of all potential confounders, then $\hat{\alpha}_{0t}$ is an unbiased predictor of $\propto_0$. Now, this study can evaluate the impact of the regulatory intervention using Eq. (3.8), following the attainment of the vector w* which reduces Eq. (3.9) (for more details computational explanation please read (Abadie et al., 2010, 2015).

Finally, this study follows the stepwise procedural synopsis for SCM, depicted in Figure 3.1. Figure 3.1 illustrates the complete methodological flowchart to investigate the impact of RGGI on a firm's market competitiveness.

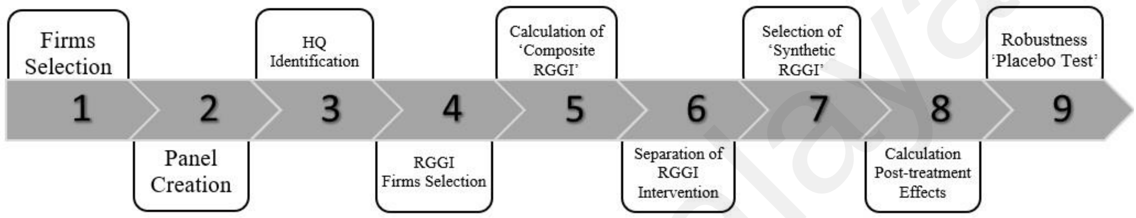

Figure 3. 2: Methodological Synopsis for SCM

Stage 1: Firm's selection for the regulated sector and unregulated sectors

Stage 2: Separation of panels based on regulated and unregulated sectors

Stage 3: Identification of the firm's headquarter location

Stage 4: Separation of firms through dichotomous variable, 1 if the firm's HQ is located within RGGI states and does not change after RGGI implementation and 0 otherwise

Stage 5: Calculation of 'Composite RGGI' based on an optimal weighted average for a convex combination between treatment and control group

Stage 6: Separation of pre-intervention and post-intervention period through dichotomous variable, '0' if 2000≤ t ≥2009 and '1' if 2010≤ t ≥2019

Stage 7: The 'Synthetic RGGI' is chosen based on the optimal weights assigned to linear combinations of variables that minimize the synthetic control estimator's mean square error.

Stage 8: Finally, calculate the Average Treatment Effect (ATT) by comparing the 'Actual Outcome' and 'Predicted Outcome' of post-treatment periods.

Stage 9: Check the prediction results with the 'Placebo Test' with fake treatment units and time.

3.4.3 The Panel regression model estimation

In objective three, this study empirically investigates the relationship between firm-level innovation activities (total innovation and green innovation separately) and market competitiveness based on the following functions:

$$C = \int (I, GI, Z) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3.10)$$

Where C indicates the firm's market competitiveness, I, GI represents the firm's innovation and green innovation activities, and Z is the appropriate covariate.

From 2000 to 2019, panel data for regulated and unregulated enterprises were utilized, and the benchmark model to be tested is built up as in Equation (3.11).

$$Y_{it} = \alpha_i + \beta_{it} TPAT_{it} + \varepsilon_{it} \; (u_i = 0) \cdots\cdots\cdots\cdots (3.11)$$

Here, Y_{it} is the firm's market competitiveness indicating the firm's ability to compete in the market and measured based on Eq. (3.11). 'TPAT' is the firm's annual successfully accepted patent application, a commonly used proxy for a firm's innovation activities. This study used the firm's accepted yearly total patent application (TPAT) as a proxy for the U.S. firm's innovation activities. Moreover, α_i is the fixed effects of the firm i; and ε_{it} is the random disturbance. It is worth noting that this work assumes that the individual impact u_i (cross-sectional or time-specific effect) does not exist (u_i =0), and pooled ordinary least squares (POLS) give efficient and consistent parameter estimations.

There are several benefits to using panel data. However, panel data estimators cannot concurrently manage serial correlation and cross-sectional dependency, which may lead to inefficiency and bias in estimating standard errors (De Hoyos & Sarafidis, 2006; Reed & Ye, 2011). One estimate that may help overcome these challenges is Parks' Feasible Generalized Least Squares (FGLS) estimator (Parks, 1967). Unfortunately, the FGLS estimator cannot be used in this investigation since the number of total periods (T) was not higher than or equal to the number of cross-sections (N) (this study used N = 384 and T = 20). Parks' FGLS estimator also has a documented issue of underestimating SEs in limited samples (Reed & Ye, 2011).

The Wooldridge test for first-order autocorrelation was used in this investigation. The null hypothesis (no first-order autocorrelation) was rejected with extraordinarily high confidence—more than 99.99 percent. It indicates the presence of a first-order autocorrelation or serial correlation reported in Appendix K. Therefore, this study used 'Stata' COMMAND= 'xtreg' with Option= 'Cluster ID' for the name of the cross-section and time variable to minimize the heteroscedasticity, robust serial correlation, and cross-section dependence robust (Drukker, 2003; Reed & Ye, 2011; Wooldridge, 2010). The result of POLS is reported in Appendix L.

3.4.3.1 Panel regression function for fixed and random effect model

This study checked the goodness-of-fit of POLS proposed by Breusch and Pagan (1980) Lagrange multiplier (LM) test for a random effect. The output of the LM test for random effects is illustrated in Appendix M. The output of the LM test indicates the rejection of the null hypothesis (with chibar2(01) = 56695.60; Prob > chibar2 = 0.0000), which means POLS was not able to provide the expected result. Therefore, this study investigated an individual's or time's fixed or randomized impacts. The use of dichotomous variables is the main difference between fixed and random effect models (Park, 2011). In a model with fixed effects, the parameter estimate of a dichotomous variable is part of the intercept. In a model with random effects, however, it is an error term. Slopes stay constant across groups or periods in fixed or random effect models. One-way fixed and random effect models have the following functional forms:

Fixed effect model: $Y_{it} = (\alpha_i + u_i) + \beta_{it} TPAT_{it} + v_{it} \cdots\cdots\cdots\cdots\cdots (3.12)$

Random effect model: $Y_{it} = \alpha_i + \beta_{it} TPAT_{it} + (u_i + v_{it}) \cdots\cdots\cdots\cdots (3.13)$

Where u_i is a fixed or random effect not included in the regression but is particular to an individual (group) or time, and errors are independently identically distributed, v_{it} ~ IID (0, σ_v^2).

A fixed group effect model evaluates individual intercept variations, assuming that all individual units have the same slopes and variance (groups and entities). Because a particular specific impact is time-invariant and is included in the intercept, u_i may be associated with other regressors. In this case, the OLS assumptions are not violated, such as the expectation of disturbances being zero or that disturbances are not connected with any regressors. This fixed-effect model is estimated using "Least Square Dummy Variable (LSDV)" regression (OLS with a set of dummies) and within-effect estimation techniques. In contrast, a random effect model presupposes that the individual effects (heterogeneity) are unrelated to any regressor and then calculates group-specific error variance (or times).

Thus, u_i represents an instance of random heterogeneity or a part of the composites error term. Therefore, a random effect model is sometimes referred to as a model of error components. Individuals have identical intercepts and slopes for regressors, and their unique errors, not intercepts, distinguish individual units (or periods). This study ran the Hausman test to compare the fixed and random effect models to achieve consistent output. In the Hausman specification test, which compared fixed and random effect models under the condition that no regressor is related to any other regressor, individual effects are unrelated to any regressor (Hausman, 1978). The results of the Hausman test are shown in Appendix N. The null hypothesis was rejected because the difference in coefficients was not consistent. This means that the fixed effect model was better in this case.

3.4.3.2 Regression function with covariates and interactive fixed effects

This study introduces the eight covariates to control the influence of other variables on the firm's market competitiveness. Also, this study checked the necessity of a time-fixed effect in the fixed-effect model and found the Prob>F is < 0.05 (indicating to use time-fixed effect in the model) reported in Appendix O. This research contradicts the null hypothesis that all coefficients are equivalent to zero, requiring the inclusion of time-fixed effects in this section. Therefore, Equation (3.11) changes to:

$$Y_{it} = \alpha_i + \beta_{it} TPAT_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.14)$$

where, X_{it} is the vector of covariates representing the firm's characteristic differences from each other. This study also introduced time fixed effect to observe the time-varying impact, which is denoted as γ_t in Eq. 3.14.

3.4.3.3 Regression function for green innovations with covariates and interactive fixed effects

Green innovation is the most accepted tool to hold the firm's high emitting tendency. Though the carbon emissions mitigating regulation is not considered directly in this section, this study intends to examine the firm's green innovation's effects on market competitiveness. Therefore, this study replaced the firms that successfully accepted total patent applications (i.e., 'TPAT') with the firm's green patents application (GPAT) in Eq. 18. Note that this study classified green patents based on WIPO's green inventory. Hence, Equation (3.14) changes to:

$$Y_{it} = \alpha_i + \beta_{it} GPAT_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots\cdots (3.15)$$

3.5 Estimation techniques for robustness test

This study mainly considers the three objectives as three separate relationships. First, the relationship between US RGGI implementation and firm-level innovative activities. Second, the relationship between RGGI and market competitiveness. Third, the relationship between innovation activities and market competitiveness is in the presence of two moderating factors, "RGGI" and "firm's innovativeness". Moreover, this study used 20 years of panel data from 2000 to 2019. Therefore, this study used multiple robustness tests to validate the original findings in each section of the results analysis chapter.

3.5.1 Propensity score matching based DID

This study uses the propensity score matching (PSM) approach to calculate propensity scores (PS) for regulated and non-regulated firms. The PSM-DID method was introduced by Heckman et al. (1998); (Heckman et al., 1997). The general concept is to identify firm j in the control group and discover as many observable features as possible that distinguish firm ‘j’ from firm ‘i’ in the treatment group. PSM-DID can control for observable variable variation, whereas DID can reduce the effects of unobservable factors, such as time-varying changes in variables. DID offers the unique benefit of examining the ATE before and after implementing regulation while qualifying common trend assumptions. However, in conducting causality analysis, DID has limitations in minimizing detectable differences in the firms' unique characteristics between the treatment and control groups (H. J. Zhang et al., 2019). The RGGI is experimental for ten states, not a national policy. Like CN-ETS, this market-based approach to environmental policy is being developed as quasi-experimental (Huang & Zhou, 2019; Lee & Park, 2019). There is a possibility that unanticipated treatment effects could exist in inverse causal relationships (Y. J. Zhang et al., 2019). Based on the PSM score, this study omits firms with no systematic change in PS to account for unobserved treatment effects and reverse the causal relationship. Thus, this study controls the purpose of self-selection bias (Y. J. Zhang et al., 2019). Self-selection bias is characterized as the selection of F500 firms that is not random. It suggests that the RGGI is not the only factor influencing the firm's innovation and green innovation; other firm characteristics (covariates) also play a role. In this regard, the PSM was used to ensure that the effect of RGGI on the innovation was not affected by self-selection bias or endogeneity issues.

Using PSM, this study compares firms in RGGI-regulated states to firms with similar interests but not located in RGGI-regulated states. This methodology establishes a plausible counterfactual context and thus successfully mitigates the effect of selection bias on parameter estimation accuracy (Sun et al., 2021). However, the application of PSM needs to satisfy the ignorable conditional independence assumption (CIA)[2] (Rosenbaum & Rubin, 1983), which implies that conditional on the observable attributes, whether the sample accepts the intervention must be independent of the potential outcome. Although this study cannot test this assumption here, this study could help to satisfy this assumption by controlling more covariates that may affect the treatment participation of the sample (Sun et al., 2021). This study applies the Iterative Comparison Method proposed by Imbens and Rubin (2015) and recently used by Sun et al. (2021); Y. J. Zhang et al. (2019) to choose the covariates for matching[3] and determining of propensity score of regulated and unregulated firms.

Instead of using random sampling, this study uses PSM to choose the companies from the treatment and control groups. Thus far, this study has maintained control over the self-selection bias effects. Nonetheless, there are time or group variances, such as firm

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[2] Multiple terms are used to describe this hypothesis, such as conditional independence and unconfoundedness.
[3] As a covariate screening framework, this method combines data-driven approaches with theoretical considerations.

heterogeneity between regulated and unregulated jurisdictions. Discrepancies in the dynamics of the dependent variables may lead to non-overlapping or density weighting biases (Abadie & Imbens, 2011). Furthermore, PSM is not well fit for analyzing extended panel data settings, whereas DID can only be if the treatment and control groups exhibit similar pre-intervention patterns. On the other hand, panel data is a better option than repeated cross-sections to minimize the treatment endogeneity issue. Additionally, PSM can address endogeneity issues more effectively than DID (Y. J. Zhang et al., 2019). Lastly, this study uses PSM-DID on 20-year panel data to make sure that the real effect of RGGI on the firm's innovation and green innovation is accurately measured, which can lead to stronger conclusions in the next sections.

3.5.1.1 Estimate the propensity scores of regulated firms by RGGI

PSM is a statistical approach that examines non-experimental, quasi-experimental, and observational data to determine the impact of an intervention (Rosenbaum & Rubin, 1983; H. Wang et al., 2019; H. J. Zhang et al., 2019; Y. J. Zhang et al., 2019). The total patents and green patents of firms attributable to RGGI regulation and observable individual characteristics also determine firms' innovation and green innovation and whether RGGI covers the firms. Therefore, the PSM method estimates each firm's propensity score (PS) by observable individual characteristics. The PS determines the probability of selected firms covered by the RGGI. Based on PSM, the chances of a firm being considered a regulated firm by RGGI depends on two specific characteristics. First, the firm's headquarter should be in the regulated states and remain unchanged before and after the effective launch of RGGI, i.e., before and after 2009. Secondly, observable individual characteristics of firms also influence the firms' innovation and green innovation like RGGI. Unfortunately, the study cannot measure state-wise propensity scores because sample firms covered only 38 states (as state selection depends on firm selection) out of

50 states in the USA. According to Angrist and Pischke (2008), fewer clusters are less than 42, and the study covered 38 states with less than 42. They also posit that few clusters mean biased standard errors and misleading inferences and enhance the risk of intra-correlation in the Moulton problem and the serial correlation in random shock. So, the study goes with the second option for PSM. That is, the process of PSM is used to estimate a "propensity score" for each chosen firm based on observable characteristics of that firm. Thus, the propensity score infers the probability of a firm being covered by the RGGI. This study estimates the propensity score process by Probit and Logit Regression, and the function is shown below:

$$P(X_n) = Pr(Regulated_{nt} = 1|X_{nt}) = \frac{\exp(X_{nt}^{'}\beta)}{1+\exp(X_{nt}^{'}\beta)^{'}} \quad (3.16)$$

In equation 3.16, X_n denotes the observable individual characteristics of a firm that may be influenced by the US RGGI whether the firm is covered under regulation or not, whereas $P(X_n)$ denotes the propensity score that infers the conditional probability with the characteristics of X_n that firms will be covered through RGGI. Several individual characteristics are Tobin's q, firm's profile, management ability, firm growth, business ability, innovation ability, leverage, size, and age. '$Regulated_{nt}$' is dummy '1' when the firm is located in the RGGI-covered states and after 2008, '0' for otherwise, and β represents the regression coefficient.

3.5.1.2 Selection of unregulated firms to match regulated firms

This study selected all electric power producing and transmission companies listed on major US stock exchanges for the regulated sector. It rated US F500 companies based on specific criteria to avoid self-selection bias in firm selection. Based on firm-specific observable individual characteristics, the study used nearest neighbor matching (NNM) to select nonregulated firms to compare with regulated firms and keep this study free from self-selection bias. The NNM score directly guided this study to choose N-nearest neighbors from nonregulated firms for each regulated firm, and a simple algorithm is depicted in Equation (4). According to NNM, every regulated firm is matched to its "N" nearest neighbors among unregulated firms (see Equation 3.17). Standing on Abadie and Imbens (2011) for the conceptual framework and Y. J. Zhang et al. (2019) for the similar nature of the study and the current sample size, this study chooses the given formula to estimate the least distance of propensity scores.

$$D(r,s) = \min \|P_r - P_s\| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.17)}$$

In Equation (3.17), $D(r,s)$ denotes the minimum distance of propensity scores (PS) that are estimated from the PS of the regulated firm 'r' (P_r) and Ps of the unregulated firm 's' (P_s). Now, the study is free from the self-selection bias with the help of PSM and ready to estimate the pure effects of RGGI on the firm's innovation and green innovation through the DID model as Equation (3.3).

3.5.2 Dynamic panel model estimation

In addition, a static panel data model lacks an account for these dynamic characteristics, and the exclusion of time lags in corporate innovation efforts may lead to biases, deviations, and inconsistent estimated values (Lin et al., 2019). To reduce the impact of unobservable confounders, it is beneficial to use a two-step GMM estimator in innovation research, particularly when examining firms (Y.-J. Zhang et al., 2020). Followed by Arellano and Bover (1995) and Blundell and Bond (1998), this research constructs a dynamic panel model by adding the lag term of the DV (Y_{nt-1}) on the right hand side of Eq. (3.3).

$$Y_{nt} = \propto + \beta_1 Y_{nt-1} + \beta_2 RGGI_{nt} + \beta_3 YD_{nt} + \beta_4\, RGGI_{nt} \times Year\ Dummy_{nt} + \beta_4 X_{nt} + \gamma_n + \delta_t + \varepsilon_{nt} \ldots \text{(3.18)}$$

This study employs a two-step system GMM in each section to cross-validate the results of benchmark regression.

Moreover, this study also applied a two-step system GMM as robustness in the third object. For this reason, a dynamic panel data model based on Eq. 3.14 was developed to investigate the link between innovation and market competitiveness. The two-step System-GMM model listed below was created:

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_{it} TPAT_{it-1} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.19)$$

where, as noted, Y_{it} represents firm-level market competitiveness measured based on Eq. 4.1, and Y_{it-1} is the lag term of dependent variable. This study also considers $TPAT_{it-1}$as one year lag of all annual patents. All other inclusion remains as same as before; X presents the covariates that affect to the Y_{it}, with θ_i being the matching parameters to be estimated; α is the intercept term; η is the coefficient of Y_{it-1}on the Y_{it}; γ_t represents individual effect, and ε designates the residuals.

This study considers two different interaction terms to measure the moderating effects of the U.S. RGGI. First, this study intends to validate the impact of RGGI between the firm's innovation activities (TPAT) and market competitiveness (Y_{it}). Second, this study considers subsample based on the firm's innovativeness (higher than the mean value of total patents application as discussed before) and then evaluates the effects of RGGI between the firm's innovation and market competitiveness. Equations 3.20 and 3.22 show the regression functions of the moderation effects with dynamic effects.

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_{it} TPAT_{it-1} + \beta_2 Treated_{it} \times TPAT_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.20)$$

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_1 INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.21)$$

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_1 INNOVATIVENESS_{it} + \beta_2 Treated_{it} \times INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.22)$$

In Eq. 3.21 and Eq. 3.22, the term ‘INNOVATIVENESS’ refers to another dichotomous variable, such as it is equal to one if the company has fewer patents than the average patent each year, zero otherwise. Many authors have measured firm innovativeness through various proxies, but this study follows some previous literature in classifying firm innovativeness (Guarascio & Tamagni, 2019; Handrich et al., 2015; Lee et al., 2011; Zaman et al., 2021; Zhuge et al., 2020). Following the previous works by Preacher and Hayes (2004), Lange et al. (2012), and Lin et al. (2019) for assessing the direct and indirect effects of the moderation and mediation models, this study needs only to test the significance of the β_2. In Eq. 4.5, if β is sufficiently positive, this research could say that the RGGI can push F500 firms toward technical innovation. Thus, RGGI stimulated innovation, making them more competitive in the market and helping the PH and vice versa. This study follows the same approach to measuring the dynamic effects of the relationship between green innovation and market competitiveness. In this case, the term 'GPAT' i.e., green patents of the firm is considered instead of total patents 'TPAT'.

3.5.3 DID model specification for robustness test

In terms of objective two, this study uses SCM as a benchmark model compared to DID and PSM-DID to determine how RGGI affects a firm's ability to compete in the market. However, as discussed above, each method has significant advantages over other methods and some noticeable drawbacks. For example, SCM calculates a weighted mean of existing control units and hence a composite outcome compared to treated firms. Because of the aggregation among treated firms, this study could not assess heterogeneity in each firm's or industry's responses to RGGI adoption. This study found firm-specific variation across the regulated sector in firm growth, including firm size, age, performance, leverage, business ability, operating ability, and firm growth with state-specific heterogeneity. Additionally, this study also considers multiple sectors for the unregulated sectors. Thus, a firm's specific heterogeneity is a big concern in this study, especially in this section. This section cross-validates the benchmark model results with DID and PSM-DID to reduce the composite weight calculation or lack of assessment heterogeneity problem. Also, it can help this study overcome the endogeneity issue (Lee & Melstrom, 2018).

Using panel data for firms from different states in the U.S., this study employs the DID estimator to analyze the effects of RGGI on firms' market competitiveness in the United States. This section presents the empirical strategy and discusses various threats to the identification strategy. The results are reliable if the regional exposure to RGGI was essentially random and there was no correlation with potential outcomes. However, the exogeneity assumption may not be fully satisfied; some states' characteristics may influence market competitiveness. Unlike ordinary least squares (OLS), DID does not require the random distribution of regulatory effects in different states; however, it requires the parallel trends assumption between the treated and the untreated (control) group to be passed (Sun et al., 2021). This section conducts an ex-ante common trend test as motivated (Sun et al., 2021). This study controls the necessary covariates in the model to address selection bias and make the treatment and control group trends as parallel as conceivable. Some states' changes in other policies or the unobserved characteristic variables can invalidate the similar trend assumption. This section isolates the changes in unobserved states' characteristic variables by controlling the state's fixed effects and the correlations between the state's fixed effects and the time dummy and carries out multiple robustness tests to guarantee the credibility of the findings. This study matches the firms in the control group using propensity score matching (PSM) to make it easier for the firm-level market competitiveness in different states to satisfy common trends.

The basic DID model for both regulated and non-regulated firm-level panel data is as follows:

$$y_{it} = \alpha_i + \beta_{it} Treated_{it} + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.23)$$

Where y_{it} is the variable representing the firm's market competitiveness; α_i is the fixed effects of the firm i, and ε_{it} is the random disturbance. $Treated_{it}$ is the treatment variable, i.e., $Treated_{it} = RGGI_i \times Year\ Dummy_t$. $= RGGI_i$ is representing policy intervention 1 if the firm headquarters is located in the RGGI-regulated states; for other firms, it is '0'; $Year\ Dummy_t$ is representing the implementing year of RGGI, i.e., it is 1 if the year is ≥2009, and for another year from 2000 to 2008, it is '0'. If the treatment and the control group qualify for the common trend assumption, then β_{it} is the impact of RGGI on a firm's market competitiveness. Moreover, y_{it} represents the firm's ability to compete in the market, estimated based on the following measurement scale discussed in Eq. (4.1) and Eq. (4.2).

This study introduces the eight covariates to control the influence of other variables on the firm's market competitiveness. As a result, Equation (3.23) changes to:

$$y_{it} = \alpha_i + \beta_{it} Treated_{it} + \theta_i X_{it} + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.24)$$

In the state panel data, X_{it} is a vector of covariates representing firms' differences from each other. In the analysis of firm-level data, the covariates include firm characteristic variables.

This study also introduced time fixed effect to observe the time-varying impact, which is denoted as γ_t in the Equation below. Additionally, as the states enact different policies, including economic and environmental policies at different times, a term representing the state-year interactive fixed effect, as $\alpha_i\gamma_t$ is introduced into Equation (3.24) to isolate the state's differences.

$$y_{it} = \alpha_i + \beta_{it}Treated_{it} + \theta_i X_{it} + \gamma_t + \alpha_i\gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (3.25)$$

In the above Equation, when conducting regulated firms' analysis, $\alpha_i\gamma_t$ represents the state-year interactive fixed effect. When analyzing non-regulated firms' data, a sector-year interactive fixed effect is further introduced into $\alpha_i\gamma_t$. This study ran the DID benchmark regression using the most recent approach to minimize the serial correlation or other issues (Brewer et al., 2018; Wooldridge, 2021).

3.5.4 Placebo test-fake treatment units

This study faced a dual dilemma, such as the SCM approach favoring a placebo test over a statistical test for robustness check, but the number of potential control units should be limited, not large (Abadie et al., 2010). This study overcomes these challenges by limiting the firm's average market share from 0.05 to 0.15 (±0.05 of the mean value of 'Real RGGI' and 'Synthetic RGGI') and found 41 potential control units. The main idea is that this study considered all 41 potential control firms as fame-treated units and ran the SCM to examine the deviation of treated and control units. According to Abadie et al. (2010), this analysis implies that the RGGI program was added to a limited number of unregulated enterprises in the donor pool in 2009. Then, this study employed synthetic control estimates for every unregulated business to undertake a series of placebo tests to evaluate the estimated impacts of RGGI implementation on actual regulated enterprises and the distribution of placebo effects for non-RGGI firms.

3.5.5 Placebo test-fake treatment times

This study used a placebo test to determine how well this section works. Instead of the real intervention in 2009, the policy intervention was changed in 2007 and 2008. However, members of the donor pool remain unchanged. This study refers to these tests as “fake treatment times placebos.” This fake treatment time placebo test required adequate periodic coverage before and after the policy intervention (Abadie et al., 2015). This study does not face any challenges due to the extensive coverage period from 2000 to 2019.

3.5.6 Alternative measures approach

Next, this study tests the alternative measure of a firm’s market competitiveness as the market share calculated in Eq. (4.1) suffers from some lack of precision. For instance, the term "industry" is similarly broad (4-digit SIC code), and it is unclear if enterprises in a particular industry compete based on products or pricing. Furthermore, this analysis does not differentiate between current competitors and possible newcomers to the market (Karuna, 2010; Li, 2010). As a result, this study uses sales growth to competitors to create product market competitiveness (J. Hu et al., 2021). As a result, this study follows past research (Campello, 2006; Fresard, 2010; J. Hu et al., 2021) in computing competitive values by dividing the difference between firm to industry-average annual sales growth by the industry's standard deviation. Therefore, the alternative measures of market competitiveness will make another robustness of original findings.

3.6 Chapter Conclusions

Based on the Eco-efficiency theoretical framework (generally known as Porter Hypothesis) and the conceptual model presented in Figure 2.3a and Figure 2.3b so far serve as the basis for all three empirical models. This study employed three benchmark empirical models for three different objectives. First, this study used "Difference-in-Difference (DID)" as a treatment effect model to measure the impact of the RGGI on a firm's innovation in regulated and non-regulated sectors. Second, the "Synthetic Control Method (SCM)" was used to figure out how the RGGI affects a firm's ability to compete in the market. Third, the panel regression (fixed-effect model) was used to analyze the relationship between a firm's innovation activities and market competitiveness.

This study considered a series of robustness tests to cross-validate the original results of each objective based on different conditions and circumstances. For objective one, this study used PSM-DID to minimize the self-selection biases, endogeneity, and serial correlation issues. For the dynamic nature of firm-level innovation activities, this study cross-validated the original findings through the dynamic panel estimation, namely the two-step system GMM. For objective two, this study considers a few robustness tests such as DID, PSM-DID, Placebo tests, and alternation measures of the dependent variable. For objective three, this study again used dynamic panel estimation to cross-validate the relationship between innovation activities and market competitiveness.

CHAPTER 4: ESTIMATION OF VARIABLES AND DATA

4.1 Introduction

This chapter mainly explains three issues, namely selection of the sample, estimation techniques of variables, and overview of data. In Chapter 4.2, this study explains how firms are selected for regulated and non-regulated sectors, with exclusion criteria for the final selected firms. In Section 4.3, this study explains the technique of measuring variables, including predicted, predictors, and control variables. In Section 4.4, the data overview is explained, which includes data sources and descriptions, including pre-estimation problems based on actual data. This chapter concludes with a summary discussion in Section 4.5.

4.2 The selection of the sample

As mentioned in the previous sections, the US RGGI is a pilot market-based regulation implemented to cover the electric power sector in the ten northeastern states of the US. Hence, this study considers the 'Electric Power Generation, Transmission and Distribution (NAICS 2211)', and 'Natural Gas Distribution (NAICS 2212)', as regulated firms. This study only considers listed firms for higher similarity and reliability data. On the other hand, inventing and filing patents, i.e., pursuing innovations, are expensive processes (D. Y. Zhang et al., 2019); as a result, a company's financial strength and capacity for innovation initiatives are strongly interconnected. Meanwhile, more than 35% of the global top 100 innovating companies are US-originated, and most of these companies ranked in the US F500 (Derwent-Index, 2019). Therefore, the selection of F500 companies offers the dual advantage of covering high-performing (total revenue) companies and patent activities. Based on the Fortune 500 database, this study initially screened 1015 U.S. companies for the non-regulated sector between 2000 and 2019 and considered specific criteria for finalizing the sample companies.

This study chooses states based on where the headquarters of F500 companies are located. Companies are then put into groups based on whether they have adopted RGGI and what year this happened. This strategy of selecting firms before states help avoid self-selection bias since this study aims to compare treatment effects in RGGI-regulated states and other states. Figure 4.1 illustrates the selection of sample firms for regulated and non-regulated sectors. Initially, this study screened 2883 firms for regulation but selected 110 firms (110 companies, or 2200 firm-years) listed in the major US stock markets.

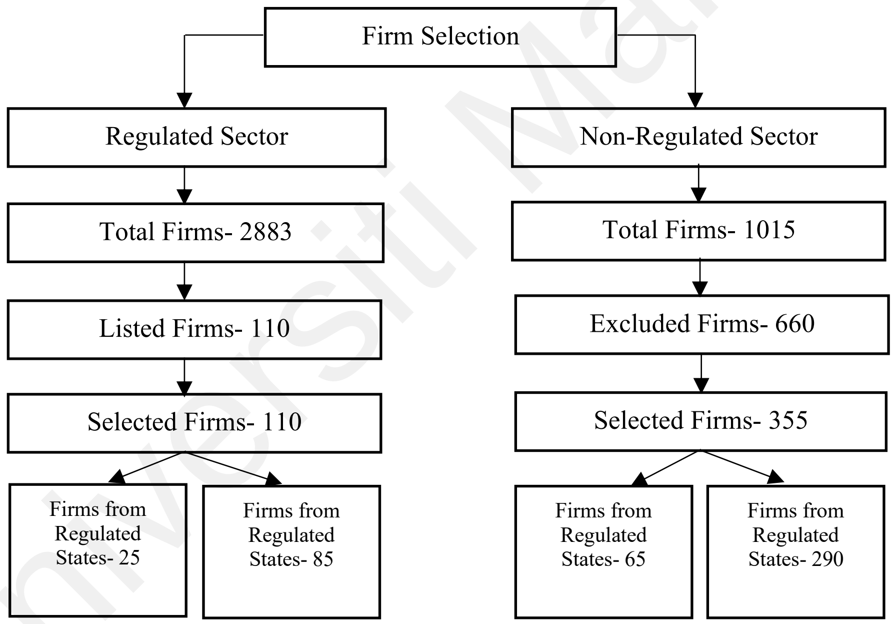


Figure 4. 1: Selection of sample firms for regulated and non-regulated sectors

For sectors that are not regulated, this study started by finding 1015 US companies on the US Fortune 500 list from 2000 to 2019. They were chosen based on specific and clear criteria. Table 4.1 illustrates the exclusion criteria and process for selecting sample firms for non-regulated sectors. Finally, this study selects 355 firms as non-regulated firms from 2000 to 2019, thus representing 43 states in the USA. In the case of non-regulated sectors, 65 firms' headquarters are in RGGI-regulated states, whereas 290 companies are from non-regulated states.

Table 4. 1: Firms' selection process for non-regulated sectors

Selection Step	Particulars	Number of Companies
Step-1	Total ranked companies in F500 from 2000 to 2019	1015
Step-2	Exclusion of all financial companies, namely 1. Commercial Banks 2. Diversified Financials 3. Financial Data Services 4. Securities 5. Insurance: Life, Health (Mutual) 6. Insurance: Life, Health (stock) 7. Insurance: Property and Casualty (Stock) 8. Insurance: Property and Casualty (Mutual) 9. Financial data services	151
	Total number of companies after the exclusion of all financials	864
Step-3	Excluded 'Delisted,' 'Unlisted,' 'Merged,' and 'Private' Companies	371
	Total number of companies currently listed in NYSE, NASDAQ	493
Step-4	Headquarters located outside of the US	08
	F500 listed firms' headquarter are located in the US	485
Step-5	Firms founded after 2009	35
	Total currently listed but founded before 2009	450
Step-6	Firms ranked less than three times in the F500 list	21
	Total listed F500 Firms ranked more than three times in F500	429
Step-7	Change Headquarters' location after 2009	38
	Total Firms for selection	391
Step-8	Firms from the regulated sector	36
	Selected Firms for non-regulated sectors	355

4.3 Estimation technique of variable

This section summarizes the conceptual explanation and measurements of the variable used in this study. This study used predicted or dependent variables, predictor or independent, moderating, and control variables. Definitions and measurements of all the variables are also shown in Table 3.2.

4.3.1 Predicted or dependent variable

4.3.1.1 Measuring Innovation

Research and development (R&D) data provide a simple indicator of innovation activities. R&D contributes to the innovation process. Variations in environmental R&D expenditures reveal the relative significance of such innovation. As R&D is an input, however, metrics of R&D effort do not provide insight into the consequences of the innovation process. In addition, specific information on certain kinds of R&D is frequently unavailable (Popp, 2019). In recent studies, authors have used various measurement proxies for corporate innovation activity, but mostly they have used the total number of patents registered by the firm. Appendix H illustrates the proxies for corporate innovation activity that have been used in recent research to measure the quantity of firm-level innovation. Licensing patents is another way of evaluating innovation. Because patent applications are often submitted early in the research process, they are a useful predictor of R&D activity when sorted by filing date (Popp, 2019). Consequently, the number of patents granted may be used as an indicator of the intensity of innovation.

Patents are in-depth documentation of every innovation. Information about the inventor and its place of origin, the innovation itself, and related patents may all be obtained from the bibliographic information associated with a patent. Utilizing patent data allows researchers to acquire data in very comprehensive formats. Patent classifications can distinguish between different forms of R&D, for example, air pollution control devices to reduce NOX and SO2 emissions. Recent efforts by the European Patent Office to classify sustainable technology patents using the "Y scheme," which provides separate classifications for technologies on climate change mitigation and adaptation and intelligent grids, are particularly useful to researchers. These classifications go along with standard patent classification schemes like the Cooperative Patent Classification (CPC) and the International Patent Classification (IPC). They group relevant technologies in an extensive range of traditional patent categories (Angelucci et al., 2018; Veefkind et al., 2012). Following the recent studies by Scarpellini (2019) and J. Hu et al. (2020), this study used the firm's total successfully accepted patent applications as a proxy for the firm's innovation activities.

4.3.1.2 Measuring Green Innovation

Many researchers relied on the Pollution Abatement Costs and Expenditures (PACE) survey to measure corporate environmental consciousness for a long time. Inadequate data quality is to blame for PACE's inability to accurately reflect a company's green initiatives (Jaffe & Palmer, 1997). Recently, empirical studies have used several proxies to measure firms' green activities, as illustrated in Appendix H. Some authors used green patents by separating them from the total patents through ‘green keywords’ to measure FGI (D. Y. Li et al., 2019; L. Zhang et al., 2019). But this proxy could be inappropriate for two reasons: first, a few words are insufficient to establish green identification. Second, it's more important to use the international patent classification (IPC), which the WIPO and OCED pushed for in 2010 and 2015. To avoid controversy, like Ghisetti and Quatraro (2017) and Z. Yang et al. (2020), this study quantified by counting the annual total green patent applications of each sample firm defined in WIPO’s green inventory or IPC list for Environmentally Sound Technologies (ESTs).

4.3.1.3 Measuring Market Competitiveness

As noted, measuring firm-level competition and market competitiveness is complex. However, many authors have recently measured firm-level competitiveness and market competitiveness using various proxies as illustrated in Appendix I. According to theory, a firm can expand the business scale through innovation activity. Scale growth enables firms to gain market share, which tends to boost their competitiveness in terms of market share (Nguyen et al., 2021). Thus, this study considers market share as an outcome variable in this section. This study redefined the firm’s market share as

$$y_{it} = \frac{x_{it}}{\sum x_{jt}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4.1)$$

Where, x_{it} is the sales of the firm *i* in the year *t,* $\sum x_{jt}$ sales of industry *j* in the year *t.* The 'j' or respective industry was defined as a 4-digit GICS (Global Industry Classification Standard) code (Przychodzen, 2019; Tian & Twite, 2011). Further, the firm's sales are considered as total annual sales revenue.

Next, this study tests the alternative measure of a firm's market competitiveness as the market share calculated in Eq. (4.1) suffers from some lack of precision. For instance, the term "industry" is similarly broad (4-digit SIC code), and it is unclear if enterprises in a particular industry compete based on products or pricing. Furthermore, this analysis does not differentiate between current competitors and possible newcomers to the market (Karuna, 2010; Li, 2010). As a result, this study uses sales growth to competitors to create product market competitiveness (J. Hu et al., 2021). This concept is congruent with the literature on corporate strategy, which defines competitiveness as an organization's strength compared to competitors (Porter, 1997). When competing in a market, the primary goal is to increase market share at the expense of competitors (J. Hu et al., 2021). Product market competitiveness measures a company's ability to compete with its competitors in the industry and shows how competitive the company is. It can be measured by comparing a company's sales growth to its competitors in the industry.

As a result, this study follows past research (Campello, 2006; Fresard, 2010; J. Hu et al., 2021) in computing competitive values by dividing the difference between firm to industry-average annual sales growth by the industry's standard deviation. The following equation illustrates how the measurement is calculated.

$$Competitive_{i,t} = \frac{Growth_{i,t} - IndMeanGrowth_t}{IndSDGrowth_t} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4.2)$$

"Growth" is a measure of a company's annual sales growth. *"IndMeanGrowth"* measures the industry's average yearly sales growth rate. An industry *"IndSDGrowth"* year reflects the average standard deviation of sales growth across all companies.

4.3.2 Predictor or independent variable

The impact of environmental policy on innovation can only be estimated using concrete environmental policy actions. During the last decade, scholars have made substantial progress in analyzing the effects of various policy tools on environmental technologies. For example, Jaffe and Palmer (1997) and Brunnermeier and Cohen (2003), two of the first empirical studies, employed pollution abatement control expenditures (PACE) as a stand-in for the stringency of environmental regulations. Other research concentrates on pricing and innovation, implying that stricter environmental rules increase costs (Popp, 2002). Policy tools have been studied in more detail. Researchers in many fields have analyzed survey data to learn more about different kinds of policies, the importance of such policies, and the degree to which they are consistent.

Recent studies have used 0/1 dummies to represent multiple policy choices. Motivated by those recent studies, this study followed the dichotomous (0/1) variable separation approach as a predictor variable for policy intervention. Emphasizing the market-based environmental regulations or emissions trading system, some authors employed the DID method with the micro-and-macro-level panel data, e.g., Ren et al. (2020a), K. Tang et al. (2020), Lyu et al. (2020), Qu et al. (2022), Q. Liu et al. (2022), and Li et al. (2021). Using policy descriptions and implementation years, they split the regulated and unregulated sectors and made 0/1 dummies to measure the before and after effects.

4.3.3 Control variables

To avoid the bias caused by the fact that firms are different in ways that cannot be easily observed, some control variables were added to make sure the results were correct. These control variables are discussed in the following sections.

4.3.3.1 Tobin's Q

Tobin's Q is the ratio of a company's market capitalization to its total book value of assets (Dechezlepretre et al., 2019; Shin et al., 2018). Tobin's Q is a helpful metric that may be used as a stand-in for the company's worth from an investor's viewpoint (Tobin, 1969). Tobin's Q is a normalized performance indicator that enables meaningful comparisons across enterprises and sectors because of the ratio it is based on (Chung & Pruitt, 1994). Brainard and Tobin (1968) and Lang et al. (1989) found that Tobin's Q was a good indicator of investment opportunities, growth potential, and the overall quality of management teams.

The concept of Tobin's Q is commonly used in studies examining the value of companies (Miroshnychenko et al., 2017; Yu et al., 2018). This indicator shows how profitable a company is now and how it could grow in the future (F. Zhang et al., 2020). In addition, Tobin's Q is used to evaluate the firm's performance, which has a substantial favorable impact on the firm's innovative activities (Cabeza-Garcia et al., 2021) and positively affects the firm's productivity and environmental impact (Seclen-Luna et al., 2021). However, ecological regulation negatively affects the performance of highly polluting firms in China due to improving their green innovation investment (X. T. Liu et al., 2022). According to the past literature, a firm's value can influence the relationship between environmental regulation and the firm's green innovation. To avoid this problem, the study aims to control the firm's value using Tobin's Q (mostly accepted proxy for the firm’s long-term value). Referring to the ‘*Thomson Eikon and Datastream, this study calculates Tobin’s Q’* as the ratio of the firm’s market cap to the book value of total assets.

4.3.3.2 Firm Size

The firm's size is measured as company “Market Capital (MC)”, i.e., the multiplication of the number of Share types outstanding and average market value. This study considers the logarithm of market capital to minimize the scale difference between small and large firms. Meanwhile, many recent studies have controlled the firm size (Lin et al., 2020; Rezende et al., 2019; Z. Yang et al., 2020; F. Zhang et al., 2020). Moreover, the firm size significantly influences the relationship between the firm’s innovation activities, productivity, and environmental impact (Seclen-Luna et al., 2021). In addition, they found that innovation strategies had a more significant beneficial influence on the environment in large companies than in small ones. Therefore, this study also controlled the size to reveal the actual impact of RGGI on firms' innovation activities and market competitiveness.

4.3.3.3 Firm Age

Firm age is measured by business duration minus the founding date in years. Experts found a significant relationship between the firm’s number of years in business and its performance (Coad et al., 2018). Mature firms tend to perform higher than young firms (Xue, 2019). In addition, firm age may indicate how the passing of time affects the green reputation (Xie, 2019). This study follows prior studies to calculate the firm’s age (Yang, 2019; J. M. Zhang et al., 2020). Therefore, this study controlled the firm age so that it might not affect the relationship between the impact of RGGI on firms’ innovation activities and their ability to compete in the market.

4.3.3.4 Leverage

A firm's Leverage generally explains the association of the firm's operational risk, and literature suggests this can influence firms' green innovation behavior and market competitiveness. Furthermore, the financial structure could affect the innovation of corporate technology. A firm with a high level of leverage may suffer severe financial constraints. Therefore, they will not raise R&D expenditures, impacting the firm's innovative efforts. In contrast, financially leveraged firms have a higher asset-liability ratio and are more motivated to establish their credibility with creditors. Companies will be under intense pressure to satisfy stakeholders' expectations for sustainable growth, which includes lowering energy use, decreasing emissions, and developing innovative green solutions. This study used leverage to control the enterprise's financial structure (Bronzini & Piselli, 2016; Y. J. Zhang et al., 2019). Referring to the Thomson Eikon and DataStream databases, this study calculated the firm's leverage as the ratio of total debts and total assets.

4.3.3.5 Firm's Profile

This study limits the firm's profile by its operating profit margin rate; according to the Thomson Eikon and DataStream database, this value indicates the percentage of revenue left after all operational expenditures have been deducted. It is computed as operating income divided by the fiscal period's total revenue (TR) multiplied by 100 (Isaksson & Woodside, 2016). A company's average operating profit rate (AOPR) is a crucial motivator for future R&D investment or independent innovation (Jiang et al., 2018; Yang et al., 2010). In addition, the firm's operating profit margin is also vital for maintaining the firm's ability to compete in the market. Therefore, this study controlled the firm's profile or operating profit margin.

4.3.3.6 Firm growth

The relationship between the firm's patent activities and firm performance is still inconclusive in empirical studies. Some concluded with a positive effect (Cho & Pucik, 2005), and others suggest no relationship exists (Macdonald, 2004). There is a favorable correlation between a company's capacity to innovate and its success and growth (Artz et al., 2010; Cho & Pucik, 2005). Innovation and company growth are not always positively correlated (Spescha & Woerter, 2019). In contrast, sustainable innovation solutions will boost a company's reputation, save additional expenses, and protect the natural environment that draws in consumers. (X. H. Hu et al., 2020). However, green technology has a greater impact on business growth than non-green technology, excluding underperforming or proliferating enterprises (Leoncini et al., 2019). Followed by Kang et al. (2019), Qian and Wang (2020), and Bai et al. (2020), this study measured firm growth as annual sales growth and controlled it to keep the relationship between RGGI and the firm's innovation activities and market competitiveness free from the influence of other firm's characteristics.

4.3.3.7 Operating Ability

A firm's context-specific, dynamic, relational, and humanistic knowledge and actions, tailored to its unique organizational routines, are known as "firm-specific competencies" and are key factors in sustaining innovation (Widya-Hasuti et al., 2018). With the current technology and management level, businesses can only use energy more efficiently to a certain point. To reduce energy use, they must upgrade manufacturing technology and technological innovation (Kang et al., 2018). Enterprises should expend considerable effort to construct contemporary enterprise systems and management reform, consolidate their authority, and prioritize the development of green technologies. Thus, this study considers the firm's operating ability to emphasize technological innovation activities and compete in the market, characterized by the firm's net profit margin measured as net profits divided by revenues (Michaelides et al., 2019; Przychodzen & Przychodzen, 2018). As a result, as proxied by net profit margin, the firm's operating ability always depends on the firm's internal capacity and is influenced by external issues. Therefore, this study controls the firm's operating ability so that it cannot influence the actual impact of policy intervention.

4.3.3.8 Business ability

The firm's return on equity, referring to the 'Thomson Eikon and DataStream,' is a ratio of the company's net income to the total equity of common shares (ROE). In recent studies, ROE has been used to measure a firm's profitability (Tariq et al., 2019; F. Zhang et al., 2020), firm's financial performance (Lin et al., 2021); output factor of market competitiveness (G. C. Chen et al., 2021), and firm's performance (X. T. Liu et al., 2022). On the other hand, return on assets (ROA) was proposed as a useful performance metric for firms in green research (Albertini, 2013; Zhou et al., 2019). Thus, unlike other performance measures, ROA reflects the firm's internal values and demonstrates the effect of resource utilization on projected returns rather than the organization's actions in response to external factors (Y. J. Zhang et al., 2019). However, this study does not want to prolong this debate. Still, it denotes a business ability guided by Shi et al. (2018), which has a significant effect on the firm's investment in R&D expenses. It is generally accepted that the firm's R&D is an essential input to its innovation activities. Therefore, this study controlled the firm's business ability to get an unbiased impact of RGGI.

4.3.3.9 Year, Sector, and State-Fixed Effect

As mentioned earlier, the US RGGI has been implemented in specific sectors and states. This study compares the regulated and unregulated sectors across the RGGI participating and non-participating states. It is widely recognized that a firm's innovation activities and ability to compete in the market varied year, sectoral, and state-wise. For instance, there is substantial intra-industry variation in the impact of environmental legislation, with the effect being most pronounced in strongly polluting sub-industries, less in moderately polluting sub-industries, and negligible in mildly polluting sub-industries (Liu & Xie, 2020a). In addition, they demonstrated that environmental legislation had vastly diverse effects on various technological innovation strategies. Moreover, energy consumption and CO2 emissions also vary in other sectors. This research uses state-sector-year data since firms across the same state may share characteristics, such as tax deductions and wage requirements. Finally, formulations such as state, sector, and year dummies represent the unobserved state and sector fixed effect as well as time-specific effects that are time-varying and universal to all companies. Guided by the recent literature by Zhuge et al. (2020), Liu and Xie (2020a), and Y. C. Hu et al. (2020), this study gradually employed all the covariates, states, sectors, and year-fixed effects to explore the effects in this study context.

Table 4. 2: Summary variables' meaning, measuring method, and data sources

Symbol	Meaning	Variable Calculation Method	Unit	Type	Database
TPAT	Total Patent	Measured as the total number of successful patent grants to individual firms each year	Pieces	DV	USPTO, EUPTO
GPAT	Green Patent	Measured as the number of green patents according to the IPC's Green Patents from the firm's total number of successful patent grants per year	Pieces	DV	USPTO, EUPTO, WIPO
COM2	Market Competitiveness	The ratio of individual firm's sales to aggregate industry (4-digit GICS) sales	Ratio	DV	Eikon, S&P Capital IQ
COM1	Market Competitiveness	Difference between the industry-average sales growth and the firm's sales growth and divided by the standard deviation for the industry	Ratio	DV	Eikon, S&P Capital IQ
RGGI	CO_2 Regulation	It is equal to one if the firms headquarter is in a regulated state, zero otherwise	Dummy	IV	RGGI
YD	Year Dummy	It is equal to one if the year ≥2009, zero otherwise	Dummy	IV	RGGI
INNO	Innovativeness	It is equal to one if the company has fewer patents than the average patent each year, zero otherwise	Dummy	M	USPTO, EUPTO
TQ	Tobin's Q	The ratio of the firm's Market Cap to the Book Value of Total Assets	Ratio	CV	Eikon

FP	Firm's Profile	Firm's Operating Profit Margin	Ratio (%)	CV	Eikon
OA	Operating Ability	Total Net Profit Margin of the firm, calculated as net profits divided by revenues	Ratio (%)	CV	Eikon
FG	Firm growth	Rate of change in current year total revenue relative to the previous year	Ratio (%)	CV	Eikon
BA	Business ability	The ratio of the company's net income to total equity of ordinary shares (ROE)	Ratio (%)	CV	Eikon
AGE	Firm Age	Year since the firm was incorporated	Year	CV	Eikon
SIZE	Size of the Firm	Company Market Capital (MC), i.e., the multiplication of the number of Share types outstanding and the avg. market value	LOG (MC)	CV	Eikon
LEV	Leverage	The ratio of total debts and total assets	Ratio (%)	CV	Eikon

Note. DV, IV, M, and CV denote 'Dependent', 'Independent', Moderating, and 'Control' variables. 'Eikon' means '*Thomson Eikon and DataStream,'* WIPO-World Intellectual Property Organization, USPTO-The US Patent and Trademark Office, and EUPTO-EU Patent and Trademark Office-Espacenet. Innovativeness represents that the firm has higher patent activities than the mean of TPAT; it also represents the firm's green patent activities in the case of green innovation.

4.4 Data overview

4.4.1 Data sources

As discussed in the previous sections, this study intends to investigate the impact of RGGI sets by the US authorities on the firm's innovation activities and market competitiveness. Also, it is explained that RGGI was introduced to hold the greenhouse gas emissions from the electric power sector. Thus, this study identified the electric power sector as a regulated sector. However, based on the findings of previous studies, it is also accepted that market-based carbon mitigation schemes have significant effects on the unregulated sectors. Therefore, this study separately measures the impact of RGGI on both the regulated and unregulated sectors. In the regulated sector, this study considers 'Electric Power Generation, Transmission and Distribution (NAICS 2211)' and 'Natural Gas Distribution (NAICS 2212)' as regulated firms.

On the other hand, this study selected top revenue-earning firms from 2000 to 2019, i.e., the U.S. Fortune 500 companies for unregulated sectors. Meanwhile, inventing and filing patents, i.e., pursuing innovations, are expensive processes (D. Y. Zhang et al., 2019); as a result, a company's financial strength and its capacity for innovation initiatives are strongly interconnected. Meanwhile, more than 35% of the global top 100 innovating companies are U.S.-originated, and most of these companies ranked in the U.S. F500 (Derwent-Index, 2019). Hence, selecting F500 companies provides dual benefits to cover high-performing (total revenue) companies and patent activities.

This study used six different databases to measure the impact of the US RGGI on the green innovation of US Fortune 500 companies. First, the official website of RGGI (https://www.rggi.org) and the United States Environmental Protection Agency (EPA) (https://www.epa.gov) to cast reliable status and information on RGGI and CO2 emissions, respectively. Secondly, a year-wise rank of F500 firms enlisted by the Fortune website (https://fortune.com/fortune500) was collected for F500 companies from 2000 to 2019. Thirdly, the European Patent Office (EPO) (www.worldwide.espacenet.com) and USPTO have been used to gather firms' patent information; EPO, mainly the Espacenet, is the most ancient and the free access patent database that covers more than 120 million patent documents. In the fourth stage, the study classified the patent as a green patent (as a proxy of green innovation) based on IPC’s green inventory classified by WIPO. The study used the S&P Capital IQ and the ‘Thomson Eikon and DataStream’ for all control variables in the last data collection stage.

4.4.2 Data description

As Figure 3.1, this study finally selected 110 firms from the regulated sector and 355 from unregulated sectors. Additionally, the headquarters of the chosen firms are in different states. Hence, the selection of 465 firms (both regulated and unregulated) allows representing a total of 43 states of the US. Table 3.3 illustrates the overview of the firm’s industrial classification based on the ‘North American Industry Classification System

(NAICS)'. The selection of 465 firms confirms representation from 15 NAICS economic sectors, 67 NAICS subsectors, and 134 different industries.

Table 4. 3: Firms Classification based on NAICS

Economic Sector	Sector Code	NAICS Subsector	Industry	Firms
Utilities (Electric Power Generation, Transmission and Distribution, and Natural Gas Distribution)	22	2	2	110
Total Firms from Regulated Sector				110
Manufacturing	31-33	20	50	155
Mining, Quarrying, Oil, Gas Extract	21	3	4	13
Agriculture, Forestry, Fishing, Hunting	11	1	1	1
Construction	23	3	4	13
Transportation and Warehousing	48-49	6	8	21
Accommodation and Food Services	72	2	4	9
Administrative and Support and Waste Management	56	2	5	8
Arts, Entertainment, and Recreation	71	2	2	2
Health Care and Social Assistance	62	3	6	12
Information	51	6	9	23
Professional, Scientific, and Technical Services	54	1	6	18
Real Estate	53	2	5	9
Retail Trade	44-45	12	16	45
Wholesale Trade	42	2	12	26
Total Firms from Non-Regulated Sector				355
Full Sample	15	67	134	465

N.B.: This study considers only two industry groups from Utilities Sector, 'Electric Power Generation, Transmission and Distribution (NAICS 2211)', and 'Natural Gas Distribution (NAICS 2212)' as regulated firms.

4.4.3 Pre-estimation issues

This study emphasized the policy intervention and its impact on firm-level innovation activities and market competitiveness. As a result, this study used treatment effect models based on a quasi-experimental framework such as DID, PSM-DID, and SCM. For instance, the fundamental challenge in DID is to successfully qualify the "Parallel Trend" assumption, i.e., a common or similar trend between the treatment and control groups before policy intervention. Also, the 'Jointly Support Hypothesis test" in propensity score matching is vital before employing PSM-based DID. According to Abadie et al. (2015), in the case of SCM, showing actual data trends is essential prior to implement the

"Synthetic Control Method." Therefore, to over these challenges, this study discussed the pre-estimation issues before implementing the econometric estimations.

4.4.3.1 Parallel trend test

DID has been a remarkably used method to investigate policy intervention for the last couple of decades. Notwithstanding, a parallel trend assumption is one of the main conditions to compare before and after treatment with ordinary least square assumptions (OLS) (Angrist & Pischke, 2008, pp. 171-172). This study measured the parallel trend test proposed by Cerulli and Ventura (2019) before evaluating the policy intervention's average treatment effects for the whole study period with the entire sample. Figures 3.4 and 3.5 depict the results of the average treatment effect (ATE) firm's innovation and green innovation separately. For each year from 2000 to 2019, the ATE(t) estimate of the coefficient of β3 in Eqn. (3.3) is revealed with a segment representing two standard-error confidence intervals. None of the points in Figures 3.4 and 3.5 deviated over two ends of standard deviations from zero. This study should accept the alternative hypothesis that assessed β3 coefficients are different from zero, supporting the common trend hypothesis. Thus, before adopting the RGGI, innovation and green innovation were comparable between regulated and non-regulated states. The 'common trend assumption' is further explained in the next chapter.

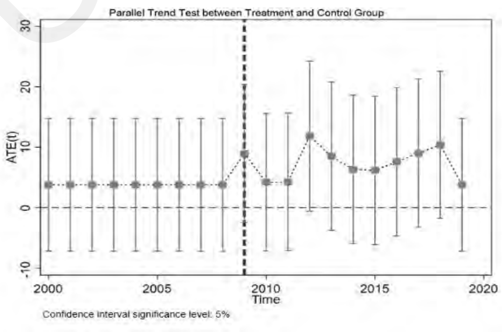


Figure 4.2: Parallel trend test for innovation

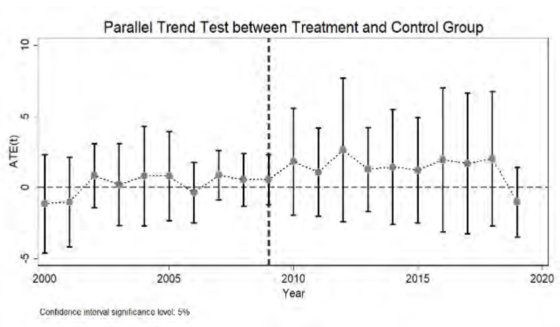


Figure 4.3: Parallel trend test for green innovation

Note: Data are for 2000–2019 of 465 US companies, including 110 firms from the regulated sector and 355 fortune 500 firms from unregulated sectors. Point estimates by year are β3 in Eq. (3.3), illustrating the average treatment effects (ATE) of the firm's TPAT and GPAT, respectively, and the difference between regulated and unregulated states compared to the base year of 2009. Vertical segments capture two standard-error confidence intervals.

Sources: Author Compilation

4.4.3.2 SCM pre-estimation based on actual data trend

As illustrated in Figure 4.4, the remainder of the United States may not be a good reference group for the RGGI region when examining the effect of RGGI deployment. The RGGI implementation is not the only factor influencing a firm's market share. It has shown that market share increases in both regions during the study period. The upward trend may pause in 2009 for the regulated firms. The RGGI region's market share (for regulated firms) slope appears to be faster than non-RGGI areas (for unregulated firms). This research defined synthetic RGGI as the convex composition of other firms in the control group (from 38 states other than RGGI states) that most precisely resembles RGGI in ranging from pre-RGGI market competitiveness. To calculate this, predictors, and covariates in the vector z_i in Eq. (3.7), are carefully chosen. Also, this study considers the pre-interventional outcome variable of 2007 and 2004 as predictors and control variables.

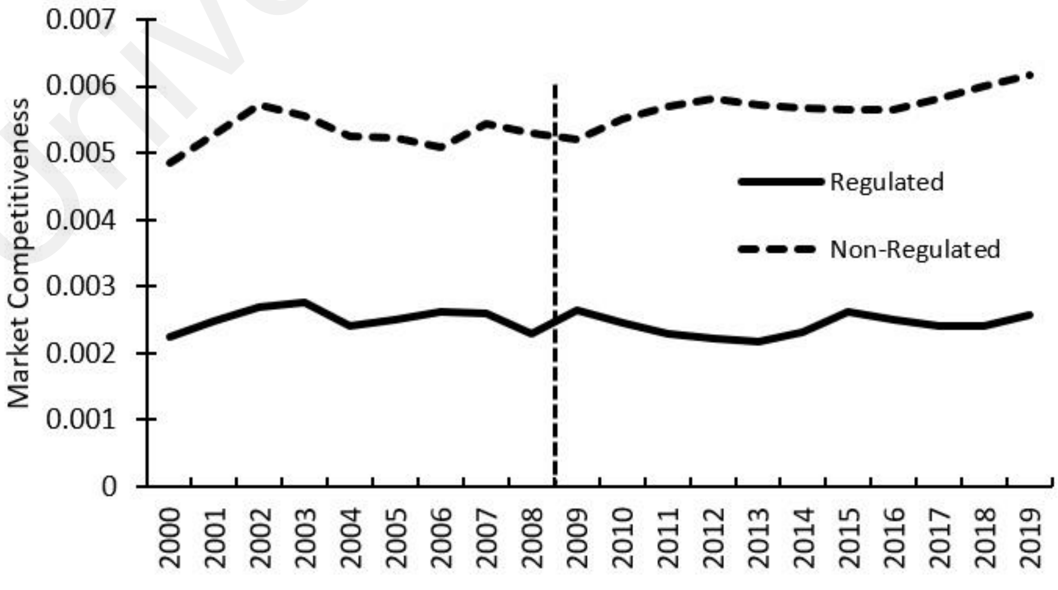


Figure 4.4: Market shares in the regulated sector in the RGGI states and the other U.S. States

Note:

- ✓ The RGGI implemented in 2009 is indicated by the vertical dotted line.
- ✓ 'Market Competitiveness' is calculated by the Eq.4.1 and firms' arithmetic mean.
- ✓ 'Regulated' means the electric power generation and transmission company located and operating in the 'RGGI State'.
- ✓ 'Non-regulated' means the electric power generation and transmission company located and operating in the 'Non-RGGI States'.

Source: Calculated based on S&P Capital IQ data and Eq. 4.1

Figure 4.5 shows the average firm's ability to compete (market competitiveness) between the regulated and non-regulated firms. This study considers the firm's headquarters in the RGGI-regulated states as regulated and non-regulated firms if their headquarters are outside RGGI participating states. Figure 4.5 suggests a wide gap between the regulated and non-regulated firms, especially before RGGI began, which seems incomparable. Therefore, this study required statistical methods to find a better comparable sample between regulated and non-regulated firms. This study classified synthetic RGGI as the convex combination of other businesses in the control group (from 38 states other than RGGI states) that most closely matches RGGI in the pre-RGGI market share values. It is accomplished by selecting predictors that include outcome variables, which are covariates in the vector z_i in Eq. (3.7).

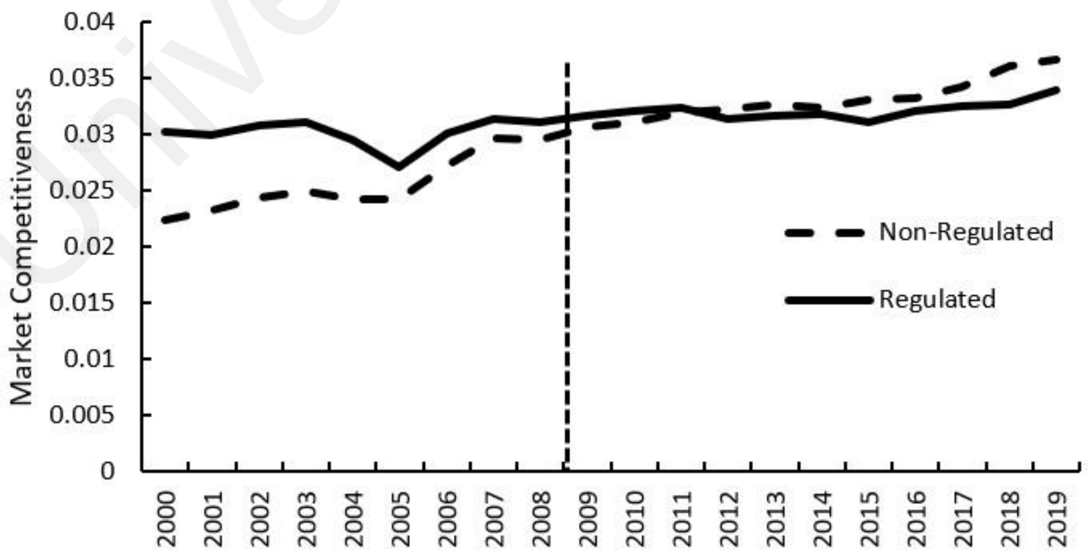


Figure 4.5: Market shares in unregulated sectors in the RGGI and other U.S. States.

Note:

- ✓ The RGGI implemented in 2009 is indicated by the vertical dotted line.
- ✓ 'Market Competitiveness' is calculated by the Eq.4.1 and firms' arithmetic mean.
- ✓ 'Regulated' means the firm from other sectors (excluding electric power generation and transmission) located and operating in the 'RGGI State' .
- ✓ 'Non-regulated' means the firm from other sectors (excluding electric power generation and transmission) located and operating in the 'Non-RGGI States'.
- ✓ No structural break found, results reported in Appendix DD.

Source: Author's measured based on S&P Capital IQ data and Eq. 4.1

4.5 Chapter conclusions

This chapter mainly discussed the firm selection process for regulated and non-regulated sectors, variable measurement techniques, and an overview of data. It is important to understand direct policy effects and spillover effects, which are significantly related to firm selection processes. This section also explains the reasons why certain characteristics of the firm are controlled. Also, this chapter explains pre-estimation issues that are important for the reliability of difference-in-difference and synthetic control models.

CHAPTER 5: RESULTS ANALYSIS

5.1 Introduction

This chapter contains analysis and empirical results presented separately for each objective. In Sections 5.2 to 5.4, this chapter explains the results of objective one, that is, examining the relationship between RGGI deployment and changes in innovation activity, including green innovation. Also, this section discusses the pre-estimation, post-estimation, and robustness tests. In Section 5.5, the effects of RGGI on the firm's market competitiveness in the regulated sectors were shown through a series of robustness validations of the Synthetic Control Method's benchmark results using placebo tests and alternative ways to measure market competitiveness. Using the same method as Section 5.5, Section 5.6 investigates how RGGI affects a company's ability to compete in the market in unregulated sectors. Section 5.7 explains the empirical results of the relationship between the firm's innovation activities (both innovation and green innovation) and its market competitiveness. This includes how RGGI and the firm's innovativeness affect the relationship between innovation activities and market competitiveness. Finally, Section 5.8 explains the chapter’s conclusion.

5.2 Objective One: Impact of the us RGGI implementation on innovation

The consequences of RGGI adoption on innovation activities in US firms are the exclusive focus of this section. Based on the literature review, this study first measures the impact of RGGI on firm-level innovation. Then, it narrows innovation activities to green innovation by distinguishing green patents according to WIPO's green inventory classification. Thus, this objective is divided into two parts: the impact of US RGGI on firm-level innovation and the impact of RGGI on firm-level green innovation. As discussed earlier in the "estimation of variables and data" section (Figure 4.1), this study also separately measures the direct impact of the US RGGI on firm-level innovation in regulated and non-regulated sectors for policy spillovers. This section has two subsections for each part of objective one: DID benchmark model with parallel hypothesis testing and robustness testing in regulated and non-regulated sectors. Cross-validation with propensity score matching based on DID (PSM-DID) with joint hypothesis testing and two-step system GMM for unobservable confounding effects was used to check the result of the DID benchmark regression.

5.2.1 Descriptive statistics

The US RGGI was induced to reduce GHG emissions from the electric power sector of only ten states. Hence, this study considers 'Electric Power Generation, Transmission and Distribution (NAICS 2211)' and 'Natural Gas Distribution (NAICS 2212)' as regulated firms for 20 years (110 companies or 2200 firm-year) and others as non-regulated firms (355 companies or 7100 firm-year). The firms' home states are used to identify the states that have implemented RGGI and those that have not. Priority for companies' selection before states eliminates self-selection bias, particularly in the treatment effect measures between RGGI-regulated sectors/states and other sectors. Table 5.1 illustrates the descriptive statistics of the variables. According to Table 5.1, the average green patent

(GPAT) is 0.20 with a 1.70 standard deviation. However, green patent classification is also very low in empirical firm-level studies. According to D. Y. Zhang et al. (2019), firms' green patenting initiatives by keywords quantified zero at the third quartile level (P75 = 0.00).

In addition, 'COM1' is used as a second proxy for the firm's market competitiveness to capture the degree to which a firm is competitive and to indicate the degree to which it can compete with its competitors in the industry. It is outlined as a company's sales growth compared to its competitors in its industry. Due to the variable calculation function (for COM1), the mean value is negative similar to the original study (J. Hu et al., 2021). Moreover, the mean and median for Competitive are -0.07 and -0.09, respectively. The standard deviation is 0.674. It suggests that the distribution is positively skewed, and there is a considerable variation in observations. Control variables (AGE, OA, BA, and FG) show a significant performance discrepancy.

Table 5.1: Descriptive statistics of the variables

STATS	$\bar{X}$	σ	MIN	P50	MAX	N	R_{St}
TPAT	2.17	14.34	0.00	0.00	293.00	2200	REGULATED
GPAT	0.20	1.70	0.00	0.00	44.00	2200	
COM1	-0.07	0.67	-3.91	-0.09	16.23	2200	
COM2	0.01	0.016	0.00	0.002	0.24	2200	
AGE	66.45	52.03	0.00	44.00	215.00	2200	
SIZE	8.87	1.70	1.48	9.38	11.70	2200	
TQ	2.29	18.51	0.00	0.44	405.59	1899	
FP	8.53	21.53	-287.54	10.91	175.71	2170	
OA	3.29	21.22	-279.17	4.35	439.35	2200	
BA	2.80	49.00	-931.44	6.77	879.16	2200	
LEV	40.56	69.33	0.00	34.09	1718.75	1767	
FG	10.40	92.00	-99.60	0.00	3570.34	2114	
TPAT	102.73	422.04	0.00	1.00	7810.00	7100	NON-REGULATED
GPAT	2.87	11.99	0.00	0.00	224.00	7100	
COM1	-0.10	0.42	-2.16	-0.09	20.15	7100	
COM2	0.03	0.05	0.00	0.01	0.48	7100	
AGE	42.97	36.56	0.00	29.00	219.00	7100	
SIZE	9.90	0.70	6.85	9.90	11.93	6582	
TQ	1.20	1.32	-29.44	0.85	20.95	6818	
FP	10.37	17.43	-829.71	9.05	68.00	7099	
OA	5.87	35.21	-296.93	4.71	2103.33	7094	
BA	20.44	215.48	-1310.87	14.08	10523.08	7100	
LEV	29.12	20.14	0.00	25.97	262.41	6846	
FG	10.00	36.53	-93.10	5.91	967.31	7100	

Note: TPAT= Firm's total accepted patents, GPAT= Firm's total Green Patents, COM2= Market Competitiveness, COM1= Market Competitiveness (alternative DV), AGE= Years of incorporation, SIZE= log of market capitalization, TQ= 'Tobin's Q' measured as market capitalization to book value of total assets; FP= 'Firm's Profile' measured as operating profit margin

(%); OA= 'Firm's Operating Ability' calculated as net profit margin (%); BA= 'Business ability' defined as return on equity (%); LEV= 'Leverage' measured by total debts to assets (%), FG= 'Firm growth' calculated by firm's annual sales growth (%); R_{St}= Regulatory Status.

Patents data collected from the US PTO, EU PTO-Espacenet and the WIPO's IPC Inventory were used for the green patent classification, and S&P Capital IQ; 'Thomson Eikon and DataStream' for the covariates.

Table 5.2 shows the descriptive statistics for full sample firms that measure how firms' innovation activities affect their ability to compete in the market.

Table 5.2: The descriptive statistics for the full sample

STATS	N	MEAN	SD	MIN	P50	MAX
COM2	7680	0.03	0.05	0.00	0.011	0.48
TPAT	7680	88.92	396.49	0.00	0.00	7810.00
GPAT	7680	2.41	10.91	0.00	0.00	224.00
AGE	7680	48.96	39.57	0.00	33.00	196.00
SIZE	7680	22.43	1105.76	0.00	9.86	96832.00
TQ	7672	1.12	1.19	-0.07	0.75	20.95
FP	7679	11.69	16.75	-829.71	10.66	175.71
OA	7675	6.04	14.17	-296.93	5.74	213.32
BA	7680	20.53	206.26	-1310.87	13.17	10523.08
LEV	7680	29.78	17.89	0.00	28.42	262.41
FG	7662	9.10	31.54	-93.10	5.91	967.31

Note: This study considers only the entire sample companies, including regulated and non-regulated sectors

5.2.2 The effect of RGGI on the firm-level Innovation

As mentioned earlier, the RGGI only covers the electric power sector. Hence, in this study, companies in the electric power sector that are listed on the major stock exchanges in the US are thought to be regulated. The non-regulated sectors included the other F500 sectors (for more information, see Section 4.2: The Sample Selection). Thus, this study separated the sample firms into two panels: panel one comprises all the regulated firms generating and transmitting electricity. In addition, all F500 companies except those that generate and transmit electricity were placed in Panel 2 with the other non-regulated companies.

Based on Equation (3.3), the coefficient $\beta 3$ shows how the RGGI affected the firm's innovation (used as a proxy for the number of patents published) with the interaction term (RGGI × Year Dummy) before and after the RGGI adoption.

This study runs six models for regulated and non-regulated firms with changed inclusions, which also help to make the effects of multiple inclusions visible. Table 5.3 summarizes the results. Model 1 has no control variables, fixed effects, or other parts, but other models use it. It serves as a baseline regression model for both regulated and unregulated firms. In contrast, model 6 considered all relevant inclusions.

Table 5.3: The effect of the RGGI on firm-level innovation

Model VARIABLES	**(1) TPAT**	**(2) TPAT**	**(3) TPAT**	**(4) TPAT**	**(5) TPAT**	**(6) TPAT**	**R_{St}**
RGGI × Year Dummy	**4.022***** (0.820)	**3.483***** (0.907)	**3.413***** (0.907)	**7.177***** (1.399)	**7.157***** (1.501)	**7.259***** (1.595)	**REGULATED**
Constant	1.737 (1.099)	0.882 (1.366)	-0.689 (1.576)	-13.82** (5.757)	-8.323 (6.434)	-8.935 (6.618)	
R^2	0.012	0.0152	0.0535	0.0329	0.0366	0.0797	
Firms	110	110	110	102	102	102	
Observations	2,200	2,200	2,200	1,485	1485	1,485	
RGGI × Year Dummy	29.22 (21.35)	6.250 (24.42)	5.784 (24.28)	8.999 (21.37)	19.60 (24.73)	19.14 (24.53)	**NON-REGULATED**
Constant	100.2*** (19.54)	51.05*** (10.58)	95.30*** (22.63)	-787.4*** (269.4)	-864.3*** (291.5)	-808.9*** (292.3)	
R^2	0.0045	0.0033	0.0505	0.0783	0.0831	0.1121	
Firms	355	355	355	355	355	355	
Observations	7,100	7,100	7,100	6,577	6,577	6,577	
Control Variables	NO	NO	NO	YES	YES	YES	
Sector Fixed Effect	NO	NO	YES	NO	YES	YES	
Time Fixed Effect	NO	YES	YES	NO	NO	YES	

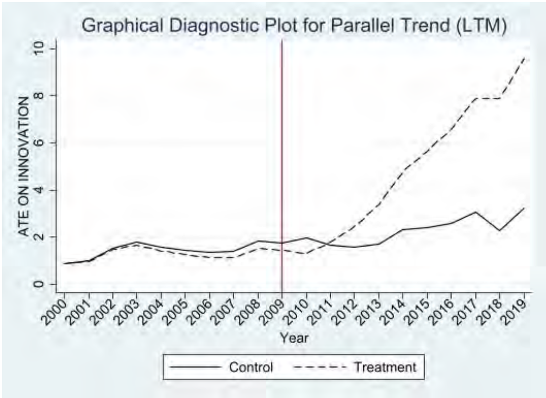
- Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
- **R_{St}** denotes the regulatory status of the firms.
- **Regulated Sector** means all electric producing and transmitting firms listed in the major us stock exchanges and headquarters in the USA.
- **Non-Regulated Sectors** were **s**elected based on multiple criteria from the top 500 revenue-earning firms (Fortune 500) from 2000 to 2019, excluding Financial and Electric producing and transmitting firms.
- **RGGI** defines the firm that is operated and located in the RGGI participating states (i.e., 10 Northeastern States), helping to separate the firms from the regulated sector and regulated states. It is the same for Non-regulated sectors.
- **Year Dummy** used to separate the year before and after RGGI implementation

In the regulated sector, RGGI's average effect on a firm’s innovation (TPAT) is shown in Model 1 (column 1 in the regulated part). Using the interaction term (*β3*) in the benchmark regression, which is 4.022 and statistically significant at a more than 99% confidence level and stays the same in the other models, RGGI adoption increases the number of patents held by companies that are regulated. Also, it showed that the relationship between RGGI implementation and innovation activities in firms was stronger in models 4, 5, and 6, especially when a few firms' specific features were controlled. The coefficient of desire, i.e., the value of β_3, was more than 7.16, almost twofold higher than that of the firm-specific control variable.

On the contrary, in the non-regulated section, the coefficient is 29.22 in benchmark model 1, but this is not statistically significant. All the other inclusions in models 2, 3, 4, 5, and 6 show the same sign and level of significance. During this study, the DID regressions show that RGGI implementation significantly affects innovative companies in the electric power industry. The consistent results in all models with various inclusions show that the baseline DID regression is relatively resilient at the initial stage. Overall, this study can conclude that RGGI positively impacts the firm’s innovation activities in regulated and non-regulated firms. However, the results are not statistically significant in the case of non-regulated sectors.

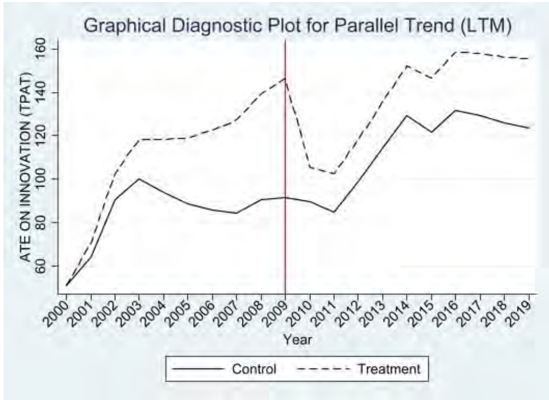
5.5.2.1 The Parallel Trend Test

The main challenge of the Difference-in-difference method is to qualify the similar trend of a firm’s innovation activities before the policy intervention. If the panel data sets do not meet the parallel-trend assumption, then the consistency of measuring impact is low. There are two ways to test the ‘common or parallel trend assumption’. First, the post-estimation of parallel trend tests is used to measure the existence of pretreatment common trends between treatment and control groups. Failing to reject the null hypothesis (i.e., linear trends are parallel) retained the common trend between the treatment and control groups. Figures 5.1 and 5.2 represent the graphical output of common trend test. A pretreatment trend between the treatment and control groups and a p-value higher than 0.05 indicates the presence of a common trend between the two groups.



Regulated Sector

H_0: Linear trends are parallel; $F(1, 109) = 0.58$; Prob > F = 0.4496



Non-Regulated Sectors

H0: Linear trends are parallel; $F(1, 354) = 0.52$; Prob > F = 0.4727

Treatment Year: 2009
Pre-treatment Year: 2000-2008
Post Treatment Year: 2010-2019

Figure 5.1: Parallel trend test (pretreatment-time-period) for innovation

Second, the parallel-trend assumption holds if all the 'Pre' year coefficients are statistically not significant, but the coefficient of constant is significant (Angrist & Pischke, 2008; Cerulli & Ventura, 2019). The results of the parallel trend test for regulated and non-regulated firms are reported in Appendix P. According to Appendix P, this study found that none of the "pre-periodic" coefficients were statistically significant, but the constants were. It was true for regulated and non-regulated firms in Models 1, 2, 3, and 4. Before the RGGI was adopted, this study could not find a significant difference between the treatment group and the control group in the annual accepted whole sample trend, which showed that the parallel-trend assumption was valid. Note that the desired coefficient of interaction instrument term (RGGI × Year Dummy), i.e., β_3 is also like the benchmark DID regression. Hence, it's clear that the RGGI encouraged firms to innovate between 2000 and 2019. No firm characteristics, time frames, or sector-specific effects had a significant impact on this relationship.

5.2.3 Robustness test

To cross-validate the benchmark regression results, this section considers two robustness tests, namely the propensity score matching based difference-in-differences and the two-step system generalization method of moments.

5.2.3.1 Propensity score matching (PSM) based DID

Even though this study shows that the parallel trends hypothesis is true and uses a panel data set to measure how policy interventions affect innovation at the firm level, it is still suspicious of policy endogeneity issues. However, Besley and Case (2000) cautioned against endogeneity issues in a policy or treatment and urged that the policy equation be explored to identify feasible instruments. Panel data are a better way to deal with endogeneity across treatments than repeated cross-sections, and PSM is a better way to deal with endogeneity than DID (Lee & Sawada, 2020). Also, PSM helps to address the endogeneity issue, especially in policy intervention (Lee & Melstrom, 2018). However, PSM is not well suited to exploiting extended time series, but DID can because it is based on parallel pre-intervention trends in the treated and untreated groups (Lee & Melstrom, 2018). Therefore, this study intends to validate the findings with PSM based DID.

As discussed in the previous sections, DID is widely recognized among academics due to some favorable conditions. Yet, it has some statistical inference problems, such as selection bias, endogeneity, serial correlation, and asymptotic distribution. However, a 20-year panel helps this study to evade some of these problems. Bootstrapping is one of the harmless solutions to minimize asymptotic distribution problems (Angrist & Pischke, 2008, p. 227). Additionally, this study employed the Kernel 'Probit' and the 'Logit' to resolve the asymptotic distribution problem. Also, this study used propensity score matching (PSM), specifically the “Nearest Neighbor Matching (NNM)” and kernel matching, to strongly minimize selection bias and endogeneity problems. Two PSM methods, namely Leuven and Sianesi (2003) and Blundell and Dias (2009) are used to perform both 'Probit' and different types of 'Logit' regression with the same inclusions as benchmark regression.

This study separately conducted the jointly support hypothesis testing for regulated and unregulated data proposed by Austin (2009) to keep the results free from biases when matching data for PSM-DID. Table 5.4 presented jointly supporting the hypothesis test for regulated and non-regulated firms. By reducing biases, this test chose a control group that was similar to the treatment group in terms of the "Propensity Score (PS)" of the control group. Results indicate that all variables (dependent and control) are concentrated in bias percentage. Almost all the values are statistically significant in 'Unmatched' but insignificant in the 'Matched' condition. It implies that the original hypothesis is rejected, specifying no systematic difference in the dataset before and after matching other than correction of bias (error of data); thus, the RGGI can be a random allocation experiment.

Table 5.4: Jointly support the hypothesis test for both regulated and non-regulated firms

Variable		REGULATED					NON-REGULATED				
		Mean			%reduct	t-test	Mean			%reduct	t-test
		Treated	Control	%bias	bias	p>t	Treated	Control	%bias	bias	p>t
TPAT	U	6.7021	1.6239	21	68.3	0.00	194.95	93.951	16.2	21	0.00
	M	7.82	1.7669	41.5		0.09	200.8	120.97	12.8		0.33
AGE	U	68.868	66.165	4.7	-111.4	0.05	53.199	41.992	30.7	99.2	0.00
	M	98.654	92.94	9.9		0.46	54.247	54.341	-0.3		0.97
SIZE	U	7.9188	8.9966	31.1	79.9	0.00	10.092	9.8761	30	94	0.00
	M	9.2046	8.9875	0.6		0.17	10.092	10.105	-1.8		0.76
TQ	U	3.2061	2.1829	54.7	-434.9	0.04	1.1572	1.2048	-4.1	45	0.04
	M	4.3159	9.513	11		0.23	1.1707	1.1969	-2.2		0.63
FP	U	5.7224	8.8665	-13.4	-115.2	0.03	14.104	10.016	26.4	99	0.00
	M	8.6425	1.8772	28.8		0.17	14.51	14.552	-0.3		0.95
OA	U	2.1666	3.4299	-5.8	7.2	0.39	8.1679	5.6464	9.1	98.1	0.09
	M	4.105	2.9329	5.4		0.72	8.478	8.4309	0.2		0.96
LEV	U	53.125	39.348	14.5	15.5	0.02	30.609	28.972	8.2	96.9	0.06
	M	58.085	69.727	-12.3		0.46	30.251	30.303	-0.3		0.96
FG	U	20.927	9.0803	7	-117.2	0.06	9.284	10.072	-1.8	18	0.06
	M	34.224	8.4891	15.1		0.34	6.8063	7.4523	-1.4		0.63

BA	U	-3.4771	3.5558	-13.6	63.2	0.04	27.715	19.75	4.4	33.8	0.04
	M	-3.5256	-0.94078	-5		0.69	28.527	33.801	-2.9		0.69

* if variance ratio outside [0.87; 1.15] for U and [0.87; 1.16] for M; U=Unmatched, M=Matched

Graphical visualization of the differences between matched ('×') and unmatched ('•') samples for regulated and non-regulated firms depicted in figures 5.2 and 5.3 represent the standardized percentage of bias across covariates before and after matching. This study found that matched samples are noticeably closer to the grey line at zero than unmatched samples, indicating that the jointly supported hypothesis test successfully allowed us to use PSM-DID.

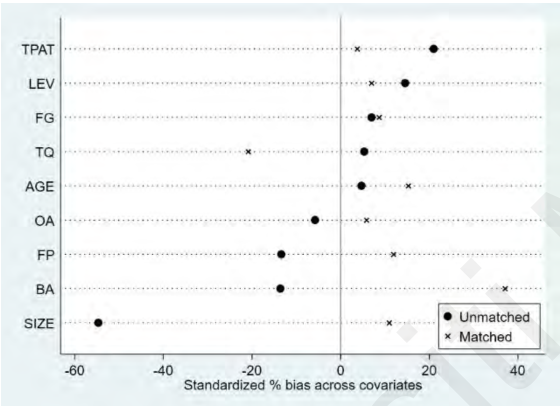


Figure 5.2: Standardized Bias across covariates before and after the matching of variables regulated sector

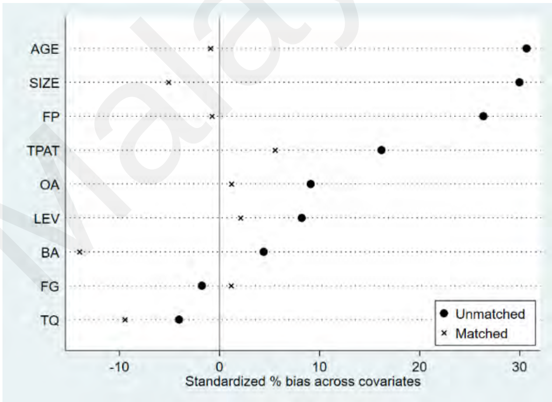


Figure 5.3: Standardized Bias across covariates before and after the matching of variables Non-regulated sector

Source: Graphical Output of Balance Test

After matching both groups and minimizing the biases, the probability density of the propensity scores has mandatorily been consistent (Abadie & Imbens, 2011). Thus, this study calculates the Kdensity balance plot to get visual confirmation of data consistency for both the regulated and non-regulated sectors. Figures 5.4 and 5.5 portray outputs, signifying that the matching effect is improved (compared to raw and matched), allowing this study to apply PSM-DID as the robustness of benchmark regression.

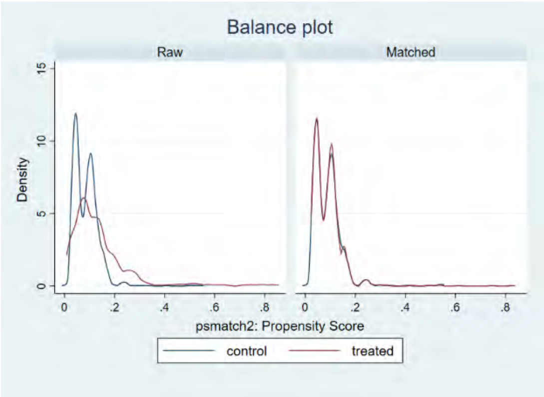


Figure 5.4: Kdensity balance plot for the regulated sector

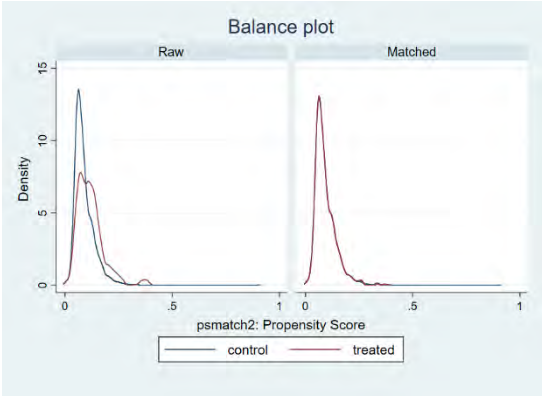


Figure 5.5: Kdensity balance plot for non-regulated sector

Source: Graphical Output of PSM Balance plot

After reducing bias and increasing data similarity in the jointly supported hypothesis test and the Propensity Score (Kernel), this study ran both the Probit and the Logit regressions as a PSM-DID. Table 5.5 depicts all the results of different kernel matching methods for regulated and unregulated firms. Moreover, this study used 500 bootstrapping replications to minimize the asymptotic distribution problems, especially the standard error issue. The coefficient of interest, specifically the coefficient of policy interaction instrument (RGGI × Year Dummy), mirrored the benchmark DID regression. It indicates that the RGGI has a positive and statistically significant influence on firms' innovation activities in the regulated sector. Also, this study found positive but statistically insignificant influences in the non-regulated sectors. In other words, this study revealed that RGGI adoption significantly influences firm' innovation, supporting the benchmark DID regression.

Table 5.5: A propensity score matching based DID (PSM-DID) for innovation

Model	Probit	Logit					
	Epan	Epan	Gaussian	Uniform	Biweight	Tricube	R_{St}
VARIABLES	TPAT	TPAT	TPAT	TPAT	TPAT	TPAT	
RGGI × Year Dummy	8.797**	8.925*	8.674*	8.666*	9.160**	8.584*	REGULATED
	(4.676)	(4.795)	(4.681)	(4.523)	(4.528)	(4.837)	
_cons	0.487	0.521	0.581	0.714	0.409	0.679	
	(1.376)	(1.390)	(1.397)	(1.427)	(1.386)	(1.397)	
Observations	1,478	1,480	1,481	1,480	1,480	1,480	
RGGI × Year Dummy	28.83	19.55	41.14	33.57	12.62	28.55	NON-REGULA
	(44.64)	(43.14)	(42.16)	(41.29)	(41.65)	(41.12)	
_cons	109.4***	106.7***	104.7***	108.0***	105.8***	108.0***	

	(17.68)	(17.91)	(17.70)	(18.23)	(17.26)	(17.58)
Observations	6,553	6,595	6,595	6,595	6,595	6,595
Control Variables	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Bootstrap	500	500	500	500	500	500

Bootstrap standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
R_{St}=Regulatory Status, Epan means 'Epanechnikov'.

5.2.3.2 Impact of unobservable confounders

Historically, a new technology's performance has been subpar upon its initial release until it reaches a certain level of maturity (Montagna & Cantamessa, 2019). Then, technology advances, and performance steadily improves until it hits a technological frontier, beyond which further improvements are impossible due to technical constraints. On the other hand, the policy effect is not limited to the immediate but over time (Yan, 2021). Additionally, Montagna and Cantamessa (2019) argued that innovation is not always linear. This research employs regression analysis on the lag time in addition to the standard regressions to determine whether there is a lag impact. Also, a static panel data model cannot show how these things change over time, and leaving out time lags in corporate innovation activities can cause biases that lead to deviations and estimates that do not match up (Lin et al., 2019). When studying innovation, especially at the firm level, it is essential to avoid the effects of unobservable confounders. A two-step system GMM estimator is an excellent way to do this (Y.-J. Zhang et al., 2020). Referring to Arellano and Bover (1995) and Blundell and Bond (1998), this study constructs a dynamic panel data model by adding the lag term of TPAT (Y_{nt-1}) on the right hand side of Eq. (3.18).

This study uses the two-step system GMM in the same way as DID regressions (results are shown in Table 5.3), which means that time, sector fixed effects, and covariates are all used. The results are shown in Tables 5.6 and 5.7, and three conditions fundamentally take the count to consider SGMM as applicable. First, instrument proliferation, the number of instruments should not be higher than the number of units. According to Table 5.6, this study observed that the number of forms used in the regulated sector is higher than the number of instruments, indicating no problem with instrument proliferation. Also, second-order autocorrelation, insignificant AR (2) indicates no second-order serial correlation in level regression among the error term. Meanwhile, the Arellano–Bond test and the Hansen test account for the lag effect and minimize over-identification issues. Thus, the choice of SGMM is appropriate in both cases for regulated and non-regulated sectors.

According to SGMM outputs reported in Table 5.6, this study found that the coefficients of lagged firm's patent activities are highly significant in all the models (from Model 1 to Model 4), confirming the dynamic phenomenon of a firm's innovation initiatives. Also, the coefficient symbol of the lag of the interaction terms (RGGI × Year Dummy) is like the benchmark regression, indicating another evidence of robustness. Finally, this study can conclude that the US RGGI has a statistically significant effect on a firm's innovation in the regulated or electric power sectors of the RGGI member states.

Table 5.6: Estimated results of SGMM for Regulated Firms

Variables	**Model 1 TPAT**	**Model 2 TPAT**	**Model 3 TPAT**	**Model 4 TPAT**
$TPAT_{t-1}$	1.050***	1.051***	0.9997***	1.018***
	(0.056)	(0.054)	(0.0599)	(0.0543)
RGGI × Year Dummy	5.464**	5.939**	6.166**	8.0418**
	(2.637)	(2.522)	(2.718)	(2.264)
Constants	-0.515**	-0.497*	-0.466**	-0.411**
	(0.2427)	(0.2936)	(21.954)	(16.577)
Control Variables	No	No	Yes	Yes
Year Fixed Effects	No	YES	No	YES
Sector Fixed Effects	No	No	No	No
AR (1)	-1.73**	-1.77**	-1.70*	-1.75*
AR (2)	-0.07	-0.07	-0.06	-.06
Observation	2090	2090	1422	1422
Number of firms	110	110	102	102
Number of Instruments	86	104	94	95
Hansen test	0.518	0.128	0.650	0.255

Inference: *** p<0.01; ** p<0.05; * p<0.1 and Corrected Std. Err. Parentheses in the bracket.

Table 5.7 portrays the estimated outputs of two-step SGMM for non-regulated sectors. This study ran six models with different combinations of inclusions such as time, sector, and firm characteristics. Also, this study found that the coefficients of lagged patent activities are statistically significant, indicating the existence of a dynamic phenomenon. Furthermore, this study found a positive but insignificant desire coefficient of policy interaction (RGGI × Year Dummy) in model 1; the value is 75.81. However, it was altered by including time-fixed effects and covariates. Model 6 found a positive relationship between the implementation of RGGI and the firm's innovation activities in non-regulated sectors again when considering all inclusions. Whether the relationship was positive or negative in model 1 to model 6, one thing was found steady in all cases: the relation was not statistically significant, which remains the same as benchmark regression for non-regulated sectors. Finally, this study can also conclude that the implementation of US RGGI has no significant impact on the firm's innovation initiatives in the non-regulated sectors.

Table 5.7: Estimated results of SGMM for non-regulated firms

Variables	**Model 1 TPAT**	**Model 2 TPAT**	**Model 3 TPAT**	**Model 4 TPAT**	**Model 5 TPAT**	**Model 6 TPAT**
$TPAT_{t-1}$	0.926***	0.91***	0.427***	0.899***	0.824***	0.433***
	(0.0203)	(0.0190)	(14.27)	(0.0229)	(0.0376)	(0.0588)
RGGI × Year Dummy	75.81	-48.71	47.45	-47.67	-53.83	68.10
	(51.28)	(65.92)	(63,563)	(58.18)	(55.03)	(55.34)
Constants	18.47**	463.5**	369.8	-909.8**	0.00	-42.44
	(7.502)	(187.6)	(8.569)	(366.8)	(0.00)	(1,639)
Control Variables	NO	NO	NO	YES	YES	YES
Year Fixed Effects	NO	YES	YES	NO	YES	YES
Sector Fixed Effects	NO	NO	YES	NO	NO	YES
AR (1)	-2.44***	-1.89*	0.000*	-2.44***	-1.9*	-2.14**
AR (2)	-0.85	-1.81*	0.000	-0.87	-2.27**	-1.2
Observation	6,745	6,745	6,746	6,292	6,292	6,292
Number of firms	355	355	356	355	355	355
Number of Instruments	191	192	192	199	200	200
Hansen test	0.519	0.000	0.000	0.000	0.495	0.207

Inference: *** p<0.01; ** p<0.05; * p<0.1 and Corrected Std. Err. Parentheses in the bracket.

5.2.4 The effect of RGGI on the firm's Green Innovation

The RGGI facilitates energy efficiency, renewable power, low-carbon innovation, household utility bill support, and other GHG alleviation measures. Green technical innovation includes inventions about clean energy, saving energy, making and distributing energy with low carbon emissions, and the WIPO's Green Inventory IPC classification (WIPO., 2020). As a result, we anticipate that the implementation of RGGI will directly impact the FGI that operates with participating states. Therefore, this study intends to examine the impact of the RGGI on a firm's green innovation. In addition, this study considered all the "IPC green inventory" classifications as a proxy for firm-level green innovation. Finally, this study assumes that the RGGI cloud significantly influences the regulated firms' green patenting efforts in the participating states. Like the last section, this study divided the sample firms into two groups: panel one comprises all the regulated firms that generate and transmit electricity, and panel two comprises all the other top-earning F500 companies that are not in the regulated sector.

Based on Equation (3.3), this study considers the firm's annual green patents as the dependent variable and all other inclusions as in the previous section. The coefficient of β_3 signifies the effects of the RGGI on the firm's green innovation of respective firms. This study runs four models for regulated firms and six for non-regulated firms with changed inclusions. The results are summarized in Table 5.8. There are no control variables, fixed effects, or other items in Model 1 used in the other models, and it serves as a baseline for both regulated and unregulated enterprises. In contrast, model 4 for regulated and model 6 for non-regulated firms considered all relevant inclusions.

Table 5.8: The effect of the RGGI on green innovation

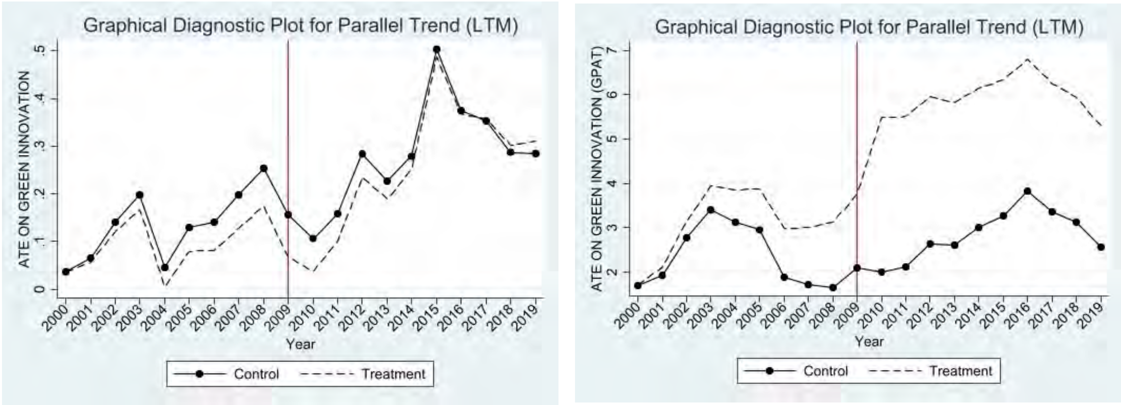
Model Variables	REGULATED (1) GPAT	(2) GPAT	(3) GPAT	(4) GPAT	NON-REGULATED (1) GPAT	(2) GPAT	(3) GPAT	(4) GPAT	(5) GPAT	(6) GPAT
RGGI × YD	0.0846	0.102	0.200	0.238	1.614	1.687	1.685	1.890	1.864	1.867
	(0.24)	(0.23)	(0.43)	(0.44)	(2.08)	(2.15)	(2.15)	(2.20)	(2.27)	(2.27)
Constant	0.16**	0.07**	-1.76**	-1.56**	2.33***	1.59***	4.18***	-16.2**	-18.7**	-15.7**
	(0.068)	(0.029)	(2.03)	(1.92)	(0.45)	(0.32)	(0.78)	(7.62)	(9.42)	(9.63)
Control Variables	NO	NO	YES	YES	NO	NO	NO	YES	YES	YES
SFE	NO	NO	NO	NO	NO	NO	YES	NO	YES	YES
TFE	NO	YES	NO	YES	NO	YES	YES	NO	NO	YES
R2	0.0028	0.006	0.1113	0.1151	0.0108	0.013	0.0536	0.1355	0.1251	0.1503
Observations	2,200	2200	1,485	1,485	7,100	7,100	7,100	6,577	6,577	6,577
Firms	110	110	102	102	355	355	355	355	355	355

- Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
- **Regulated Sector** means all electric producing and transmitting firms listed in the major us stock exchanges and headquarters in the USA.
- **Non-Regulated Sectors** were **s**elected based on multiple criteria from the top 500 revenue-earning firms (Fortune 500) from 2000 to 2019, excluding Financial and Electric producing and transmitting firms.
- **RGGI** defines the firm that is operated and located in the RGGI participating states (i.e., 10 Northeastern States), helping to separate the firms from the regulated sector and regulated states. This is the same for Non-regulated sectors.
- **YD=Year Dummy** used to separate the year before and after RGGI implementation
- The interaction term "$RGGI_{nt} \times Year\ Dummy_t$" is a multiplication of regulation and year indicators, i.e., $RGGI_{nt} \times Year\ Dummy_t = (RGGI \times YD)$, for instance, 1×1=1, and 1×0=0.
- SFE= Sector Fixed Effect; TFE= Time Fixed Effect

RGGI's average effect on firm-level green innovation is shown in model 1 (column 1 in the regulated part). Green patents of regulated companies are promoted by RGGI adoption by using the interaction term (β3) in the benchmark regression, which is 0.0846 but statistically insignificant; the coefficient and significance level remain similar in models 2, 3, and 4. However, for the non-regulated section, the coefficient in benchmark model 1 is 1.614, which is also not statistically significant. All the other inclusions in models 2, 3, 4, 5, and 6 show the same sign and level of significance. During this study, the DID regressions show that the adoption of RGGI does not make a remarkable difference in how firms make green innovations, whether they are regulated or not, are made. In the beginning, the baseline DID regression is relatively stable, as shown by the fact that all models with different inclusions get the same results. It indicates that all the inclusions besides RGGI do not have a noticeable influence on the relationship between RGGI and the firm's green innovation.

5.2.4.1 The parallel trend test

To make sure that these results are reliable, this data set needs to be compared to the firm's green innovations before RGGI was implemented. The parallel trend is one of the assumptions of DID, which indicates that green innovation had a common trend before the implementation of RGGI, both in regulated and non-regulated sectors and states. As noted, this study followed two means to ascertain pretreatment common trends between treatment and control groups. Figure 5.6 illustrates evidence of common trends between the two groups.



Regulated Sector | Non-Regulated Sectors

H_0: Linear trends are parallel; F(1, 109) =0.01.
Prob > F = 0.9299

H_0: Linear trends are parallel; F(1, 354) =1.18.
Prob > F = 0.2783

Treatment Year: 2009
Pre-treatment Year: 2000-2008
Post Treatment Year: 2010-2019

Figure 5.6: Parallel trend test (pretreatment-time-period) for green innovation

According to Cerulli and Ventura (2019), a parallel trend exists when all the coefficients of “Pre-Year” (before regulation) are statistically insignificant, and the coefficient of “Constant” is significant. This study conducted multiple experiments with different combinations and found a parallel trend in RGGI and firm-level green innovation (results are not reported here but are available in Appendix Q). According to Appendix Q, this study found all the ‘Preperiodic’ coefficients insignificant, but constants are statistically significant among the regulated firms in model 1 and model 2. This study also found similar results for the non-regulated firms, except for models 1 and 2. However, when all the inclusions were considered, all the "pre-periodic" data was insignificant at a 95% confidence level. Therefore, this study confirmed the common trend of firms’ green innovation before implementing RGGI in the regulated and non-regulated states. Overall, this study can conclude that RGGI has no statistically significant effects on corporate green innovation though the relation is positive.

5.2.5 Robustness test

This section considers two robustness tests to cross-validate the benchmark regression results, namely the difference-in-difference-of-moments based propensity score matching method and the two-step system generalization method.

5.2.5.1 Propensity based DID

This study uses DID and PSM-DID to reduce the differences in observed confounders between the regulated and non-regulated groups that could be linked to the dynamics of the outcome and to make the parallel trend assumption more likely. This study used the PSM-DID method to keep the investigation free from the effect of sample selection bias and to find samples from the control group (from unregulated states) that have similar (nearest neighbor) or matched characteristics to the treatment group (sample from regulated states). Before running the PSM-DID method, a joint support hypothesis test is essential to check its validity, especially for studying the robustness of DID (Xin & Qu, 2019; H. R. Zhang et al., 2019). According to Abadie and Imbens (2011), the propensity score matching must significantly reduce the data error rate after completing the matching. Table 5.9 portrays the outputs of jointly supported hypothesis tests. The biases of the dependent and most control variables in both treated and control groups remarkably reduce the data error rate.

Table 5.9: Jointly support the hypothesis test for both regulated and non-regulated firms

Variable		REGULATED					NON-REGULATED				
		Mean		Bias Reduction		t-test	Mean		Bias Reduction		t-test
		Treated	Control	%bias	%reduct bias	p>t	Treated	Control	%bias	%reduct bias	p>t
GPAT	U	0.234	0.200	22.30	35.08	0.08	6.66	2.51	20.40	29.6	0.00
	M	0.406	0.165	16.10		0.11	6.86	3.94	14.40		0.02
AGE	U	68.868	66.165	4.70	-111.4	0.45	53.20	41.99	30.70	97.0	0.00
	M	98.654	92.940	9.90		0.46	54.25	54.58	-0.90		0.88
SIZE	U	7.919	8.997	-54.70	79.9	0.00	10.09	9.88	30.00	83.0	0.00
	M	9.205	8.988	11.00		0.17	10.09	10.13	-5.10		0.39
TQ	U	3.206	2.183	5.30	-408.0	0.47	1.16	1.20	-4.10	-133.7	0.40
	M	4.316	9.513	-26.90		0.23	1.17	1.28	-9.50		0.06
FP	U	5.722	8.867	-13.40	-115.2	0.03	14.10	10.02	26.40	97.1	0.00
	M	8.643	1.877	28.80		0.17	14.51	14.63	-0.80		0.87

OA	U	2.167	3.430	-5.80	7.2	0.39	8.17	5.65	9.10	87.0	0.09
	M	4.105	2.933	5.40		0.72	8.48	8.15	1.20		0.65
LEV	U	53.125	39.348	14.50	15.5	0.02	30.61	28.97	8.20	74.6	0.06
	M	58.085	69.727	-12.30		0.46	30.25	29.84	2.10		0.71
FG	U	20.927	9.080	7.00	-117.2	0.06	9.28	10.07	-1.80	34.8	0.61
	M	34.224	8.489	15.10		0.34	6.81	6.29	1.20		0.70
BA	U	-3.477	3.556	-13.60	63.2	0.04	27.72	19.75	4.40	-217.5	0.38
	M	-3.526	-0.941	-5.00		0.69	28.53	53.82	-14.0		0.25

* If variance ratio outside [0.87; 1.15] for U and [0.87; 1.16] for M; U=Unmatched, M=Matched

The main issue for successful matching is that the 'p-value' of the 't-test' after matching has to be statistically insignificant. According to Table 5.9, almost every control variable is found statistically insignificant in the 'Matched' condition compared to the 'Unmatched' condition. Likewise, in the case of GPAT or 'Total Green Patent' (considered dependent variable here), the jointly support hypothesis test successfully reduced about 30% of biases after the propensity score matched compared to unmatched conditions for both regulated and non-regulated sectors. It implies that the original hypothesis is rejected, indicating no systematic difference in the data before and after matching other than correction of bias (error of data); thus, the regional greenhouse gas initiative can be a random allocation experiment.

Figures 5.7 and 5.8 show the graphical visualization of the bias reduction between matched ('×') and unmatched ('•') samples based on propensity scores for regulated and non-regulated firms. The standardized percentage of bias across covariates and dependent variables before and after matching are noticeably closer to the grey line at zero than unmatched samples, indicating that the jointly supported hypothesis test successfully allows this study to get unbiased output through the PSM-DID.

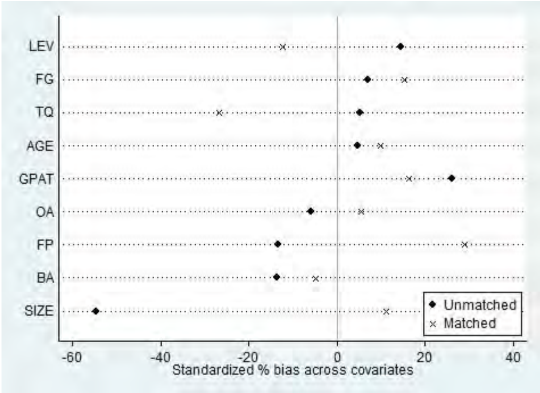


Figure 5.7: Standardized Bias across covariates before and after the matching of variables regulated sector

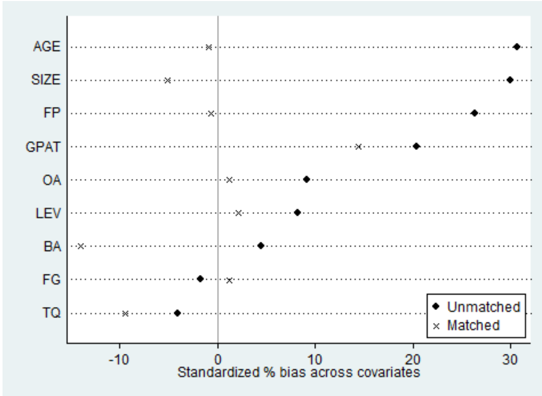


Figure 5.8: Standardized Bias across covariates before and after the matching of variables Non-regulated sector

Source: Graphical Output of Balance Test

After pairing up the groups and reducing any potential biases, the propensity score distribution should be uniform in terms of its probability density (Abadie & Imbens, 2011). Thus, this study calculates the Kdensity balance plot, including firms' green patenting activities (GPAT), to get visual confirmation of data consistency for both the regulated and non-regulated sectors. The visual balancing output plots are shown in Figures 5.9 and 5.10. They show that the matching effect is better than with raw and matched; this study can use PSM-DID as the robustness of benchmark regression.

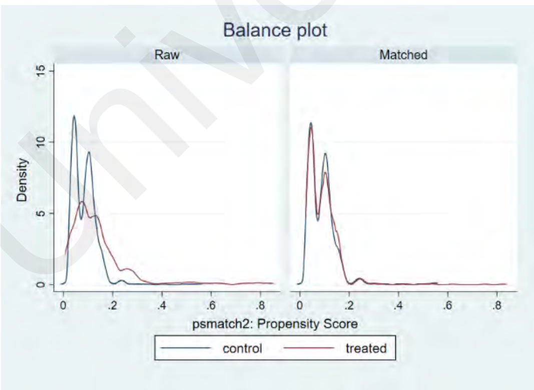


Figure 5.9: Kdensity Balance Plot for the regulated sector

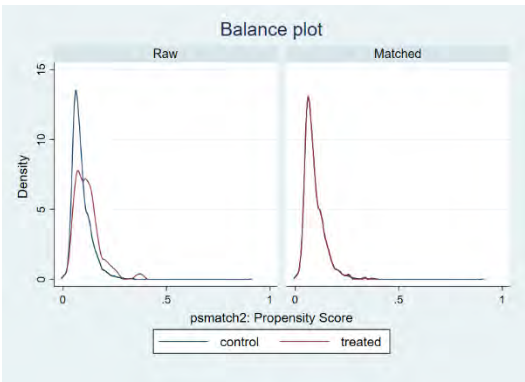


Figure 5.10: Kdensity Balance Plot for Non-regulated sector

Source: Graphical Output of PSM Balance plot

After reducing bias and increasing data similarity in the jointly supported hypothesis test and the propensity score (kernel), this study ran both the Probit and the

Logit regressions as a PSM-DID. Moreover, this study used 500 bootstrapping replications to minimize the asymptotic distribution problems, especially the standard error issue. In this part, this study tried to overcome the asymptotic distribution problem by using bootstrapping both in the Kernel Probit and Logit regression (Angrist & Pischke, 2008, p. 227). Furthermore, the current study used multiple periods (from 2000 to 2019, i.e., 09 years before RGGI and 10 years after RGGI). It used many states (08 treated states and 35 control states) that create opportunities to avoid data inconsistency, serial correlation, and self-selection bias problems. According to Angrist and Pischke (2008, p. 231), "Bias problems and heteroskedasticity rarely lead to dramatic changes in inference, and bias is not likely to be a problem in large samples." As further attention, the study used 9300 samples but did not yet confirm what large samples are! Hence, the study strongly opposes the involvement of the selection bias problem by using propensity matching score, nearest-neighbor matching, and kernel matching. In this section, different PSM methods, like Leuven and Sianesi (2003) and Blundell and Dias (2009), are used to perform both Probit and Logit regression along with control variables, time, and sector fixed effects.

Then, a control group is selected with the similarities of propensity scope of the treatment group. Table 5.10 depicts all the results of different types of PSM-DID for regulated and unregulated firms. The coefficient of interest, specifically the coefficient of policy interaction instrument (RGGI × Year Dummy), mirrored the benchmark DID regression. It indicates that the RGGI has a positive but statistically insignificant influence on firms' innovation activities in the regulated and non-regulated sectors. In other words, this study found that firms' adoption of RGGI has not significantly affected their green innovations, which backs up the benchmark DID regression.

Table 5.10: Propensity Score Matching based DID (PSM-DID) for green innovation

Model	Probit	Logit					R_{St}
	Epanechnikov	Epanechnikov	Gaussian	Uniform	Biweight	Tricube	
VARIABLES	GPAT	GPAT	GPAT	GPAT	GPAT	GPAT	
RGGI × Year Dummy	0.155	0.164	0.158	0.172	0.179	0.154	REGULATED
	(0.139)	(0.149)	(0.142)	(0.146)	(0.134)	(0.157)	
Constant	0.146**	0.156***	0.148**	0.159**	0.149**	0.163**	
	(0.0616)	(0.0599)	(0.0615)	(0.0660)	(0.0590)	(0.0668)	
Observations	1,586	1,586	1,587	1,586	1,586	1,586	
RGGI × Year Dummy	1.652	1.603	2.257*	1.851	1.484	1.756	NON-REGULATED
	(1.252)	(1.244)	(1.198)	(1.232)	(1.240)	(1.168)	
Constant	4.742***	4.735***	4.519***	4.687***	4.755***	4.719***	
	(0.562)	(0.530)	(0.521)	(0.543)	(0.574)	(0.532)	
Observations	6,595	6,595	6,595	6,595	6,595	6,595	
Control Variables	√	√	√	√	√	√	
Time Fixed Effect	√	√	√	√	√	√	
Sector Fixed Effect	√	√	√	√	√	√	
Bootstrap	500	500	500	500	500	500	

Bootstrap standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; R_{St}=Regulatory Status

5.2.5.2 Impact of unobserved confounders on green innovation

Environmental regulation is part of Environmental Management (EM). In addition to taking active measures to reduce and track emissions, EM as a dynamic management job also necessitates communication and coordination between the environmental department and other divisions, as well as harmony between ecological and other business objectives (Alemzero et al., 2021; Sun et al., 2020). This study found that market-based environmental regulations' effects on firm-level green innovation are dynamic across the different implemented jurisdictions. For example, regulatory pressure directly affects a firm's green innovation, suggesting that ETS regimes encourage the potential for green innovation. However, previous studies have found inconclusive results. In other words, the RGGI authorities have distributed billions of dollars for energy efficiency, the progress of renewable energy and low-carbon technology, and direct electric bills, making the RGGI attractive to promote green innovation.

Moreover, some unobservable confounders may influence the green innovation of RGGI-covered US companies. To avoid the effects of unobservable confounders in innovation studies, a two-step system generalized method of moments (SGMM) estimator is appropriate, especially in firm-level research (Y. J. Zhang et al., 2019). In this view, to reveal the pure effect of RGGI on the green innovation of RGGI-covered companies, eliminate the effect of other time-invariant unobservable confounders, and check the robustness of benchmark DID as well, the two-step SGMM is employed. Referring to Arellano and Bover (1995) and Blundell and Bond (1998), in this section, the study constructs a dynamic panel data model by adding the lag term of green patent counts on the right side of benchmark regression.

Panel data cannot reveal these dynamic features, and missing time lags in the capacity to generate sales may lead to biases and inconsistent estimations of value, which can be problematic (Marrero, 2010). In contrast, Baležentis and Oude Lansink (2020) and W. Wang et al. (2020) emphasized the need to take in lags, particularly when analyzing technological development owing to its dynamic nature. Following these previous works, the first-order lag value of a firm's green innovation (Y_{it-1}) was added as a right-had-side variable to reflect its dynamics in Eq. 3.18. The GMM estimator assists in determining the robustness of prior findings (Blundell et al., 2001; Sukumar et al., 2020). This technique prevents serial correlation and heteroscedasticity and avoids the endogeneity problem (Bond, 2002).

Table 5.11: Estimated results of SGMM for regulated and non-regulated firms

R_{st}	Regulated				Non-regulated					
Model	**(1)**	**(2)**	**(3)**	**(4)**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variables	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**	**GPAT**
$GPAT_{t-1}$	0.61***	0.60***	0.56***	0.58***	0.81***	0.81***	0.75***	0.76***	0.72***	0.688***
	(0.014)	(0.041)	(0.041)	(0.036)	(0.030)	(0.031)	(0.057)	(0.048)	(0.058)	(0.050)
RGGI × YD	0.0408	2.998	0.0878	0.344	2.471	2.579	2.138	2.591	5.983	3.487
	(0.068)	(2.696)	(0.243)	(0.270)	(2.112)	(2.450)	(2.443)	(2.282)	(5.565)	(2.512)
Constants	0.700	-0.821	-12.58	-10.30	-0.270	0.317	6.136	-10.13*	-31.5**	-37.09
	(0.989)	(2.646)	(10.40)	(7.303)	(1.071)	(1.539)	(4.158)	(5.891)	(13.04)	(27.49)
CV	×	×	√	√	×	×	×	√	√	√
YFE	×	√	×	√	×	√	√	×	√	√
SFE	×	×	×	√	×	×	√	×	×	√
AR (1)	0.216	0.25	0.233	0.231	0.008	0.008	0.008	0.014	0.001	0.001
AR (2)	0.209	0.14	0.234	0.233	0.287	0.288	0.286	0.31	0.105	0.18
Observation	2090	2090	1422	1422	6,745	6,745	6,745	6,292	6,292	6,292
Firms	110	110	102	102	355	355	355	355	355	355
Instruments	72	105	95	98	193	211	211	201	201	199

Hansen test	0.991	0.985	0.987	0.343	0.859	0.867	0.971	0.935	0.343	0.284

- Inference: *** p<0.01; ** p<0.05; * p<0.1 and Corrected Std. Err. Parentheses in the bracket.
- **Regulated Sector** means all electric producing and transmitting firms listed in the major us stock exchanges and headquarters in the USA.
- **Non-Regulated Sectors** were **s**elected based on multiple criteria from the top 500 revenue-earning firms (Fortune 500) from 2000 to 2019, excluding Financial and Electric producing and transmitting firms.
- **RGGI** defines the firm that is operated and located in the RGGI participating states (i.e., 10 Northeastern States), helping to separate the firms from the regulated sector and regulated states. This is the same for Non-regulated sectors.
- **YD=Year Dummy** used to separate the year before and after RGGI implementation
- The interaction term "$RGGI_{nt} \times Year\ Dummy_t$" is a multiplication of regulation and year indicators, i.e., $RGGI_{nt} \times Year\ Dummy_t = (RGGI \times YD)$, for instance, 1×1=1, and 1×0=0.
- CV= Control Variables, namely AGE, SIZE, TQ, BA, LEV, FG, FP, and OA; SFE= Sector Fixed Effect; TFE= Time Fixed Effect

Meanwhile, to account for the lag term's validity and avoid over-identification problems, this study considers the Arellano–Bond (AB) test, Windmeijer (2005), and the Hansen test. Thus, the present study conducts a two-step System Generalized Method of Moment (GMM) dynamic panel model based on inclusion and exclusion combinations of control variables, sector, and year fixed effects. The results are shown in Table 5.11, and three conditions fundamentally take the count to consider SGMM as applicable. First, the number of instruments is not higher than the number of firms (number of groups) in the sample, i.e., instrument proliferation has no problem. Secondly, autocorrelation AR (2) is insignificant, showing no second-order serial correlation in level regression among the error term. Thirdly, the Hansen statistic's P-value is not significantly different from zero. Hence, the instrument is valid; the null hypothesis cannot be rejected at the 10% level. Therefore, SGMM is a good option to use. Also, the coefficient symbol of the lag of the interaction terms (RGGI × Year Dummy) is like the benchmark regression shown in Table 5.8. In other words, the empirical findings presented in this section are empirically robust. Finally, this study can conclude that implementing RGGI does not significantly promote firms' green innovation in regulated and non-regulated sectors.

5.3 Objective Two: Impact of the US RGGI on the market competitiveness

This section mainly analyzes the results of this study's second object, i.e., the impact of the US RGGI on the firm-level market competitiveness. This study separately measures the effect of RGGI on firm-level market competitiveness in regulated and unregulated sectors to examine direct and spillover policy effects, respectively. This study applied the extended panel based "Synthetic Control Model (SCM)" as a benchmark model in both cases. The results are then cross-validated by a series of robustness tests, regression-based treatment effect models (e.g., DID and PSM-DID), and placebo tests using fake treatment units and time. In addition, the results are cross-validated based on alternative measures of market competition.

This section explains the results of empirical tests of the "strong version" of the Porter hypothesis. This part will continue as follows. First, before explicitly presenting the empirical findings, the structure of the data is briefly described. Second, by using the market competition of firms in each regulated state as a composite weighted average, this study creates treatment zones by averaging all firms in regulated states. It then makes a synthetic control region by weighting a portion of the non-regulated states in the donor pool; this is necessary to get the overall effects of US RGGI. Third, this study identifies heterogeneous features of the RGGI-regulated firms. Fourth, this study tests the robustness of the main results.

5.3.1 Data overview and descriptive statistics

This study used annual firm-level panel data from 2000 to 2019. Also, this study used multiple steps for an analytical panel set up to measure the effect of UG RGGI on a firm's market competitiveness. First, select the firms based on sector and headquarter location, which are listed on the major stock exchange of the US. Second, this study created two separate panels: panel-A (regulated firms) for the firms based on the regulated sector, e.g., "electric power generation, transmission, and distribution (NAICS 2211)," and "natural gas distribution (NAICS 2212)." Also, in panel B (non-regulated) are the companies that made the F500 list based on their revenue performance between 2000 and 2019. Third, separate the firms based on headquarter (HQ) location, with 1 if the firm's HQ is located within RGGI states and does not change after RGGI implementation and 0 otherwise.

This study considers firms from nine northeastern states (excluded New Jersey due to its in and out nature, as discussed above) are aggregated into a single RGGI region for "Composite RGGI." Here, this study used the optimal weighted average approach, and the two criteria ($\sum_{i=1}^{N} w_1 = 1, w_i \geq 0$), which implies a convex combination of the firm's market competitiveness between the treatment and control groups.

Firms from other than RGGI states consist of a donor pool (for the synthetic control group) to be synthesized. The pre-intervention timeframe for RGGI is between 2000 and 2008. This analysis covers 10 years following the adoption of RGGI, which constrains the range of reasonable predictions about the influence of RGGI. As previously stated, synthetic RGGI is generated as a convex combination of probable control states, with weights determined using Eq (3.9). The synthetic RGGI composite optimally reflects the value of a set of predictors (including market competitiveness, AGE, SIZE, LEV, BA, FG, FP, and OA).

Innovations bring a larger scale of business for firms. Scale growth enables firms to gain market share, which tends to boost their competitiveness in terms of market share (Nguyen et al., 2021). Thus, this study considered market share as an outcome variable in this section and measured it using Eq. 4.1. Also, this study finds an alternative measure of market competitiveness using Eq. 4.2. This study showed and discussed the actual data trends of firms' market competitiveness in Figure 4.4 and Figure 4.5 in the previous chapter.

"Synthetic RGGI" is the convex combination of non-RGGI that best resembles the actual pilots (average control) in terms of the values of their predictors. To find the "Synthetic RGGI" combination, this study applied the SCM. Table 5.12 provides an overview of the outcomes. It compares the characteristics of the "real RGGI" companies before treatment with those of the "synthetic control" companies and the average of the 84 non-regulated companies in the donor pool. Note that 'Real RGGI' is a weighted average combination of 20 regulated firms (firms located in the RGGI states excluding New Jersey), and 'Synthetic RGGI' is the optimal weighted convex combination of 11 firms from the donor pool (84 non-regulated firms). According to the predictor balance, the 84 unregulated enterprises do not appear to be a representative sample of the "real RGGI."

Table 5.12: Predictor balance in the pre-treatment periods

Covariate	Meaning	Calculation Method	Unit	V.weight	RGGI		Average Control
					Real	Synthetic	
AGE	Firm Age	Year since the firm was incorporated	Years	0.0136	49.00	50.064	61.7294
SIZE	Size of the Firm	Company market capitalization (MCap.), i.e., multiplication of the number of share types outstanding and average market value	LOG (MCap)	0.0012	8.4561	7.4124	6.0772
TQ	Tobin's Q	The ratio of the firm's market cap to book value of total assets	Ratio (%)	0.0008	72.44	50.47	71.73
FP	Firm's Profile	Firm's operating profit margin	Ratio (%)	0.0002	14.8559	11.8183	9.1777
OA	Operating Ability	The total net profit margin of the firm, calculated as net profits divided by revenues	Ratio (%)	0.0002	10.5971	3.3583	3.5569
LEV	Leverage	Percentage of total debts to total assets	Ratio (%)	0.0002	43.111	33.3165	26.9008
FG	Firm growth	Percentage change of firm's annual total revenue growth	Ratio (%)	0.0012	26.5431	20.9575	10.4323
BA	Business ability	Firm's net income to total equity of common shares (ROE)	Ratio (%)	0.0013	-18.887	-3.3702	4.1115
COM2(2006)	Market Competitiveness	Firm's sales to its industry sales	Ratio (%)	0.5284	0.85	0.85	0.51

COM2(2004)	Do	Do	Do	0.1933	0.84	0.85	0.53
COM2(2002)	Do	Do	Do	0.2596	0.99	0.99	0.57

Note: The years 2000–2008 get the overall average. When the average is calculated, the missing data is discarded. "Real RGGI" is the weighted average of RGGI-regulated units (firms' headquarters located in the RGGI participating States) in the treated pool with optimal weights. New Jersey was excluded from RGGI composite calculation. "Synthetic RGGI" is the weighted average of control units (excluding RGGI States without NJ and other non-representing States) in the donor pool with optimal weights, namely Xcel Energy Inc, CECO Environmental Corp, VISTRA Corp, PG&E Corp, Energy Transfer Partners Co, Exelon Corp, Williams Companies Inc, Edison International, Southern Co, Weyerhaeuser Co, and Viaspace Inc. "Average Control" is the simple average of control units in the donor pool with equal weights.

The predictor averages for companies in control states deviate from the accurate RGGI predictor averages, as seen in Table 5.12. RGGI synthetic predictor averages, on the other hand, are closer to "RGGI actual" than "average control" save for the age, profile, and operational ability of the company. To obtain an accurate comparison, SCM uses a weighted average of all possible comparison units.[4] This study found some differences in the predictors between the synthetic and average control groups; however, the assigned V.weight obtained was near zero. Thus, the main results should remain almost identical whether or not excluded these predictors (Abadie et al., 2015).

In addition, the majority of predictors have a much lower average standardized bias in the "synthetic RGGI" prior to the implementation of the RGGI than in the "average control" (the figure is not shown here but is available in Figure 1 in Appendix R). It indicates that the synthetic control method works better to measure the impact of RGGI. SCM also optimized covariate weight, which is reported in Figure 2 (shown in Appendix R). Thus, the best-matched predictor's balance and optimal covariate weights lead the better comparative output in the synthetic control method.

[4] Because weights that add up to one and lie inside the [0, 1] range do not exhibit extrapolation bias, interpolation biases may be significant in certain circumstances, particularly when the donor pool contains units with significantly different characteristics than the unit reflecting the case in issue. To avoid interpolation biases, this research advises restricting the donor pool to units with comparable circumstances. For the objective function $||X1 - X_0W||$ of weights, error terms may be included to account for discrepancies in attribute values between the unit representing this instance and the synthetic control units with positive weights. These penalty terms may be useful in defining a synthetic control when $||X1 - X_0W||$ minimization has several solutions, since X_1 lies inside the curve of the columns of X_0.

5.3.2 Effects of US RGGI on market competitiveness in the regulated sector

This study used the synthetic control method as proposed by Abadie et al. (2015) for the estimation of the weight vector w^* and follow the 'Stata Synth2' package developed by Yan and Chen (2021). In 'synthetic RGGI', the weights of each of the control firms are shown in Table 5.13. Table 5.13 shows that a combination of Xcel Energy Inc., CECO Environmental Corp., VISTRA Corp., PG & E Corp., Energy Transfer Partners Co., Exelon Corp., Williams Companies Inc., Edison International, Southern Co., Weyerhaeuser Co., and Viaspace Inc., which represent non-regulated states, best replicates the market competitiveness trend in the RGGI region prior to RGGI deployment. The visual distributions of optimal unit weights (U.Weight) of the control group from the donor pool are depicted in Figure 3 (reported in Appendix R). The other enterprises in the control group are assigned a weight of zero. Figure 5.9 illustrates the RGGI region's and its synthetic counterpart's market competitiveness from 2000 to 2019. As demonstrated in Figure 4.4 (discussed in the previous Chapter), market competitiveness in the synthetic RGGI closely follows the trajectory of the RGGI region's market competitiveness during the full pre-RGGI period (2000–2008), unlike other U.S. states. Table 5.12 (which shows a high degree of balance on all predictors) suggests synthetic RGGI approximates RGGI's market competitiveness.

Table 5.13: Optimal unit weight of the control group from a set donor pool

Firm Name	RIC	U.weight
Xcel Energy Inc	XEL.N	0.304
CECO Environmental Corp	CECE.N	0.272
VISTRA Corp	VST.N	0.122
PG&E Corp	PCG.N	0.094
Energy Transfer Partners Co	ET.N	0.065
Exelon Corp	EXC.N	0.043
Williams Companies Inc	WMB.N	0.034
Edison International	EIX.N	0.029
Southern Co	SO.N	0.020
Weyerhaeuser Co	WY.N	0.013
Viaspace Inc	VSPC.PK	0.005

Note: The units such as AEE, AEEI, AEP, AES, AILLP, ALE, APTL, ATO, AVA, BKH, BLNK, BLSP, CMI, CMNR, CMS, CMSPB, CNP, CPWY, CTRA, D, DFHL, DTE, DUK, ELC, ENGH, EPD, ETR, EVRG, EVUS, FE, FET, FEWP, GERI, GSLO, HE, IDA, KMI, LNT, MCPB, MDU, MGEE, MRC, MUSA, NCEN, NEE, NI, NWE, NWN, OGE, ORA, OTTR, PAA, PNM, PNW, POR, PPL, PPWLO, PRHL, PRIM, RENU, RGCO, SO, SPKE, SR, SRE, SUME, SWX, TA, TRGP, UGI, VIA, WBRE, and WEC in the donor pool get a weight of 0.

The differential in market competitiveness between the RGGI and synthetic RGGI regions is used to measure the effect of RGGI deployment on market competitiveness in the RGGI-regulated firms. The two lines began to diverge substantially shortly after the RGGI began (dotted line in Figure 5.11). Market share in the synthetic RGGI region is still growing, but the actual RGGI region has become much more competitive. (Solid blue line beyond 2009 in Figure 5.11).

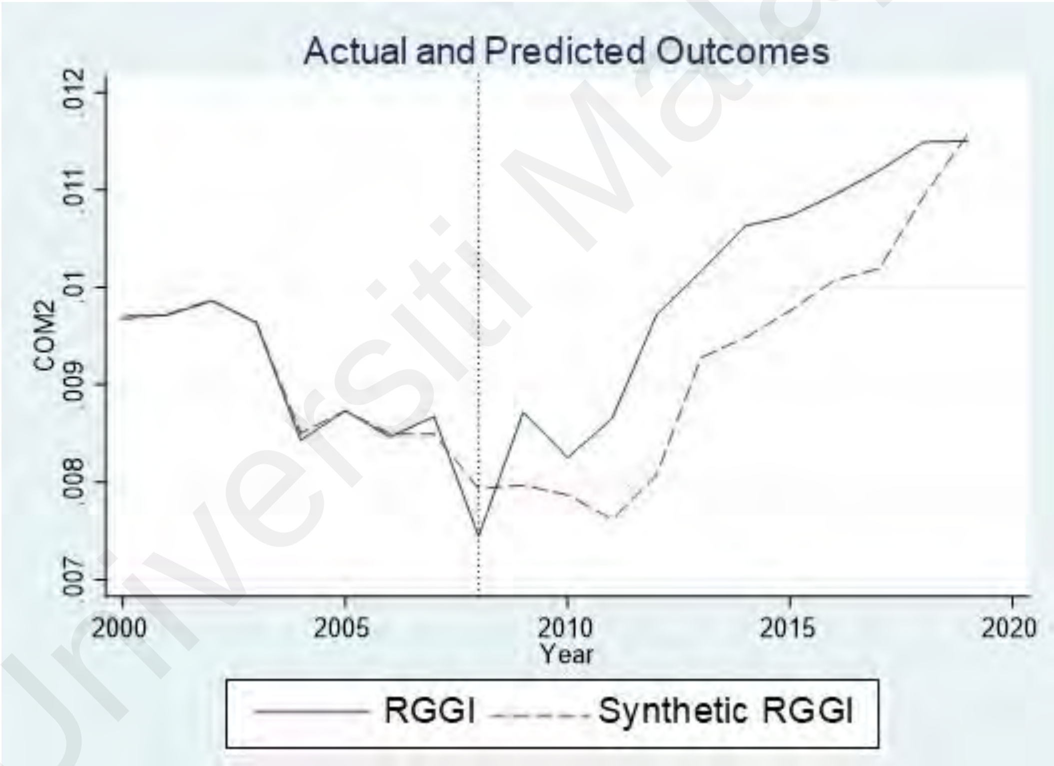


Figure 5.11: Trends of Market Competitiveness (COM2): RGGI vs. synthetic RGGI

The positive difference between the lines indicates that RGGI adoption had a beneficial effect. There are annual differences in market competitiveness between RGGI-based enterprises and their counterparts in the RGGI region. Figure 5.12 shows the Market Competitiveness (COM2) average gap between RGGI and synthetic RGGI firms from 2000 to 2019, known as the average treatment effect. According to Figure 5.12, the market competitiveness of RGGI enterprises is around 0.0004 to 0.0016 points greater than synthetic RGGI firms from 2010 to 2019. The year-by-year predictions of post-treatment periods (shown in Figure 4 in Appendix R and the table in Appendix S) show that all post-intervention treatment effects are positive except for 2019. The average treatment effect (ATE) is also positive, and its value is 0.008. It is strong evidence that the RGGI has accelerated the firm's ability to compete in the electricity production and transmission sector market during the study period.

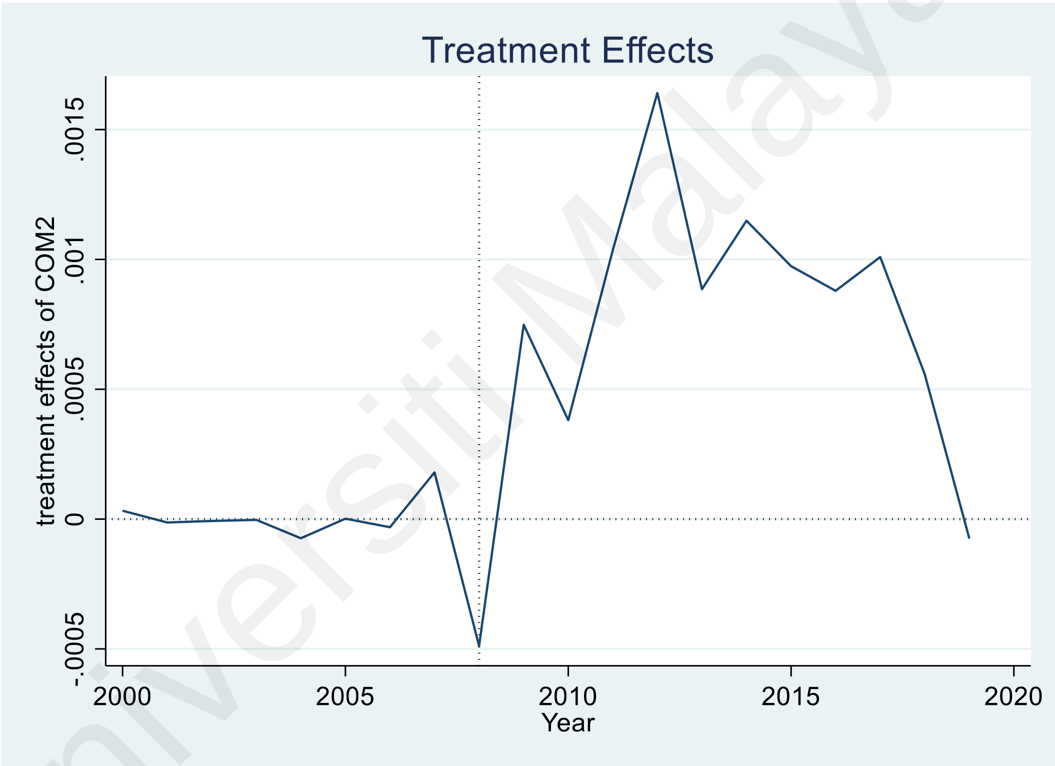


Figure 5.12: Market Competitiveness (COM2) gap between RGGI and synthetic RGGI

5.3.3 Robustness tests

To cross-validate the benchmark regression results, this section considers four robustness tests, namely the regression-based treatment effect model, placebo fake units tests, placebo fake times test, and the alternative measures of market competitiveness.

5.3.3.1 Testing treatment effect based on regression method

Based on Eq. 3.19, this study measures how RGGI deployment affects a company's ability to compete in markets in RGGI participating states. The DID baseline model describes market competitiveness, and the policy interaction term is considered an explanatory variable. Additionally, this study introduced control variables, time, and state-fixed effects in stages to assess the DID model's resilience. Table 5.14 shows the impact of RGGI on firms' market competitiveness in the regulated sector, in which model (1) represents Eq. (3.19) with no inclusion. Model (2) and model (3) gradually include control variables, time fixed effect, and states fixed effect with 500 bootstrap replications. The last two columns of Table 5.14 illustrate PSM-DID regression output for the Probit and Logit model as calculated by Eq. (3.16).

Table 5.14: The effect of RGGI on a firm's market competitiveness in the regulated sector

	Difference-in-Difference (DID)			**PSM-DID**	
Model	**(1)**	**(2)**	**(3)**	**PROBIT**	**LOGIT**
VARIABLES	**COM2**	**COM2**	**COM2**	**COM2**	**COM2**
Treated*	0.00397**	0.00760*	0.00837*	0.0175***	0.0188***
	(0.00413)	(0.00776)	(0.00854)	(0.00520)	(0.00548)
Constant	0.00567***	0.00664***	0.0179***	0.0933***	0.101***
	(0.00102)	(0.00835)	(0.0427)	(0.0130)	(0.0142)
Control Variables	NO	YES	YES	YES	YES
State Fixed Effect	NO	NO	YES	NO	NO
Time Fixed Effect	NO	NO	YES	YES	YES
Bootstrap replications	500	500	500	NA	NA
Observations	2,200	1,485	1,485	1485	1,485
Number of Firms	110	102	102	102	102
R-squared	0.021	0.052	0.061	0.276	0.288

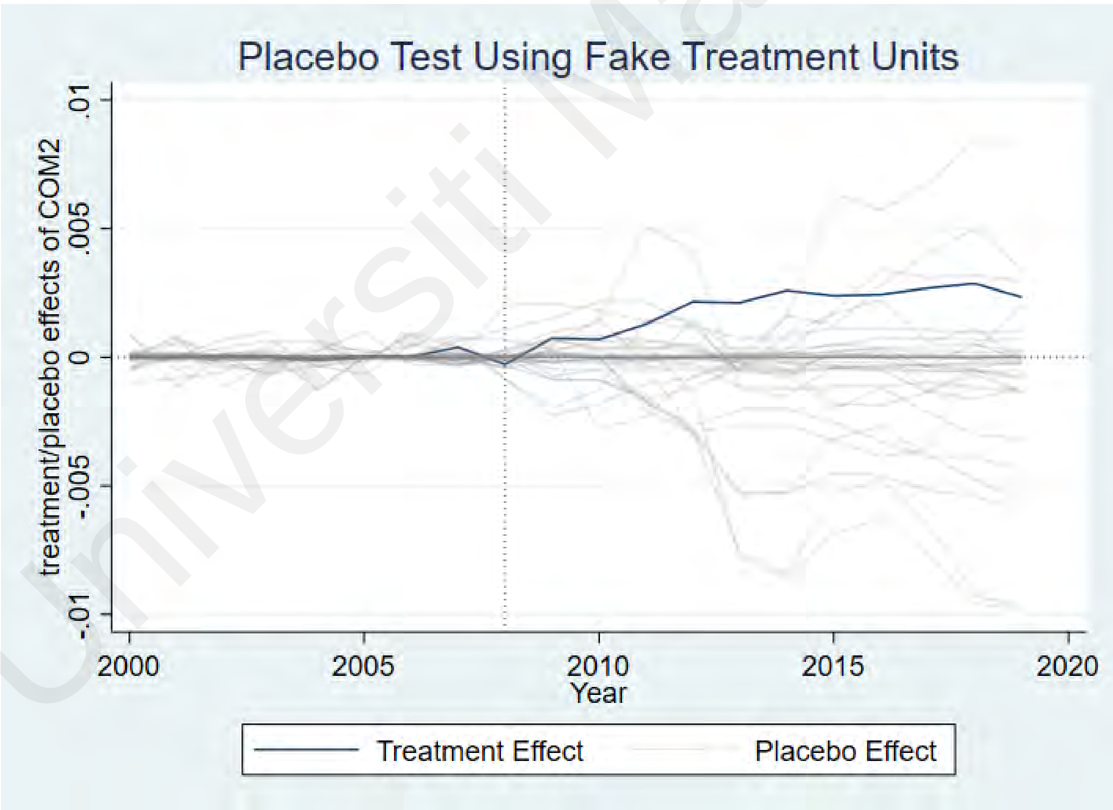
Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1; * Treated is RGGI × Year Dummy

Table 5.14 shows that the baseline model (1) without any inclusion illustrates that the interaction term 'Treated,' i.e., (RGGI × Year Dummy) is positive and statistically significant. After adding the control variables, time, and state fixed effects, the coefficient of interest in model (2) and model (3) increases to 0.0076 and 0.00837, respectively. The results are statistically significant at the 10% level. In the case of PSM-DID, the results reported in columns 5 and 6 indicate that the coefficients of interest remain positive and significant at the 1% level when considering the inclusion of covariates and time-fixed effect. Important control variables need to be added to make the model results more robust. This study found almost identical results in DID and PSM-DID, like the average treatment effect of the synthetic control method. Overall, this study can conclude that implementing RGGI increases a firm's market competitiveness. In other words, RGGI promotes a regulated firm's ability to compete in the market compared to non-regulated firms in the US.

5.3.3.2 Placebo test using fake treatment units

Statistical inference is not effective in the SCM technique since the number of control units generally needs to be minimal. Abadie et al. (2010) recommend a placebo test instead of a statistical test. Following Abadie et al. (2010), this study assumes that the RGGI scheme was implemented in 2009 in a small group of non-RGGI firms in the donor pool. Then, this study runs a series of placebo tests with synthetic control estimates for each non-RGGI to compare the estimated effects of cap-and-trade, or RGGI implementation, on regulated firms and the allocation of placebo effects for other non-RGGI. An excessively substantial effect for RGGI firms is considered in this analysis as evidence that the implementation will have a considerable impact on companies that are already subject to regulation. For example, if RGGI's impact on market competitiveness is more pronounced in the RGGI region than in control states, the RGGI effect on market competitiveness would be strong.

The SCM technique is more favorable when deciding between a placebo test and a statistical test to ensure the study's validity. However, there should not be a lot of possible control units (Abadie et al., 2010). This study overcomes these challenges by limiting the firm's average market share from 0.05 to 0.15 (±0.05 of the mean value of 'Real RGGI' and 'Synthetic RGGI') and found 43 potential control units. Then, it calculates the estimated effect of each placebo test. The graphical presentation of the standardized and bias across the predictor covariates is shown in Appendix U, which reveals that the predictor balance is better in the synthetic control group than in the average control group. To create a comparison, this analysis eliminates poorly suited placebo companies that had twenty times, five times, and two times the MSPE (Mean Squared Prediction Error) of RGGI firms, respectively, as Abadie et al. (2010) did.[5] It suggests that the pre-RGGI period's competitiveness cannot be accurately re-created by a convex combination of competitiveness in other firms, which is not acceptable for comparison with RGGI enterprises because of the higher MSPE. The MSPE of RGGI companies is 0.2093.



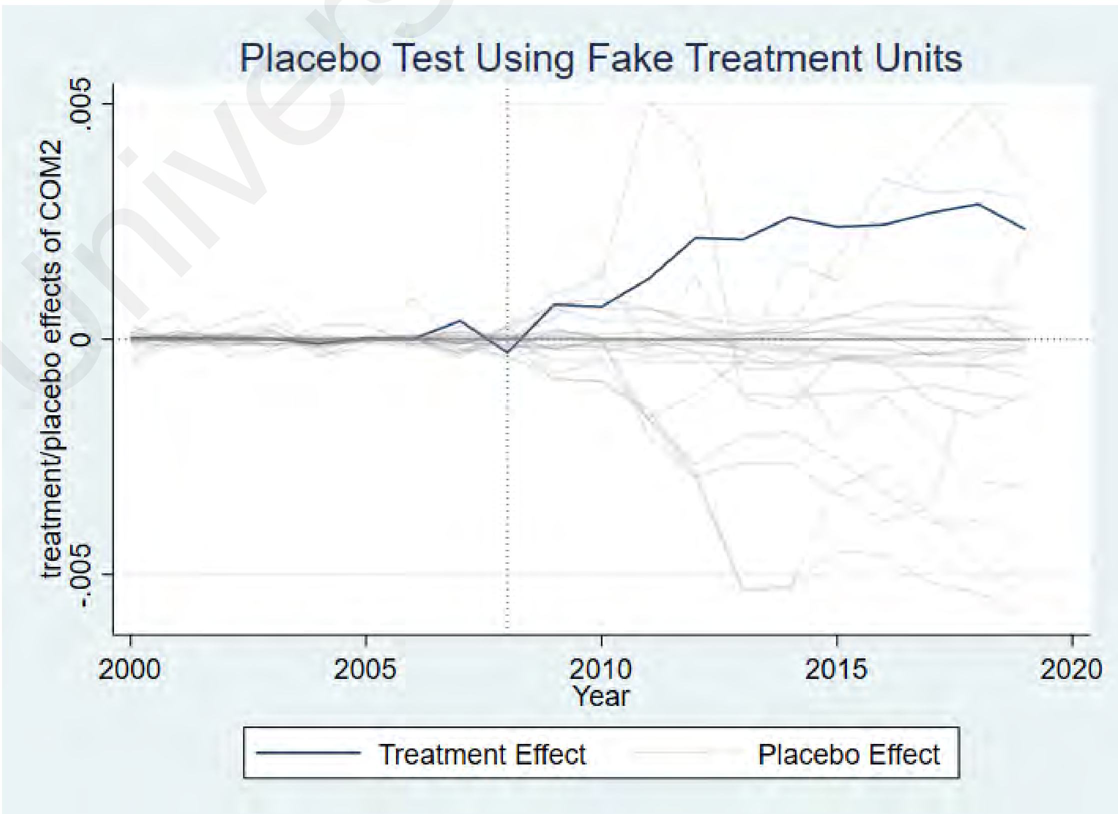
Note: (1) The probability of obtaining a post/pre-treatment MSPE ratio as large as RGGI's is 0.2093.
(2) 09 units with pre-treatment MSPE 20 times larger than the treated unit are excluded in computing pointwise p-values, including the firm’s RIC code CNP.N, D.N, DUK.N, EPD.N, ET.N, FE.N, PCG.N, WMB.N, WY.N.

5 Note: (a) The probability of attaining an MSPE ratio as great as RGGI's post/pre-treatment is 0.2093. (b) Total 22 units with pre-treatment MSPE 2 times larger than the treated unit are excluded in computing pointwise p-values, including AEP.N, AES.N, AILLP.N, ALE.N, BKH.N, CMI.N, CNP.N, D.N, DTE.N, DUK.N, EIX.N, ELC.N, EPD.N, ET.N, FE.N, NEW.N, OGE.N, PCG.N, PPWLO.PK, SRE.N, WMB.N, WY.N.

(3) The gap in market competitiveness (MC) is an assessment of the impact of RGGI implementation on MC in RGGI enterprises, defined as the difference between RGGI and synthetic RGGI enterprises in terms of MC.
(4) Control states are shown by grey lines, whereas a solid black line denotes RGGI enterprises.

Figure 5.13: Gap in market competitiveness in RGGI and placebo gaps in all 39 control firms

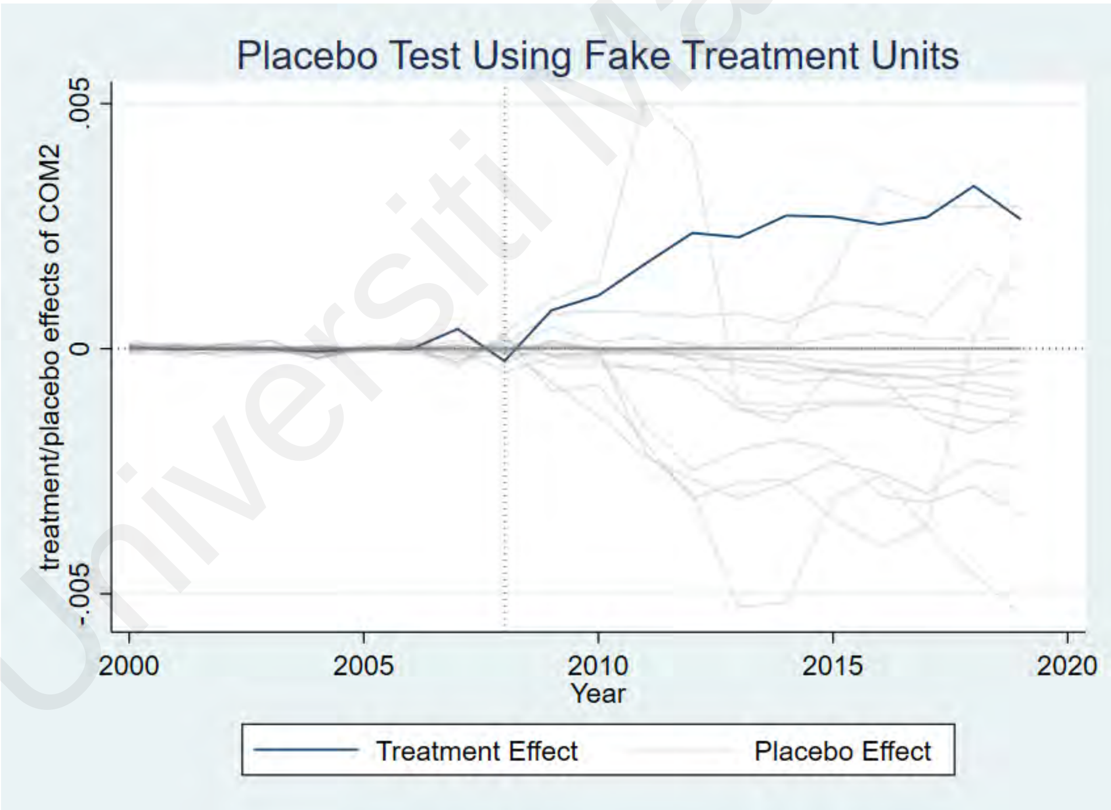
As mentioned above, the potential control unit should not be large, and this study has 85 control units in the regulated sector, e.g., the electricity production and transmission sector. This study also faced calculation errors for insufficient memory status in STATA 17. However, to minimize this limitation, this study randomly selected 43 firms out of 85 firms for control firms. Then, this study runs 43 placebo studies for all the control firms in the data and RGGI the gap in market competitiveness shown in Figure 5.13. Only nine enterprises were eliminated because their pre-RGGI MSPE was twenty times that of RGGIs. Figure 5.14 illustrates using a stricter threshold and eliminating 18 control businesses with an MSPE greater than five times that of the RGGI area prior to the RGGI. There are no visible variations between Figure 5.13 and 5.14. Figures 5.13 and 5.14 show that the RGGI gap line (solid black) is unique but not the most common.



Note: (1) The probability of obtaining a post/pre-treatment MSPE ratio as large as RGGI's is 0.2093.
(2) Total of 18 units with pre-treatment MSPE 5 times larger than the treated unit are excluded in computing pointwise p-values, including the firm's RIC code, namely AEP.N, AILLP.N, CMI.N, CNP.N, D.N, DUK.N, EIX.N, ELC.N, EPD.N, ET.N, FE.N, NEW.N, OGE.N, PCG.N, PPWLO.PK, SRE.N, WMB.N, WY.N.
(3) The gap in market competitiveness (MC) is an assessment of the impact of RGGI implementation on MC in RGGI enterprises, defined as the difference between RGGI and synthetic RGGI enterprises in terms of MC.
(4) Control states are shown by grey lines, whereas a solid black line denotes RGGI enterprises.

Figure 5.14: Gap in market competitiveness in RGGI and placebo gaps in all 30 control firms

As previously stated, a higher MSPE indicates that the market share gained before the implementation of RGGI is unlikely to be replicated. Comparing firms with pre-RGGI MSPEs less than twice as large as the RGGI MSPEs to those that are almost as well-fitted as RGGI firms are shown in Figure 5.15. The MSPE of the 22 control firms was twice that of the RGGI enterprises; hence they were discarded from the placebo test.



Note: (1) The probability of obtaining a post/pre-treatment MSPE ratio as large as RGGI's is 0.2093.
(2) Total of 22 units with pre-treatment MSPE 2 times larger than the treated unit are excluded in computing pointwise p-values, including the firm's RIC code, namely AEP.N, AES.N, AILLP.N, ALE.N, BKH.N, CMI.N, CNP.N, D.N, DTE.N, DUK.N, EIX.N, ELC.N, EPD.N, ET.N, FE.N, NEW.N, OGE.N, PCG.N, PPWLO.PK, SRE.N, WMB.N, WY.N.
(3) The gap in market competitiveness (MC) is an assessment of the impact of RGGI implementation on MC in RGGI enterprises, defined as the difference between RGGI and synthetic RGGI enterprises in terms of MC.
(4) Control states are shown by grey lines, whereas a solid black line denotes RGGI enterprises.

Figure 5.15: Gap in market competitiveness in RGGI and placebo gaps in all 26 control firms

Compared to the spread of market competitiveness gaps for the 21 control states in Figure 5.15, the gap was nearly identical in the pre-RGGI era but exceptional in RGGI firms (solid line) throughout the post-RGGI era from 2010 to 2019. Except for two control firms with a bigger positive gap in market competitiveness for short interim periods, the RGGI firm's positive effect is the highest. Given that Figure 5.15 comprises 21 control businesses, a random permutation of our data would have a 7.5% (=2/26) [6] chance of predicting an RGGI disparity of this magnitude. This test level is generally utilized in conventional statistical significance testing.

5.3.3.3 Placebo test using fake treatment times

Another technique for conducting placebo experiments is to reassign the treatment to units of the donor pool rather than in time. This study refers to these tests as "fake treatment times placebos." To conduct these tests, there must be sufficient periods where the outcome variable has not been subjected to structural shocks (Abadie et al., 2015). In the next section, this study considers the effect of the RGGI on a firm's market competitiveness in the USA. However, this study provides data from 2000 and can examine if the technique generates estimated effects before implementing the U.S. RGGI. This study reassigned two false treatment periods, one in 2007 and the second in 2008, one and two years before actual treatment in 2009.

This study applied synthetic control estimates because the effects of the intervention show up in the significant forecast, which might go away if the intervention is randomly given to units that are not exposed to it. A graphical view of the predictor balance between the average control and synthetic control groups is shown in Appendix T, and a better match was found in the synthetic control than in the average control. The

[6] Only two control firms have higher market share during 2009 to 2019 but not consistently.

estimation effects of falsification tests are presented in Figures 5.16, 5.17, and 5.18. As illustrated in Figure 5.16, the placebo treatment times do not offer visual indications of a robust treatment effect due to actual changes in market competitiveness and have remained consistent in 2007 and 2008. Then, the synthetic control approach and placebo tests are used to show that the US energy production and transmission sector's adoption of RGGI has led to a large, positive, and statistically significant improvement in firms' ability to compete in the market.

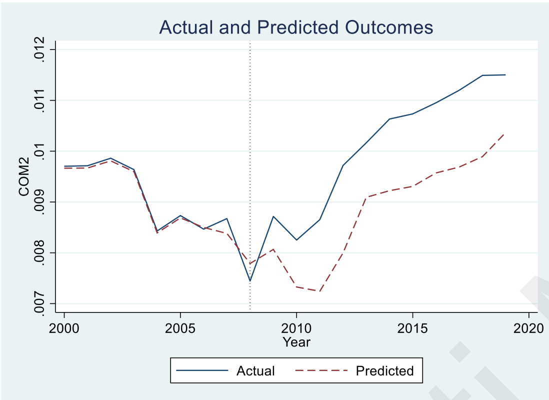


Figure 5.16: Actual effects estimation between the treatment and synthetic control groups

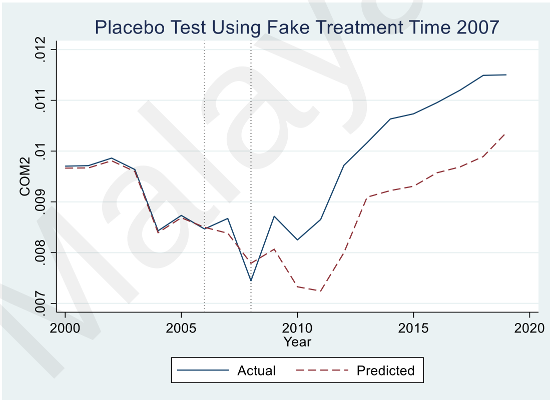


Figure 5.17: First Placebo Test in 2007 (False Treatment Times) and effect comparison of market competitiveness between Treatment and Synthetic Control Group

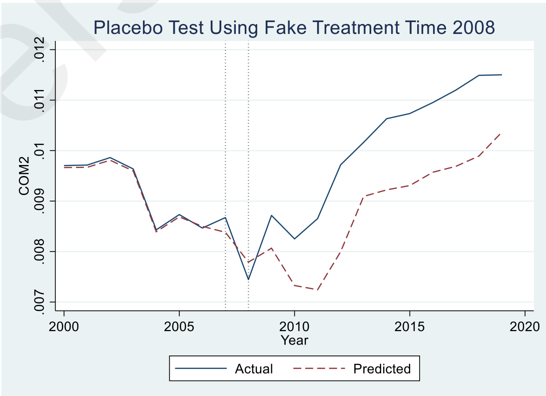


Figure 5.18: Second Placebo Test in 2008 (False Treatment Times) and effect comparison of market competitiveness between Treatment and Synthetic Control Group

5.3.3.4 Robustness test based on alternative measures of competition

This study tests the alternative measure of a firm’s market competitiveness as the market share calculated in Eq. 4.1 suffers from some lack of precision. For instance, the term "industry" is similarly broad (4-digit SIC code), and there is a chance of some ambiguities if enterprises in a particular industry compete based on products or pricing. Furthermore, this analysis does not differentiate between current competitors and possible newcomers to the market (Karuna, 2010; Li, 2010). As a result, sales growth to competitors is used to create product market competitiveness in this study (J. Hu et al., 2021). This concept is congruent with the literature on corporate strategy, which defines competitiveness as an organization's strength in comparison to competitors (Porter, 1997). When competing in a market, the primary goal is to increase market share at the expense of competitors (J. Hu et al., 2021). The degree to which a firm is competitive in the market for its products can be measured by how well the company does compare to its rivals in the same industry. It can be measured by comparing a company's sales growth to its industry competitors.

As a result, this study follows past research by Campello (2006); Fresard (2010); J. Hu et al. (2021) in computing competitive values by dividing the difference between firm to industry-average annual sales growth by the industry's standard deviation calculated Eq. 4.2 discussed in the previous Chapter. In this section, this study replaced the proxy to measure a firm’s ability to compete. Still, other covariates remained the same and used the SCM again to measure the treatment effects. Appendix V illustrates (shown in Figure 1) the predictor balance in the pre-treatment periods and found a better combination (bias-corrected) in the synthetic control group compared to the average control group to predict the actual treatment effect of the policy intervention.

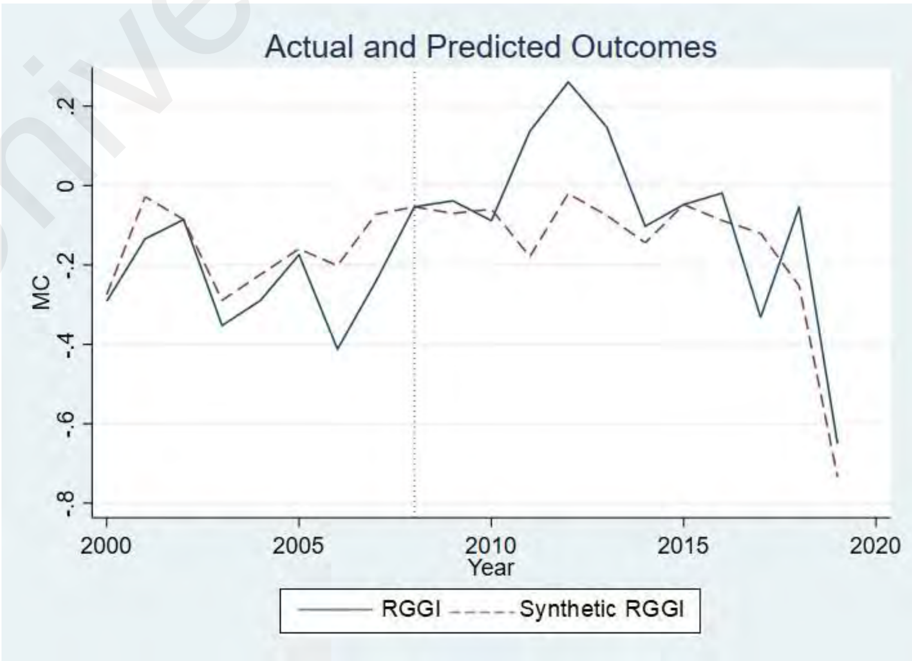
Table 5.15: Predictor balance in the pre-treatment periods

Covariate	**Meaning**	**Unit**	**V.weight**	**RGGI**		**Average**
				Real	**Synthetic**	**Control**
AGE	Firm Age	Years	0.0002	49.0000	70.5760	61.7294
SIZE	Size of the Firm	LOG (MC)	0.0020	8.4561	7.7890	6.0772
TQ	Tobin’s Q	Ratio	0.0003	0.7244	0.4970	0.7173
FP	Firm’s Profile	Ratio (%)	0.1519	14.8559	14.8806	9.1777
OA	Operating Ability	Ratio (%)	0.0033	10.5971	9.6115	3.5569
LEV	Leverage	Ratio (%)	0.0003	43.1110	28.8850	26.9008
FG	Firm growth	Ratio (%)	0.0000	26.5431	3.2475	10.4323
BA	Business ability	Ratio (%)	0.0007	-18.8872	-9.2614	4.1115

MC (2008)	Market Competitiveness	Ratio	0.4204	-0.0536	-0.0536	-0.0434
MC (2005)	Market Competitiveness	Do	0.0003	-0.1743	-0.1594	-0.1316
MC (2002)	Market Competitiveness	Do	0.4205	-0.0857	-0.0856	-0.0433

Note: Averaging all variables from 2000 to 2008 is used. When averaging, certain data is missing, which is not considered.
"Real RGGI" is the weighted average of RGGI-regulated units (firms' headquarters located in the RGGI participating States) in the treated pool with optimal weights. New Jersey was excluded from RGGI composite calculation.
"Synthetic RGGI" is the weighted average of control units from (excluding RGGI States without NJ and other non-representing States) in the donor pool with optimal weights, namely ALLETE Inc, Southern Co, Renewable Corp, Black Hills Corp., and FirstEnergy Corp. U.weight shown in Figure 3 in Appendix V.
"Average Control" is the simple average of control units in the donor pool with equal weights.

Table 5.15 shows the predictors' balance in the pre-treatment periods. According to table 5.15, the outcome variable and covariates have a better match between real RGGI and Synthetic RGGI compared to the average control, except for the age of the firm's establishment. Therefore, the 'v.weight' of each variable was assigned based on the optimum matched between "Real RGGI" and "Synthetic RGGI," which was the highest in 'MC (2008)' and 'MC (2002)' for better predictors balance in the pre-intervention. Appendix V (in Figures 2 and 3) illustrate the optimal covariate weights (v. weight) and the optimal unit weights (u. weight). Also, Figure 4 shows the average treatment effect using the SCM (shown in Appendix V).



Source: Author's compilation

Figure 5.19: Trends of Market Competitiveness (MC): RGGI vs. synthetic RGGI

Figure 5.19 shows the trend of a firm's market competitiveness as measured by Eq. 4.2 between the regulated firms (RGGI firms) and optimum-matched unregulated firms (Synthetic RGGI firms selected from the donor pool). According to Figure 5.19, it better matched the pre-intervention trend of a firm's market competitiveness. Even though the ability to compete in the market in the synthetic RGGI region keeps going up in the same way it did before the intervention, the real RGGI goes up more, especially from 2010 to 2017 (the solid blue line in Figure 5.19 after 2009). The yearly post-treatment effects are reported in Appendix W. Also, Figure 4 (reported in Appendix V) depicts the trend of treatment effect on the alternative measures of a firm's ability to compete in the market. Finally, this study found the average treatment is 0.0911, meaning that the RGGI implementation increased the firm's ability to compete in the market by 9.11%. In other words, the RGGI deployment promotes firms' ability to compete in regulated states compared to non-RGGI states.

5.3.4 The impact of RGGI on the market competitiveness of non-regulated sectors

This section measures the impact of RGGI on the firm's market competitiveness in non-regulated sectors. Similar to the previous section, the "Synthetic RGGI" was created as a convex combination of all non-RGGI donors that most closely matches the 'real RGGI' in terms of the predicted values of the predictors. The V.wights and descriptive summary in Table 5.16 compare the features of the pre-treatment firms of the "real RGGI" firms to those of the synthetic control firms and the average of the 289 unregulated enterprises in the donor pool. Note that 'Real RGGI' is a weighted average combination of 51 regulated firms (firms that are in the RGGI states excluding New Jersey), and 'Synthetic RGGI' is the optimal weighted convex combination of 07 firms from the donor pool (visualized U.weight in Figure 1 in Appendix X). The 'Average Control" presented in the last column of Table 5.16 is the mean of 289 non-regulated firms, i.e., the mean of the donor pool.

This study found that the 'Synthetic RGGI' seems to represent an appropriate control group for the 'Real RGGI'.

Table 5.16: The predictor balance in the pre-treatment periods for non-regulated sectors

Covariate	V.weight	Real RGGI	Synthetic RGGI	Average Control
AGE	0.0363	73.8382	53.7532	36.4479
SIZE	0.0036	9.9170	8.4558	8.4064
TQ	0.0051	217.76	101.58	122.65
FP	0.0202	17.6801	6.6654	8.7912
OA	0.0930	-11.4359	-5.6772	5.0297
LEV	0.1210	43.7456	40.4918	24.1688
FG	0.3571	56.9467	55.8211	15.2015
BA	0.1780	27.0709	27.100	17.3528
COM2(2006)	0.1796	11.85	11.53	2.95
COM2(2004)	0.0061	10.59	12.41	2.43
COM2(2002)	0.0000	9.26	12.59	2.56

Note:

- "V.weight" is the optimal covariate weight in the diagonal of the V matrix.
- Averaging all variables from 2000 to 2008 is used. When averaging, certain data is missing, which is not considered.
- "Real RGGI" is the weighted average of RGGI-regulated units (the firm's headquarters located in the RGGI participating States) in the real RGGI pool with optimal weights. New Jersey was excluded from RGGI composite calculation.
- "Synthetic RGGI" is the weighted average of control units (excluding firms from RGGI States, New Jersey, and other non-representing States) in the donor pool with optimal weights, namely Anixter International Inc (32), Ford Motor Co (101), iHeartMedia Inc (132), Amazon.com Inc (19), Procter & Gamble Co (218), Alphabet Inc (114), and General Motors Co (112). In parenthesis, the RIC number code was used during the calculation in Strata.
- "Average Control" is the simple average of control units in the donor pool with equal weights

As illustrated in Table 5.16, the predictor averages of firms from control states deviate from the true RGGI predictor averages. However, except for Tobin's Q (TQ), synthetic RGGI predictor averages are significantly closer to "real RGGI" than "average control" (Figure 2 for predictor balance reported in Appendix X). Hence, SCM selects the comparison unit based on a weighted average of all the available comparison units that best fit the instance in question.[7] This study found some differences in the predictors between the synthetic and average control group; however, the assigned V.weight (see Figure 3 in Appendix X for more visualized evidence) was obtained near zero (Abadie et al., 2015). Potentially, most of the predictors achieved a significantly lower standardized bias average in the 'Synthetic RGGI' in the pre-RGGI compared to 'Average control'

[7] The similar reasoning may be found in note 3 in this scenario as well.

(Figure 2 is not reported here but available in Appendix X), which confirms better results in synthetic control method.

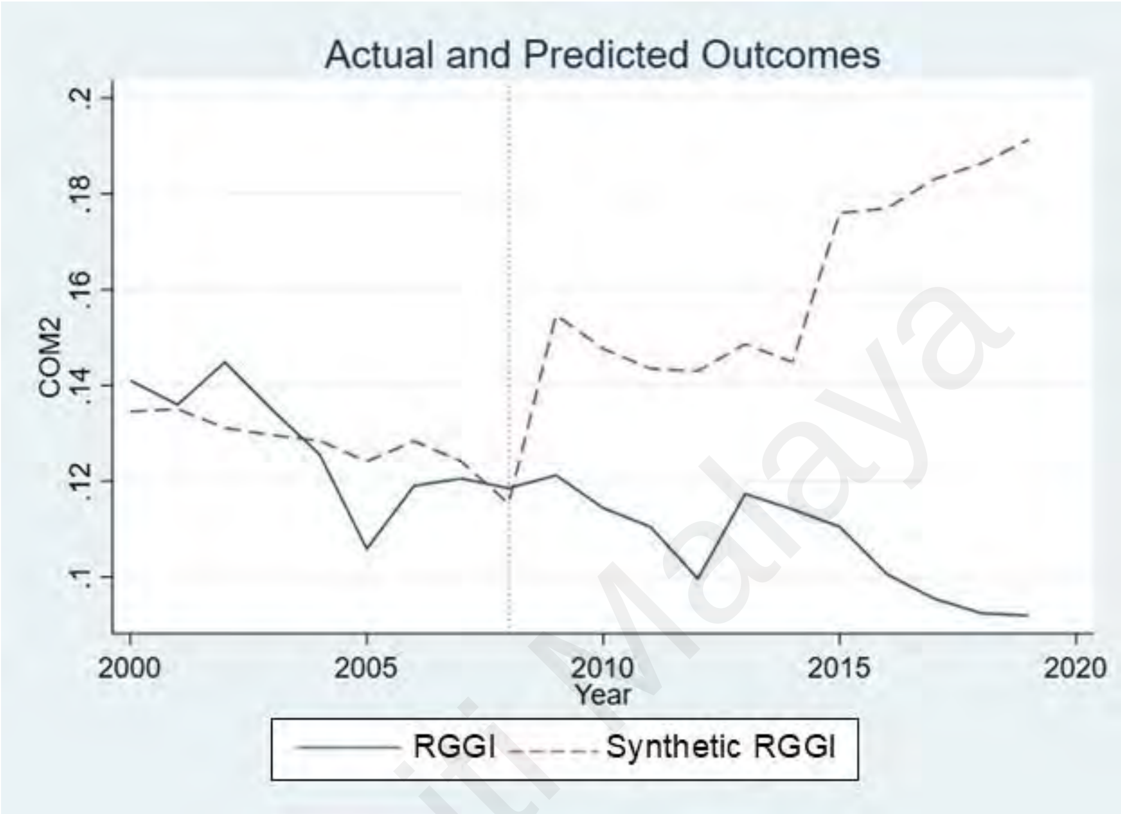


Figure 5.20: The trends of market competitiveness (COM2): RGGI vs. Synthetic RGGI for non-regulated sectors

This research compares the RGGI area with a synthetic RGGI region to ascertain the impact of the RGGI initiative on market competitiveness for unregulated industries. Immediately following the start of the RGGI, two lines had strikingly reversed tendencies. Figure 5.20 illustrates the annual differences in market competitiveness between enterprises located in the RGGI region and those based in their synthetic RGGI regions. In Figure 5.20, the Synthetic RGGI zone has more market share than the real RGGI zone, but the real RGGI zone has less market competitiveness than the Synthetic RGGI zone.

The significant difference between the lines indicates that RGGI installation had a negative effect. According to Figure 5.20, firms' market competitiveness in unregulated sectors in the RGGI region has deteriorated from 0.12 in 2010 to less than 0.05 in 2019 (solid blue line). On the other hand, the market competitiveness in the ‘Synthetic RGGI’ for unregulated sectors increased from 0.12 in 2010 to about 0.20 in 2019 (dotted line). The graphical average treatment effect is also portrayed in Appendix X (reported in Figure 4). According to the year-wise predictions of post-treatment periods (reported in Appendix Y), all the post-intervention treatment effects are negative. This study found that the average treatment effect over the post-treatment periods is -0.0571. In other words, this study can conclude that the firm's market competitiveness in the unregulated sectors in the US failed to accelerate by the RGGI implementation during the study period.

5.3.5 Robustness test

This section also follows the same procedure as the previous section to validate the findings of SCM for non-regulated sectors. First, the results are cross-validated with the regression-based approaches, namely DID and PSM-DID. Then, followed by fake placebo units and placebo fake time tests are also used to validate the SCM findings.

5.3.5.1 DID and PSM-DID regression-based robustness

Following Eq. 3.23 mentioned in the methodology section, this study measures the effects of RGGI deployment on a firm’s ability to market competitiveness in unregulated sectors. This study used three different models for DID regression, as stated in the method with three others, i.e., Eq. 3.23, Eq. 3.24, and Eq. 3.25, respectively. The regulated states are discussed using the DID baseline model with market competitiveness as the explanatory variable and the policy interaction term as the explanatory variable, as specified in Eq. 3.23. Additionally, this study introduced control variables, time-fixed effects, and state-fixed effects in stages to assess the DID model's resilience. Table 5.17 shows the impact of RGGI on firms’ market competitiveness in the unregulated sector, in which model (1) represents Eq. 3.23 with no inclusion. Models (2) and (3) gradually include control variables, time-fixed effects, and states-fixed effects. The last two columns of Table 5.17 illustrate PSM-DID regression output for the Probit and Logit model as calculated by Eq. 3.16.

Table 5.17: The effect of RGGI on a firm's market competitiveness in the non-regulated sector

	Difference-in-difference (DID)			**PSM-DID**	
Model	**(1)**	**(2)**	**(3)**	**Probit**	**Logit**
Variables	**COM2**	**COM2**	**COM2**	**COM2**	**COM2**
Treated*	-0.00194*	-0.00285***	-0.00311***	-0.00127**	-0.00147**
	(0.00109)	(0.00103)	(0.00109)	(0.00537)	(0.00547)
Constant	-0.0298***	-0.141***	-0.181***	-0.181***	-0.647***
	(0.00264)	(0.00684)	(0.0118)	(0.0356)	(0.0600)
Control Variables	NO	YES	YES	YES	YES
Sector Fixed Effect	NO	NO	YES	YES	YES
State Fixed Effect	NO	NO	YES	YES	YES
Time Fixed Effect	NO	NO	YES	YES	YES
Observations	7,060	6,537	6,537	6,537	6,537
Number of Firms	353	353	353	353	353
R-squared	0.0005	0.388	0.4526	0.625	0.626

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; * Treated is RGGI × Year Dummy

According to Table 5.17, the baseline model (1) result without any inclusion illustrates that the coefficient of expected interaction term 'Treated', i.e., (RGGI × Year Dummy) is -0.00194 and statistically significant at 10%. After adding the control variables, time, and state fixed effects, the coefficient of interest in model (2) and model (3) changed to -0.00285 and -0.00311, respectively. The results are statistically significant at a 1% level. Key control variables like time, sector and state-fixed effects need to be added to make the model results more reliable.

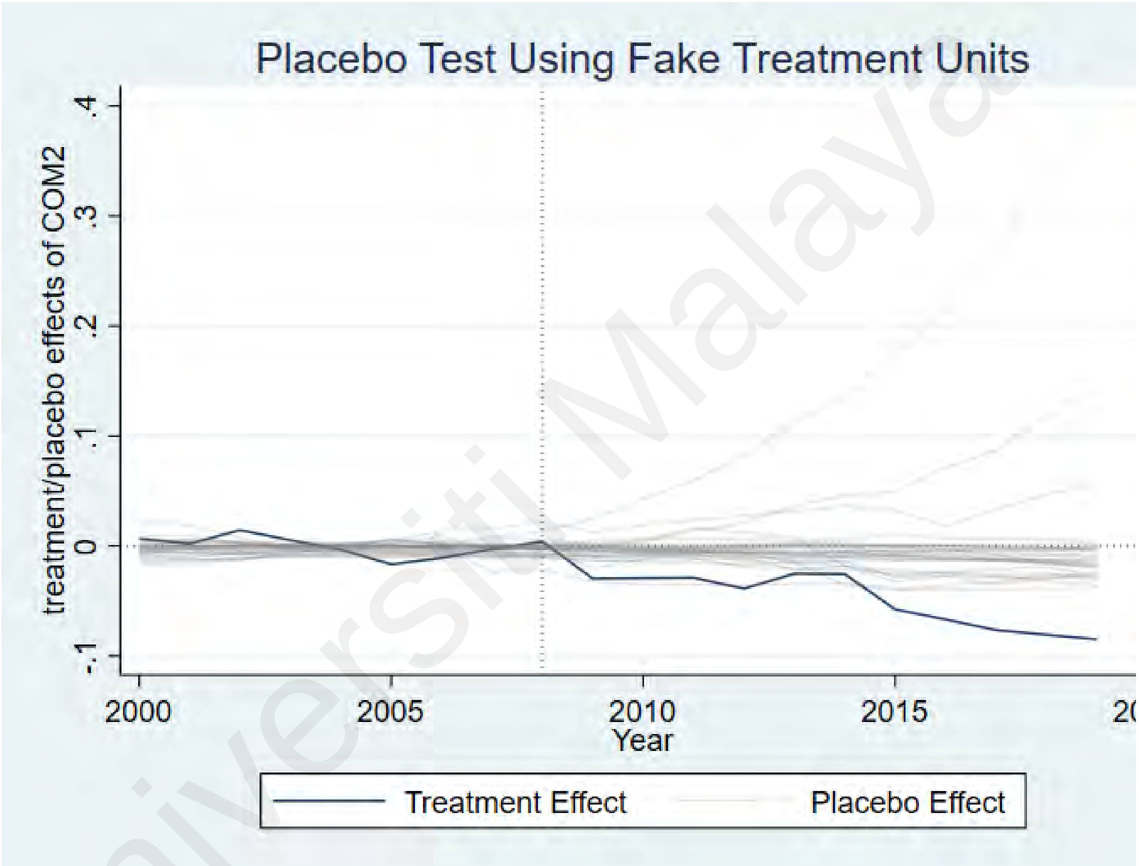
In the case of PSM-DID, the results shown in columns 5 and 6 express that the coefficients of interest are still negative and significant at the 5% level, even when covariates and the time-fixed effect are considered. This study found almost identical results in DID and PSM-DID, like the average treatment effect of the SCM. Overall, this study can conclude that implementing RGGI decreases a firm's market competitiveness.

In other words, RGGI failed to promote an unregulated firm's ability to compete in the market compared to non-regulated firms in the US.

5.3.5.2 Placebo test using fake treatment units

The SCM technique is more favorable when deciding between a placebo test and a statistical test to ensure the study's validity. However, there should not be a lot of possible control units (Abadie et al., 2010). This study overcomes these challenges by limiting the firm's average market share from 0.05 to 0.15 (±0.05 of the mean value of 'Real RGGI' and 'Synthetic RGGI') and found 41 potential control units. According to Abadie et al. (2010), this analysis implies that the RGGI program was added to a limited number of unregulated enterprises in the donor pool in 2009. Then, this study employed synthetic control estimates for every unregulated business to undertake a series of placebo tests to evaluate the estimated impacts of RGGI implementation on actual regulated enterprises and the distribution of placebo effects for non-RGGI firms. This research assumes that RGGI deployment has a substantial influence on regulated enterprises if the estimated effect is disproportionately large in comparison to the expected effect for unregulated firms. In other words, if companies from control states demonstrate that the magnitude of change in market share is smaller than the magnitude of change in the RGGI zone, the impact of RGGI on market competitiveness would be substantial.

A higher MSPE means that the market competitiveness of some firms before RGGI cannot be replicated by a convex combination of the market competitiveness of other firms, which does not work for RGGI-regulated firms. The MSPE for RGGI companies is 0.1463. This research conducted 41 placebo trials on all control companies in the data and RGGI the gap in market competitiveness by applying a stricter threshold of two times the MSPE of the RGGI controlled firms prior to RGGI implementation. Figure 5.19 shows the gap in market competitiveness in the RGGI-regulated firms and placebo gaps in 40 control firms. In Figure 5.19, the considerably lower threshold MSPE is used to compare businesses that fit almost as well as RGGI firms; that is, those whose pre-RGGI MSPE is less than twice that of RGGI enterprises. Twelve control businesses are omitted from the placebo test because their MSPE is double that of RGGI firms. As seen in Figure 5.19, the line for RGGI-regulated enterprises (solid blue) is the most remarkable, as it is substantially smaller than the other placebo gaps.



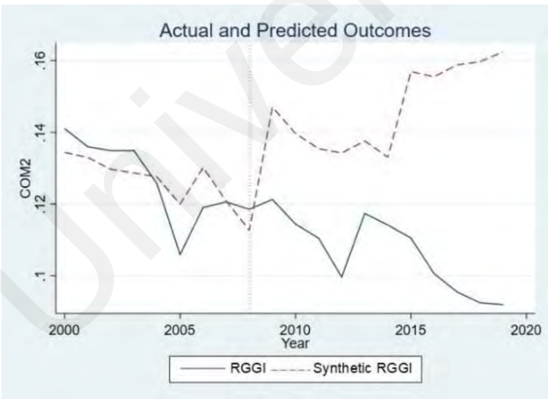
Note:
(1) The probability of attaining an MSPE ratio after treatment as high as RGGI's is 0.1463.
(2) Total of 12 units with pre-treatment MSPE 2 times greater than the treated unit are excluded in computing pointwise p-values, including F.N, ADM.N, and GILD.OQ, GM.N, INTC.OQ, AMAT.OQ, MSFT.OQ, PG.N, T.N, AVY.N, BA.N, and ABT.N.
(3) The gap in market competitiveness (MC) is an assessment of the impact of RGGI implementation on MC in RGGI enterprises, defined as the difference between RGGI and synthetic RGGI enterprises in terms of MC.
(4) Control states are shown by grey lines, whereas a solid black line denotes RGGI enterprises.

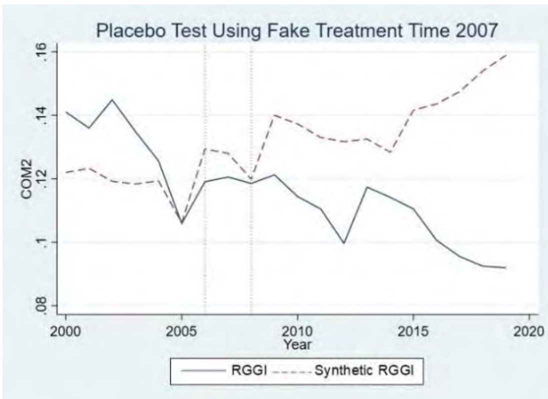
Figure 5.21: Gap in market competitiveness in RGGI and placebo gaps in 40 control firms

Figure 5.21 shows the distribution of the gaps in market competitiveness for the 29 control firms. In RGGI firms, the gap was unusual in the post-intervention period from 2010 to 2019. The negative impact on RGGI companies is the highest of all, except for one control business that only experiences a greater negative gap in market competitiveness for one or two interim periods. As Figure 5.21 comprises 29 control firms, the probability of calculating a gap of the size of the gap for RGGI under a randomized permutation of the interventions in our data is 3.44% (=1/29),[8] which is considered a conventional level of statistical significance. The conventional statistical significance tests are illustrated in Appendix Z. According to Appendix AA, this study found that all the post-treatment effects are significant at a 10% significance level.

5.3.5.3 Placebo test using fake treatment times

The research conducted a "placebo" trial to see how well the classification worked by shifting policy interventions in 2007 and 2008 rather than actual interventions in 2009. However, members of the donor pool remain unchanged. This study refers to these tests as “fake treatment times placebos.” This fake treatment time placebo test required adequate periodic coverage before and after the policy intervention (Abadie et al., 2015). This study does not face any challenges due to the extended coverage period from 2000 to 2019.

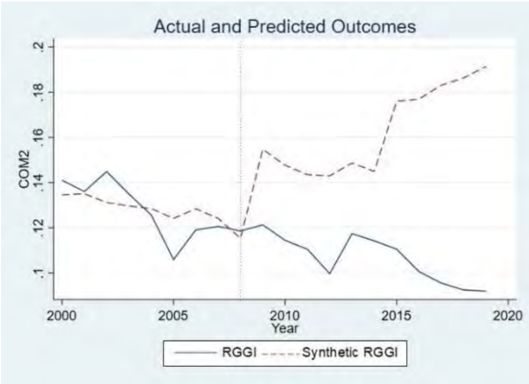




[8] Only two control firms have higher market share during 2009 to 2019 but not consistently.

Figure 5.22: Actual effects estimation between the treatment and synthetic control groups.

Figure 5.23: First Placebo Test in 2007 and effect comparison of market competitiveness between Treatment Group and Synthetic Control Group.



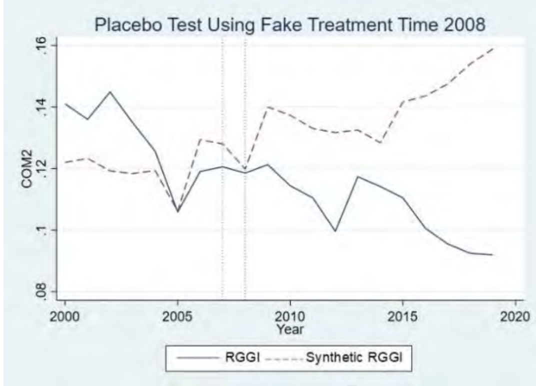


Figure 5.24: Actual effects estimation between the treatment and synthetic control groups.

Figure 5.25: Second Placebo Test in 2008 and effect comparison of market competitiveness between Treatment Group and Synthetic Control Group.

The assumption is that a substantial estimate for the synthetic control indicates the intervention's impact. This impact might fade if equal or larger estimates occurred when the intervention was randomly administered to non-exposed units. Figures 5.22, 5.23, 5.24, and 5.25 for the falsification time tests of 2007 and 2008 show the effects on the estimation of the 2007 and 2008 tests. Figures 5.22 and 5.23 illustrate that, in the case of policy intervention in 2007, the placebo treatment durations do not create visible indications of a strong treatment impact due to real changes in market competitiveness. Similar results are portrayed in Figure 5.23 and Figure 5.25 for 2008. Also, the average treatment effects of respective placebo fake time tests in 2007 and 2008 are illustrated in Appendix AA. The average treatment of placebo fake time tests was between -0.0299 and -0.0318 for 2007 and 2008, respectively. At the same time, the actual average treatment effects were found to be 0.0346, which is very similar to the fake time placebo treatment effects. Using the synthetic control approach and placebo testing, it is shown that RGGI adoption in the United States for unregulated sectors has a large, negative, and statistically significant effect on a firm's ability to compete in the market.

5.3.5.4 Robustness based on alternative measures of market competitiveness

Like the regulated sector discussed above, this study aims to check the validity of findings through an alternative measure of market competitiveness. The firms' market competitiveness is also calculated based on Eq. 4.1. This study also used the synthetic control method proposed by Abadie et al. (2010). Table 5.18 illustrates the predictor balance in the pre-treatment periods from 2000 to 2008 along with V.weights and U.weight (reported in Figure 2 and Figure 3 in Appendix BB, respectively). From the predictor balance diagram (shown in Figure 1 Appendix BB), this study found better match predictors in 'Synthetic RGGI' than 'Average Control' to compare treatment effects with 'Real RGGI'. All the predictors shown in Table 5.18, including outcome variables and covariates, were found much closer in 'Synthetic RGGI' than in 'Average Control' except for the firm's operating ability (OA).

Table 5.18: Predictor balance in the pre-treatment periods

Covariate	V.weight	RGGI		Average Control
		Real RGGI	Synthetic RGGI	
AGE	0.0039	73.8382	73.7570	36.4479
SIZE	0.0000	9.9170	9.2557	8.4064
TQ	0.0000	2.1776	1.6084	1.2265
FP	0.0000	17.6801	12.3713	8.7912
OA	0.0000	-11.4359	2.9615	5.0297
LEV	0.0000	43.7456	38.7205	24.1688
FG	0.0000	56.9467	44.2024	15.2015
BA	0.0000	27.0709	36.7363	17.3528
COM1(2008)	0.0004	-0.1374	-0.1314	-0.1021
COM1(2005)	0.9957	-0.2600	-0.2598	-0.0511

Note:

- "V.weight" is the optimal covariate weight in the diagonal of the V matrix.
- All factors are averaged during the period 2000–2008. Specific data points are missing and discarded when the average is calculated.
- "Real RGGI" is the weighted average of RGGI regulated units (firms' headquarters located in the RGGI participating States) in the real RGGI pool with optimal weights. New Jersey was excluded from RGGI composite calculation.
- "Synthetic RGGI" is the weighted average of control units (excluding firms from RGGI States, New Jersey, and other non-representing States) in the donor pool with optimal weights, namely CCK.N (52), MTOR.N (186), LLY.N (162), DISH.OQ (84), GOOGL.OQ (114), and AXE.N (32). In parenthesis, the RIC number code was used during calculation in Strata (see figure 17(a) for a more visual understanding of unit weight distributions)
- "Average Control" is the simple average of control units in the donor pool with equal weights

Figure 5.26 portrays the trend of a firm's market competitiveness (measured based on Eq. 4.2) between 'Real RGGI' and 'Synthetic RGGI' for firms from unregulated sectors. The ‘Real RGGI’ is calculated as the weighted average composite, and the ‘Synthetic RGGI’ is the average of the best predicted matched firms selected based on SCM’s optimum weighted average of pre-intervention periods. This research found that "real RGGI" and "synthetic RGGI" had a much better pre-treatment trend compared to Figure 4.5, which is shown in the "Estimation of Variables and Data" section and depicts the trend of the actual average market share of a firm in unregulated sectors in RGGI States and non-RGGI States. This similar trend indicates that SCM provides a more accurate prediction ability of the effects of RGGI on a firm’s market competitiveness in the unregulated sectors.

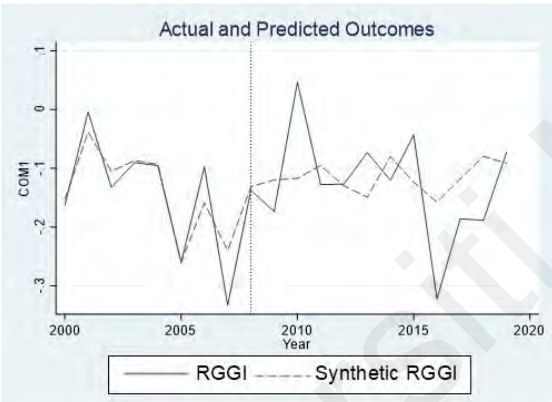


Figure 5.26: Trends of Market Competitiveness (COM1): Real RGGI vs Synthetic RGGI for non-regulated Firms

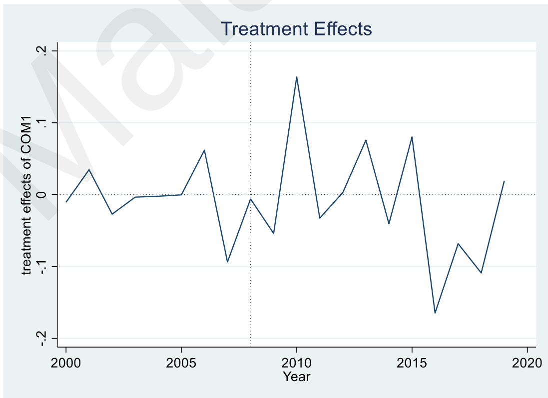


Figure 5.27: Annual Average Treatment Effects

According to Figure 5.26, the trend of RGGI firms’ ability to compete in the market was more volatile in the post-RGGI deployment periods compared to synthetic RGGI firms. Additionally, Figure 5.27 depicts the annual average treatment effects of RGGI firms (headquarters in the RGGI states) in unregulated sectors. It is more visualized in Figure 5.27 that the RGGI has some short-term positive influences on a firm’s market competitiveness, especially from 2010 to 2015, but plummeted after 2015. The year-wise prediction results in the post-treatment periods are illustrated in Appendix CC, where positive effects were predicted in 2010, 2012, 2013, and 2015 but negative treatment effects in 2009, 2011, 2014, and from 2016 to 2019. Overall, this study found the average treatment effect over the post-treatment periods is -0.0115. This negative influence on firms' market competitiveness in the unregulated sectors also validates the benchmark SCM-based treatment.

5.4 Objective Three: Impact of innovation activities on market competitiveness

This section examines the relationship between firm-level innovation activities and market competitiveness. This study also separated the firm-level green innovation activities from the total innovations. First, this study examines the relationship between firm-level innovation and market competitiveness from 2000 to 2019. Second, this study distinguishes the firm's green innovations from total innovations as proposed by WIPO's green inventory classification. The following technique for empirical analysis is based on the variables, models, and methods described in the methodology section. First, this study uses panel data regression methods to analyze the impact of innovative activity on firms' market competitiveness in F500 companies. Second, this study observes the moderating effect of the RGGI intervention between the firm's innovation activities (including green innovation) and market competitiveness. Third, this study also examines the moderating effect of firm's 'innovativeness' between innovation activity and market competitiveness. Finally, the robustness of the above results is tested by a two-step system GMM.

5.4.1 Estimating the effects of innovation activities on market competitiveness

In theory, innovations help the firm reduce production costs by improving operational efficiency, which increases the firm's productivity and improves the quality of products and services, which ultimately increases the firm's sales and ability to compete in the market. Table 5.19 presents empirical evidence of the influence of innovation on market competitiveness. There are six models with separate inclusions reported in Table 5.19. The method's covariant settings and treated units are identical to those of the preceding DID, PSM-DID, and SCM, and the intervention year is also 2009. According to the results in Table 5.19, Model 1 is a benchmark regression model because it assumes a univariate relationship between a firm's innovation and market competitiveness from 2000 to 2019 without considering firm-specific characteristics (covariates) and time-specific effects.

According to Model 1, the coefficient of 'TPAT' was 0.0000321, which is positive and significant at a 99% confidence level—indicating that the changes of 1 unit of a firm's innovation increase a firm's market competitiveness by 0.00321%. In other words, this study found a positive and statistically significant relationship between the firm's innovation activities and market competitiveness, meaning that every unit of successful patent application enhances the firm's ability to compete in the market. This finding is almost identical in Model 2 with covariates and time-fixed effects. It shows that different inclusions, like a firm's specific characteristics and time-fixed effect, do not significantly impact the relationship between a firm's innovation and its competitiveness in the market.

Table 5.19: Estimation of effects of firm's innovation on market competitiveness (without lags)

Model Variables	(1) Mkt. Com.	(2) Mkt. Com.	(3) Mkt. Com.	(4) Mkt. Com.	(5) Mkt. Com.	(6) Mkt. Com.
Intercept	0.0244*** (0.0002)	0.0241* (0.0240)	0.0202** (0.0231)	0.0255** (0.0249)	0.0222** (0.0247)	0.0193** (0.0230)
TPAT	0.0000321*** (0.00000118)	0.000031*** (0.0000012)	0.000037*** (0.00000118)			0.000036*** (0.00000119)
Treated#TPAT			-0.0000257*** (0.0000011)			-0.0000238*** (0.0000012)
INNO				0.0103*** (0.00108)	0.0125*** (0.00109)	0.00589*** (0.00103)
Treated#INNO					0.0212*** (0.00189)	0.00641*** (0.00199)
Time Fixed Effect	×	√	√	√	√	√
CV	×	√	√	√	√	√
R-squared	0.092	0.118	0.183	0.049	0.065	0.188
Observations	7,680	7,640	7,640	7,640	7,640	7,640
Number of Firms	384	384	384	384	384	384
F-test	8.15***	8.05***	9.15***	7.09***	7.19***	9.11***
Hausman	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed

- Robust Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
- Mkt. Com.=Market Competitiveness, which is measured as per Eq. 4.2.
- TPAT=Firm's total accepted annual patent applications.
- CV indicates the firm's characteristics or control variables
- INNO= Firm's Innovativeness, measured as a dummy variable, 1 if the firm's higher accepted patent application than the mean of TPAT, 0 otherwise.
- '×' means this study does not consider inclusion, but '√' means consider the inclusion in the regression.

In today's fast-paced world, organizational flexibility is a key source of competitive advantage for enterprises (Lim et al., 2011). A flexible business can maintain its competitive edge by constantly learning (Oke, 2005). When it comes to an organization's competitiveness, technical innovation is seen as a good sign of its ability to adapt to market changes (G. Li et al., 2019). The dynamic environment can boost the organization's capacity to learn and implement new ideas. An innovation in advanced technology has been recognized as an advantage in the market (Zhang et al., 2018). Nonetheless, adopting new technology places a more significant strain on an enterprise's management capability since the financial value of technology is diminished without the assistance of management policy, process, and approach (Ni et al., 2021). The present research generally accepts a substantial positive link between innovation and competitiveness, and firms' continuous improvement of creative capabilities is critical to their success and survival (Sukumar et al., 2020). Hence, advancement of products and processes through continuous innovation efforts is essential to survive or maintain a competitive edge in the market.

Interestingly, experts suggest that when firms' innovation proxies are lagged two periods, their impact on firm competition becomes significantly more critical. However, the effect is less pronounced when they are delayed three periods. Recent studies have emphasized the need to consider lags, particularly when analyzing technological progress (Baležentis & Oude Lansink, 2020; Sukumar et al., 2020; W. Wang et al., 2020). Also, at least one year lagged regressor help to avoid simultaneity (Rong et al., 2017). Inspired by previous empirical studies, this research substituted the firm's total patents (TPAT) in Equation 3.14 with the identical variable that only lagged two periods and replicated the same analysis. Table 5.20 shows the estimation of the effect of innovation with two lagged periods on a firm's market competitiveness. According to Model 1 in Table 5.20, the second-lagged period effect on firms' total patents is positive and statistically significant. The coefficient value is 0.0000274, marginally lower than Model 1 and Model

2 in Table 4.19. Overall, the results are comparable in the two contexts as positive and statistically significant.

Table 5.20: Estimation of results of innovation (with the lagged period)

Model	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Variables	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**
Intercept	0.0533*	0.0495***	0.0255*	0.0222**	0.0490*
	(0.0317)	(0.0305)	(0.0249)	(0.0267)	(0.0305)
TPATL2	0.0000274***	0.0000365***			0.0000356***
	(0.00000125)	(0.00000127)			(0.00000128)
Treated#TPATL2		-0.0000252***			-0.0000238***
		(0.00000115)			(0.00000126)
INNOL2			0.0103***	0.0124***	0.00667***
			(0.00108)	(0.00465)	(0.00112)
Treated# INNOL2				0.0209***	0.00477**
				(0.00755)	(0.00201)
Time Fixed Effect	√	√	√	√	√
CV	√	√	√	√	√
R-squared	0.096	0.159	0.049	0.064	0.164
Observations	6,884	6,884	7,640	7,640	6,884
Number of Firms	384	384	384	384	384
F-test	10.81***	12.11***	7.09***	7.17***	9.11***
Hausman	Fixed	Fixed	Fixed	Fixed	Fixed

- Robust Standard errors are in parentheses.
- *** p<0.01, ** p<0.05, * p<0.1,
- TPATL2= Firm's total accepted patent application in two lagged periods.
- Mkt. Com.=Market Competitiveness, which is measured as per Eq. 4.2.
- CV indicates the firm's characteristics or control variables
- INNOL2= Firm's Innovativeness in two lagged periods, measured as a dummy variable, 1 if the firm's higher accepted patent application than the mean of TPAT, 0 otherwise.
- '√' means consider the inclusion in the regression.

5.4.2 Moderating effect of the RGGI on the relationship between innovation and market competitiveness

Conventionally, environmental regulations affect firms' innovation initiatives and ability to compete. Additionally, environmental regulations have forced companies to redesign existing 'Environmental Management Systems' (EMS) for better environmental planning. For instance, Gasbarro et al. (2013) found that the EU ETS significantly triggered a firm's investment in technological change and innovation to reduce carbon emissions compared to an existing EMS program. Nevertheless, they also indicated that investments in technological innovation to reduce carbon emissions are still limited, and resources mainly focus on market-available technologies for core activities. Hence, technological hurdles and risks of new ideas require huge investments. Furthermore, since financial uncertainty inhibits both technological and organizational innovation, CO2 price volatility is a significant concern in ETS implementation. Therefore, when making decisions about innovation, it is essential to consider how uncertain the environment is and how risky an innovation can be (Meijer et al., 2010; Vecchiato, 2015).

There is still a lack of understanding of the risk component of innovation, nature, and future risk management. Yang and Lu (2016), Saubanov et al. (2019), and Ragulina et al. (2021), discuss selected issues related to the risks of innovation and competitiveness. Due to the high investment costs and significant environmental management risk associated with dual externalities, businesses have little motivation to innovate (Jaffe et al., 2005; Rennings, 2000). It indicates that the firm's innovation strategies are influenced by economic motives and penetrate marketability and regulatory push to reduce the hazardous environmental impact. Moreover, environmental regulations like market-based carbon trading schemes distribute part of the proceeds for developing environmentally friendly technologies, creating another dilemma of innovation or green innovation for the firms operating in the regulated states. Thus, resolving the above paradoxical conflict and motivating businesses to embrace green innovation strategies has emerged as a critical problem in innovation or green innovation. This study added the RGGI moderating term in Eq. 3.14 and the form of the Equation as follows:

$$Y_{it} = \alpha_i + \beta_1 TPAT_{it} + \beta_2 Treated_{it} \times TPAT_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots \quad (5.1)$$

Where, $Treated_{it}$ is a dichotomous interaction variable of RGGI × Year Dummy, denotes 1 if the firm is located in the RGGI-regulated states and year representing ≥2009 and 0 otherwise. At this stage, this research examines the RGGI's moderating effect on the link between a firm's innovation efforts and market competitiveness in the United States' F500 corporations from 2000 to 2019. Model 3 in Table 5.19 illustrates the moderating impact of RGGI deployment on the link between a firm's innovation and market competitiveness. The coefficient of moderating interaction term was -0.0000257, which was highly significant at a 99% confidence level. It means the RGGI weakens the relationship between the firm's innovation and ability to compete in the market. In the context discussed above, this study also checked this effect in two lagged periods in model 2, reported in Table 5.20, and found a very similar result, i.e., negative and highly significant. Therefore, the innovation dilemma among the regulated firms or innovation risk showed that implementing market-based regulation such as the RGGI negatively influences the relationship between a firm's innovation and market competitiveness during the study period.

5.4.3 Estimating the effects of innovation on market competitiveness in the innovative firms

Innovative companies may help create an atmosphere where change is not feared (Cabeza-Garcia et al., 2021). An innovative company needs to be open to new ideas and ways of thinking (Del Brío & Del Brío, 2009). According to Xing et al. (2020), a business engages in innovation efforts for two reasons. Corporations with a strong capacity for innovation are more likely to address challenges in a dynamic environment; for another, organizations use innovation to gain competitive advantages. Moreover, Bocken et al. (2014) argued that small and medium enterprises are more likely to be innovative due to their structure. Likewise, organizations with dynamic organizational structures and technology capabilities are more creative (Chandy & Tellis, 2000). Hence, large firms with dedicated innovation business units, akin to small businesses, can be inventive, benefiting from small businesses' flexibility and broader resource base (Bocken et al., 2014). Hence, it could be concluded that more innovative enterprises are riskier, eventually leading to better profitability for such firms (Olalere et al., 2021).

Moreover, Luo and Bhattacharya (2006) demonstrate that more innovative enterprises' corporate philanthropy is less likely to come at the price of product quality and innovation. According to Forsman (2013); Forsman et al. (2013), some competitive benefits from sustainability innovations are the product of a continuous process that begins prior to the innovation's creation since highly competitive enterprises already possess both inventive capacity and competitiveness.

While structural aspects are essential for external competitiveness, strategic profiles, technical competence, and proactive behaviors like innovativeness and R&D investment are also critical, as stated by Brancati et al. (2021). Firms' innovativeness and participation in R&D initiatives significantly influence their export strategy and performance (Brancati et al., 2021). This study reclassifies the firms based on their patent activities. In Table 5.1, the average value of the firm's total patent activities (TPAT) is 88.92. This study used another dichotomous variable to separate innovative and less-innovative firms (1 for and 0 for less innovative firms). Again, referring the Eq.3.23, this study added the firm's 'innovativeness' with other variables and inclusions as same as Eq. 3.24, and the regression function is as below:

$$Y_{it} = \alpha_i + \beta_1 INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.2)$$

where, $INNOVATIVENESS_{it}$ refers 1 if the total accepted patent application of firm *'i'* were higher than the mean value of 'TPAT' in the year *'t.'* Here, the mean of 'TPAT' was 88.92. Hence, it was labeled as 1 if the total number of approved patents exceeded or was equal to the mean value of TPAT, and 0 otherwise. All other variables and inclusions remain the same as in Eq. 3.24.

This research also aims to assess the moderating influence of the RGGI on the link between a firm's innovation and the market competitiveness of innovative and less-innovative companies. Therefore, this study includes a moderating interaction term in Eq. 5.2, and it becomes as follows:

$$Y_{it} = \alpha_i + \beta_1 INNOVATIVENESS_{it} + \beta_2 Treated_{it} \times INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.3)$$

Refers to Eq. 5.2 and Eq. 5.3, this study ran two different models, reported in model (4) and model (5) in Table 5.19. According to model (4) reported in Table 5.19, this study found the coefficient of interest, i.e., β_1 in Eq. 5.2 was 0.0103, significant at 1%. This means that the innovative firm's ability to compete in the market improves by 1.03% for every successful patent application during the study period. In other words, it can be concluded that innovative firms (with higher patent activities than average) are more likely to get better competitive advantages from their patenting activities. This study also found an identical result even though all regressors lagged by two years to avoid simultaneity, as reported in model 3 in Table 5.20.

Based on Eq. 5.2, this study measures the moderating effects of the RGGI implementation on the relationship between innovation and market competitiveness of innovative firms. Note that the RGGI-regulated companies are separated by the interaction dummy variable, which has a value of 1 if the company's headquarters are in one of the RGGI-participating states and 0 otherwise. Hence the coefficient of interest, i.e., β_2 indicates the moderating effect of the RGGI on the relationship between innovation and market competitiveness of innovative firms. The results are reported in model 5 in Table 5.19, and the coefficient of interest was 0.0212, which is statistically significant. This result is identical to model 4 in Table 5.20 with the two lagged periods.

Additionally, the effect of patenting activities (innovation) on firms' ability to compete in the market increased with moderating effects. Indicating that the RGGI is positive and significantly promotes the firm’s ability to compete in the market when the firm has an innovative legacy compared to less-innovative firms.

5.4.4 Estimating the effects of green innovation on market competitiveness

Green innovation is key to enhancing businesses' long-term viability and competitiveness (Chen et al., 2016). It improves companies' economic growth, organizational change, and market competitiveness (Wu et al., 2018). As a result, businesses' green innovation changes how products are made and organized. It also affects its strategy and how well it competes with other companies for customers. There has been a lot of research in the environmental field about how companies use environmental innovation to turn ecological problems into competitive advantages. According to Ong et al. (2021), the beneficial interchange between enterprises' ecological strategy and competitive advantage may be mediated through environmental innovation. As a result, manufacturers may use this data to develop their company's competitive strategy, policies, and action plans. A green company status can only be achieved by prioritizing environmental operations to maximize innovative results, so manufacturers should focus on their environmental efforts.

Furthermore, gaining a competitive edge necessitates green innovation (Barforoush et al., 2021). Zameer et al. (2022) found that business analytics and environmental focus directly influenced green competitive advantage. Companies may employ a green innovation strategy to combat the deterioration of the environment (Gao et al., 2021). However, previous research pays little attention to the influence of green innovation efforts on the long-term competitive advantage or market competitiveness of top revenue-generating corporations, such as the US F500, using panel data spanning 20 years. Therefore, this study estimates the effects of a firm's green innovation on market competitiveness. This study measures green innovation (GPAT) by WIPO's green inventory based on international patent classification. This study separates the green patents from the firm's total successfully accepted patents. Based on Eq. 3.15, this study examines the effects of green innovation activities on a firm's market competitiveness. The results are reported in model 1 of Table 5.21 and found the coefficient of interest was 0.000135, which is positive and statistically significant at a 99% confidence level. Also, this study found a similar result when running the same inclusions with two periods lagged, results reported in Table 5.22. Indicating that firm's green innovation positively and significantly enhances the firm's ability to compete in the market.

5.4.5 Moderating effect of RGGI on the relationship between green innovation and market competitiveness

Throughout recent history, Nature's retaliatory actions have engendered a series of significant disasters. Environmental protection, energy conservation, carbon reduction, and sustainable development are essential worldwide. Under the thought of sustainable development, many countries have started emphasizing the importance of environmental protection and promoting a green economy to replace the traditional economy that consumes natural resources and generates immense pollution. Also, stricter environmental regulations and growing consumer awareness about environmental protection and sustainability are significant factors in the field (Kuo et al., 2021). One thing that makes green innovation so important is its natural response to strict environmental rules and sustainability trends in production and consumption (Tu & Wu, 2021). Similarly, Gao et al. (2021) said that firms must pursue a green innovation approach to address the worsening ecological environment. Companies need to figure out how to turn green ideas into real-world practices while keeping their businesses competitive.

Additionally, Chan et al. (2016) revealed that environmental regulations benefit green product innovation since they positively impact cost efficiency and firm profitability. They also said that environmental change significantly affects the link between green product innovation and cost efficiency but has a small effect on the connection between green product innovation and firm profitability. In a recent systematic study, F. Hermundsdottir and A. Aspelund (2021) concluded that most research discovered significant linkages between sustainability innovations and company competitiveness. Although the connection is complicated, sustainability innovations may produce win-win circumstances for a company. This study also examines how the RGGI affects the relationship between a company's green patenting activities and market performance. Referring to Eq. 5.1, this study just replaced the firm's total patents (TPAT) with the firm's total green patents (GPAT). According to model 2, reported in Table 5.21, this study found the desired coefficient of the interaction term (Treated#GPAT) was -0.00104 and highly statistically significant. This moderating effect remains identical in the case of two-period lagged results reported in model 2 in Table 5.22, which means that the RGGI implementation has weakened the impact of green patenting activities on market competitiveness in the firms in the regulated states.

Table 5.21: Estimation results of Green Innovation (without lags)

Model **Variables**	**(1)** **Mkt. Com.**	**(2)** **Mkt. Com.**	**(3)** **Mkt. Com.**	**(4)** **Mkt. Com.**	**(5)** **Mkt. Com.**
Intercept	0.0261*** (0.025)	0.0229** (0.0265)	0.0248** (0.0266)	0.0219** (0.0270)	0.0222** (0.0238)
GPAT	0.000135*** (0.0000324)	0.000774** (0.0000378)			0.000667*** (0.0000414)
Treated#GPAT		-0.00104*** (0.0000259)			-0.000972*** (0.0000451)
GINNO			0.0122*** (0.00458)	0.0145*** (0.00487)	0.00819*** (0.000961)

Treated#GINNO				-0.0227*** (0.00822)	-0.00120*** (0.00220)
Time Fixed Effect	√	√	√	√	√
CV	√	√	√	√	√
R-squared	0.039	0.125	0.060	0.077	0.134
Observations	7,640	7,640	7,640	7,640	7,640
Number of Firms	384	384	384	384	384
F-test	7.3***	9.36***	6.92***	6.77***	9.04***
Hausman	Fixed	Fixed	Fixed	Fixed	Fixed

- Robust Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
- Mkt. Com.=Market Competitiveness, which is measured as per Eq. 4.2.
- GPAT=Firm's total accepted annual green patent applications.
- CV indicates the firm's characteristics or control variables
- GINNO = Green Innovativeness measured as a dummy variable, 1 if the firm's higher accepted green patent application than the mean of GPAT, 0 otherwise.
- '√' means consider the inclusion in the regression.

5.4.6 Estimating the effect of green innovation and market competitiveness of green innovative firms

The competitive landscape is fast changing due to growing public concern for the environment, and organizations are forced to implement green innovation initiatives. Many companies have acknowledged green innovation, but there has been a lack of study on its drivers and impacts. Wang (2019) claimed that corporate green culture affects green performance and competitive advantage. Additionally, they demonstrate that green innovations moderate the link between green organizational culture (GOC) and green performance and partly mediate the relationship between green corporate culture and competitive advantage under environmental stress. Similarly, Guerlek and Tuna (2018) found that OGC enhances green innovation and competitive advantage in a favorable manner.

Additionally, green innovation served as a complete mediator of the impacts of green corporate culture on competitive advantage. A competitive advantage may be expected if an organization's environmentally friendly culture. Therefore, for a firm with a higher number of green patents than the mean of green patenting applications, this study considers these firms as innovative green firms with a green organizational culture.

Consequently, this research assumes that a green corporate culture determines green innovation and market competitiveness.

Using Eq. 5.2, this research redefined "INNOVATIVENESS" as a dichotomous variable with a value of 1 if a firm has more green patents than the average number of green patent applications for the same year and a value of 0 otherwise. Model 3 in Table 5.21, this study found a positive and significant relationship with a firm’s ability to compete in the market. The coefficient value was 0.0122 and significant at a 99% confidence level. This study also checked this result with two periods of lagged effects and found almost the same result, which means that the F500 firms with green innovative legacy or culture have more ability to compete in the market.

Table 5.22: Estimation results of Green Innovation (with the lagged period)

Model	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Variables	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**	**Mkt. Com.**
Intercept	0.0545*	0.0507***	0.0248*	0.0219*	0.0495***
	(0.0328)	(0.0137)	(0.0266)	(0.0270)	(0.0313)
GPATL2	0.000269**	0.000647**			0.000586***
	(0.0000346)	(0.000371)			(0.0000435)
c.Treated#c.GPATL2		-0.00100***			-0.000970***
		(0.000267)			(0.000048)
GINNOL2			0.0122***	0.0145***	0.00845***
			(0.00458)	(0.00487)	(0.000988)
c.Treated#c. GINNOL2				-0.0227***	0.000757
				(0.00822)	(0.00220)
Time Fixed Effect	√	√	√	√	√
CV	√	√	√	√	√
R-squared	0.029	0.104	0.060	0.077	0.115
Observations	6,884	6,884	7,640	7,640	6,884
Number of Firms	384	384	384	384	384
F-test	10.22***	13.17***	6.92***	6.77***	12.26***
Hausman	Fixed	Fixed	Fixed	Fixed	Fixed

- Robust Standard errors are in parentheses.
- *** p<0.01, ** p<0.05, * p<0.1,
- GPATL2= Firm’s total accepted green patent application in two lagged periods.
- Mkt. Com.=Market Competitiveness, which is measured as per Eq. 4.2.
- CV indicates the firm’s characteristics or control variables
- GINNOL2= Firm’s Green Innovativeness in two lagged periods, measured as a dummy variable, 1 if the firm’s higher accepted green patent application than the mean of GTPAT, 0 otherwise.
- ‘√’ means consider the inclusion in the regression.

Risk is a part of innovation, and neither the core nor the future of risk management has been well-researched or defined. Yang and Lu (2016), Saubanov et al. (2019), and Ragulina et al. (2021) discuss a few worries about new technologies and competitiveness. However, firms lack the motivation to implement green technologies due to the dual externalities (Jaffe et al., 2005; Rennings, 2000), significant investment costs, and high environmental management risks (Cao & Chen, 2019). It implies that businesses that pursue green innovation strategies will encounter both possibilities and obstacles. How to resolve the above paradox conflict and persuade firms to embrace a green innovation strategy has become a significant issue in green innovation.

Some scholars argue that the competitive advantages of sustainability innovations result from a long-term process that began before the invention was even made. Meanwhile, the most competitive companies can already be innovative and competitive (Forsman, 2013; Forsman et al., 2013). For instance, Forsman (2013) discovers that successful green innovators get a better return on total assets than unsuccessful green innovators during the year before the innovation process. Influential green inventors have more significant commercial and financial benefits throughout the creation phase. It indicates that a company's advantage due to green developments may depend on existing advantages such as how excellent at what they do and how well-known they are among consumers. Dong et al. (2014) discovered that eco-organizational innovation substantially impacts environmental performance and competitiveness. The eco-organizational invention provides the framework for a holistic view of the environment and the implementation of new applications (Yurdakul & Kazan, 2020).

Additionally, stakeholder and policy pressures strengthened the mediating impact of organizational learning and competitive advantage (Tu & Wu, 2021). Along with responding to stakeholder requests for environmentally responsible manufacturing, firms should embrace policy pressures and strive to fulfill or surpass environmental laws. In contrast, Barforoush et al. (2021) advise how organizations may better plan for and capitalize on green innovation while managing risks. Businesses must assess their organizational, technological, and environmental preparedness and develop appropriate solutions. A foresighted strategy like this may assist companies in managing and reducing the risks of green innovation. Green innovation readiness assessment enables an organization to create a system for tracking changes in technology to remain current. At this point, this study assumes that a market-based carbon mitigation scheme like the RGGI also influences the ability to compete in the market for innovative green firms. Model 4 in Table 5.21 and Table 5.22 shows the moderating effects of the RGGI on market competitiveness and green innovation. This study found a negative and significant influence of RGGI on the relation of market competitiveness and green innovation of innovative firms in regulated states.

5.4.7 Robustness test

Many issues influence a firm's ability to innovate and compete in the market. For instance, larger organizations are likely to have the better technical expertise and a greater willingness to experiment with radical ideas than smaller ones (Carayannis & Samanta Roy, 2000; Dewar & Dutton, 1986). Longevity and market success are intimately correlated to a company's invention pace and acceleration (Carayannis & Samanta Roy, 2000). Consequently, an enterprise's trade behavior demonstrates inertia, leading the previous period's trade or competitiveness to impact the current period's business (Lin et al., 2017). Panel data cannot reveal these dynamic features, and missing time lags in the capacity to generate sales may lead to biases and inconsistent estimations of value, which can be problematic (Marrero, 2010). In contrast, Baležentis and Oude Lansink (2020) and W. Wang et al. (2020) emphasized the need to take in lags, particularly when analyzing technological development owing to its dynamic nature. Some authors used the first-order lag value of an enterprise's international competitiveness and competitiveness (Lin et al., 2017; Lin et al., 2019; Marrero, 2010). Following these previous works, the first-order lag value of a firm's market competitiveness (Y_{it-1}) and $TPAT_{it-1}$ was added as a right-had-side variable to reflect its dynamics. The GMM estimator assists in determining the robustness of prior findings (Blundell et al., 2001; Sukumar et al., 2020). It eliminates endogeneity as well as serial correlation and heteroskedasticity (Bond, 2002).

For this reason, a dynamic panel data model based on Eq. 3.19 was developed to investigate the link between company innovation and market competitiveness. The two-step System-GMM model listed below was created:

$$Y_{it} = \alpha_i + \eta_{it}Y_{it-1} + \beta_{it}TPAT_{it-1} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.4)$$

where, as noted, Y_{it} represents firm-level market competitiveness measured based on Eq. 4.1. All other inclusion remains as same as before; X presents the covariates that affect to the Y_{it}, with θ_i being the matching parameters to be estimated; α is the intercept term; η is the coefficient of Y_{it-1}on the Y_{it}; γ_t represents individual effect, and ε designates the residuals.

This study considers two different interaction terms to measure the moderating effects of the U.S. RGGI. First, this study intends to validate the impact of RGGI between the firm's innovation activities (TPAT) and market competitiveness (Y_{it}). Second, this study considers subsample based on the firm's innovativeness (higher than the mean value of total patents application as discussed before) and then evaluates the effects of RGGI between the firm's innovation and market competitiveness. Equations 5.5 and 5.7 show the regression functions of the moderation effects with dynamic effects.

$$Y_{it} = \alpha_i + \eta_{it}Y_{it-1} + \beta_{it}TPAT_{it-1} + \beta_2 Treated_{it} \times TPAT_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.5)$$

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_1 INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.6)$$

$$Y_{it} = \alpha_i + \eta_{it} Y_{it-1} + \beta_1 INNOVATIVENESS_{it} + \beta_2 Treated_{it} \times INNOVATIVENESS_{it} + \theta_i X_{it} + \gamma_t + \varepsilon_{it} \cdots\cdots\cdots\cdots (5.7)$$

Following the previous works by Preacher and Hayes (2004), Lange et al. (2012), and Lin et al. (2019) for assessing the direct and indirect effects of the moderation and mediation models, this study needs only to test the significance of the β_2. In Eq. 5.5, if β is sufficiently positive, this research could say that the RGGI can push F500 firms toward technical innovation. Thus, RGGI stimulated innovation, making them more competitive in the market and helping the PH and vice versa.

Specifically, this research needs to uncover the valid cause-and-effect link between the firm's patent activity and its capacity to compete in the market. Additionally, this research is required to ascertain the moderating impact of RGGI on this connection and the moderating effect of RGGI on the innovation activities of innovative enterprises and the market competitiveness of Fortune 500 corporations in the United States. However, the endogeneity issues produced by omitted variable bias and two-way causality make determining the cause-and-effect link challenging. To resolve these endogeneity issues, this study estimates Eq. 5.4, 5.5, 5.6, and 5.7 with the help of the two-step system GMM proposed by Arellano and Bover (1995), Blundell and Bond (1998), and Windmeijer (2005), which is one of the instrumental variables estimations (Baum et al., 2003). They combined the first-differenced and level equations to form a GMM estimation equation. Using first differenced equations can help with omitted variable bias, two-way causality, and weak instruments. Lagged first differences of the variables can also be used as instrumental variables in the level equations to help with these issues and help with the level equations.

The presence of autocorrelated residual components determines the reliability of GMM estimation and the validity of the instrumental variables used (Arellano and Bond, 1991). The Hansen test was also utilized to assess the appropriateness of the instrument variables in the GMM model in this research. Autocorrelation of a residual term can be tested by using an AR (1) statistic, whose p-value should be 0.05, while the residual term difference sequence needs to be negative; the p-value of the AR (2) estimate should be more than 0.05. The Hansen test was applied to check whether there are issues with over-identification or weak instrumental factors. The Hansen test requires that the p-value of the Hansen statistic be higher than 0.05 to support the null hypothesis that the instrumental variables selected for modeling are exogenous. Additionally, Roodman (2009) suggested three strategies for limiting the number of instrumental variables: (1) counting only up to q-order lags instead of all obtainable lags for instrumental variables depending on their linearity in T; (2) substituting the widening GMM-style instrumental variable matrix with a collapsing GMM-style instrumental variable matrix; or (3) combining the above two strategies for instrument containment. This study used the first option.

Before explaining the GMM estimation results, this study needs to confirm a few goodness of fit indices because of the appropriateness of the GMM estimation. This study used a two-step system GMM with 0–5 lags for the IVs (explained above) to evaluate the parameters in Eq. 5.4, 5.5, 5.6, and 5.7. Table 5.23 illustrates the benchmark results and moderating effects of RGGI in each context. The coefficient of the first-order lag value of the firm's market competitiveness is positive and significant, indicating the firm's current ability to compete is influenced by last year's ability or a one-year lagged period. Furthermore, the AR(1) value of the residual term is negative ($p<0.05$). In contrast, the p-value for AR(2) is more significant than 0.05, which means that AR(2) is not significant. Finally, no second-order serial correlation was found. Thus, no weak instrumental variables are present.

When using GMM for dynamic panel estimation, limiting the number of instruments used below the number of cross-sectional units is critical. There is a problem with instrument proliferation when more instruments are than cross-section units. This study found the number of instrument variables was less than the number of units, determining the suitability of the instrument variables in the GMM model or effectively addressing over-identification or instrument proliferation problems, in other words. Also, the Hansen statistic found more than 0.05; the range was from 0.107 to 0.608, ensuring the instrument's validity. Therefore, the Hansen statistic's P-value is not significant, and this study did not find enough evidence to reject the null hypothesis. Moreover, the entire test passed the F test in each case.

5.4.7.1 Evidence of dynamic panel estimation for the relationship between innovation activities and market competitiveness

Due to the dynamic nature of firms' competitiveness, this study applied the two-step SGMM to examine the relationship between innovation activity and market competitiveness. Column (2) of Table 5.23 contains the estimated values for Eq. 5.4. The coefficient of $TPAT_{it-1}$ is 0.00000435 and significant at the 95% confidence level. Similar findings are obtained in further experiments when models 2 and 5 are expanded, as shown in Table 5.23. It means that first-order lagged innovation significantly affects the firm's competitiveness of U.S. F500 companies during the study period. In comparison, this study also checked the validity of the impact of the firm's green innovation initiatives on market competitiveness with a similar dynamic context of the two-step system GMM estimation. Referred to Eq. 5.5, this study replaced the $GPAT_{it-1}$ instead of $TPAT_{it-1}$ with unchanged other inclusions and results reported in column (2) of Table 5.24. The coefficient of $GPAT_{it-1}$ is 0.00002 but insignificant. Also, the coefficient was positive when this study considers the interaction term of RGGI implementation presented in the model (2) and model (5) of Table 5.22 but remains statistically insignificant. At this point, this study can validate the previous findings that the firm's green patenting activities positively affect the market competitiveness of F500 companies during the study period. However, it is not statistically significant in the context of the first-order lagged value of green patent activities.

5.4.7.2 Moderating effect of firm's innovativeness in the dynamic relationship between innovation activities and market competitiveness

Meanwhile, based on Eq. 5.6, this study compared the ability of firms to grasp the market opportunities through innovation efforts between the innovative and less-innovative firms. The coefficient of the term 'INNOVATIVENESS,' i.e., β_1 found positive and significant (reported in model 3 of Table 5.23). The previous conclusion, e.g., "innovative firms are more capable of holding the existing market opportunities than less-innovative firms," is robust in the dynamic instrumental variables approach. This study also found similar results in model 3 of Table 5.24, indicating that green innovation is also likely to enhance the firm's market competitiveness than less-green innovative F500 firms. Therefore, the previous findings are robust and confirm that the firm's innovation legacy and continuity help hold more opportunities in the market than less-innovative F500 firms.

Table 5.23: Dynamic panel estimation of the relationship between firm-level innovations and market competitiveness

Model Variables	**(1) Mkt. Com.**	**(2) Mkt. Com.**	**(3) Mkt. Com.**	**(4) Mkt. Com.**	**(5) Mkt. Com.**
L.COM2	0.899*** (0.0292)	0.884*** (0.0280)	0.887*** (0.0340)	0.887*** (0.0337)	0.865*** (0.0364)
L.TPAT	0.00000435** (0.000001.87)	0.00000697*** (0.00000183)			0.00000685*** (0.000001.90)
Treated # L.TPAT		-0.00000436*** (0.00000150)			-0.00000476*** (0.00000154)
INNO			0.00653** (0.00301)	0.00654** (0.00300)	0.00469* (0.00243)
				-0.000368*	0.00212*

Treated # INNO				(0.00436)	(0.00470)
Constant	0.000134* (0.00285)	-0.000550 (0.00309)	-0.00066 (0.00262)	-0.000689 (0.00271)	-0.000227 (0.00282)
CV	Controlled	Controlled	Controlled	Controlled	Controlled
AR (1)	0.009	0.009	0.008	0.008	0.009
AR (2)	0.39	0.378	0.436	0.437	0.399
Observations	7,265	7,265	7,265	7,265	7,265
No. of Firms	384	384	384	384	384
No. of Instruments	351	351	351	351	357
Hansen test	0.131)	0.107	0.608	0.595	0.417
F-test	284.24***	284.24***	203.06***	193.54***	206.56***

- Corrected Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.
- L.COM2 and L.TPAT are the first-order lag value of a firm's market competitiveness and total successfully accepted annual patent application, respectively.
- The term "treated" is defined as the implementation of RGGI in 2009 in the participating states, i.e., if the firm's headquarters are in the participating states and represent the years 2009 and later, "INNO" means innovativeness, which indicates another dichotomous classification of the firm's patenting activities: "If the firm has more patents than the mean value of patent activities,"

5.4.7.3 Moderating effect of RGGI in the dynamic relationship between innovation activities and market competitiveness

As discussed above, ETS changed the relationship between a company's "green innovation" and its competition in the market. Based on Eq. 5.5, this study considers the moderating effects of the RGGI between the firm's innovation and market competitiveness and found the desire coefficient value is -0.00000436, which is significant at a 99% confidence level (results presented in column 3 of Table 5.23). The study also found that the RGGI weakens the relationship between the firm's innovation and market competitiveness. Therefore, this study can conclude that the RGGI negatively influences firms' ability to compete in the market through their innovation activities in regulated firms. Likewise, a similar result is found in the firm's green innovation and market competitiveness. In model 2 of Table 5.24, the coefficient of the interaction term (treated#L.GPAT) is -0.000142 but insignificant. Finally, this study can conclude that the RGGI is negatively motivated to grasp the market opportunities through innovation and green innovation in the firms in the RGGI member states.

Meanwhile, this study intends to validate the effect of the RGGI on the relationship between the firm's innovativeness and market competitiveness. Refers to Eq.5.5 and 5.7, the coefficient of interest is β_2 (-0.000368) and significant, suggesting that the RGGI failed to enhance the firm's market competitiveness with innovative F500 companies rather than negatively motivating technological innovation. A similar condition is also reported in Table 5.24; the coefficient is -0.00644 and significant. This study defines the innovative green firm with green patents as higher than the average green patenting activities. Thus, the RGGI also demotivates to hold the market opportunities through green innovation. This moderating effect remains similar in case model 5 in Table 5.23 and Table 5.24. Finally, this study can accomplish the notion that the RGGI is creating a barrier among the innovative firms to hold existing market opportunities by F500 companies.

Table 5.24: Dynamic panel estimation of the relationship between firm-level green innovations and market competitiveness

Model Variables	(1) Mkt. Com.	(2) Mkt. Com.	(3) Mkt. Com.	(4) Mkt. Com.	(5) Mkt. Com.
L.COM2	0.911*** (0.0315)	0.899*** (0.0309)	0.895*** (0.0345)	0.892*** (0.0341)	0.885*** (0.0393)
L.GPAT	0.00002 (0.0000302)	0.000071 (0.0000682)			0.0000786 (0.000071)
Treated # L.GPAT		-0.000142 (0.0000969)			-0.000162 (0.000112)
GINNO			0.00136 (0.00149)	0.00164 (0.00160)	0.00142 (0.00136)
Treated #.GINNO				-0.00644** (0.00401)	-0.00202** (0.00424)
Constant	-0.000679 (0.00267)	-0.000898 (0.00278)	-0.000546 (0.00301)	-0.000984 (0.00318)	-0.000467 (0.00293)
CV	Controlled	Controlled	Controlled	Controlled	Controlled
AR (1)	0.009	0.008	0.009	0.009	0.008
AR (2)	0.404	0.401	0.417	0.402	0.419
Observations	7,265	7,265	7,265	7,265	7,265
Number of Firms	384	384	384	384	384
Number of Instruments	351	351	351	351	357
Hansen test	0.127	0.126	0.455	0.381	0.409
F-test	228.22***	261.71***	163.77***	178.52***	125.92***

- Corrected Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
- L.COM2 and L.GPAT are the first-order lag value of the firm's market competitiveness and total successfully accepted annual green patent application, respectively.

- Treated defined as the implementation of RGGI in 2009 in the participating states, i.e., 1 if the firms headquarter is in the participating states and representing the year 2009 and later, GINNO indicates another dichotomous classification firm's green patenting activities 1 for if the firm has higher green patents than the mean value of green patent activities.

5.5 Chapter Conclusions

This chapter illustrates the empirical findings through the econometric models. Also, this section cross-validates each result through multiple robustness tests. Objective one is divided into two subsections: firms' innovation activities are separated into firms' innovations and green innovations, then subdivided into the regulated and non-regulated sectors to measure the direct and spillover effects, respectively. This study used the 'Difference-in-Difference (DID)' as a benchmark model through the 'quasi-experimental' framework to investigate the treatment effects of the RGGI on firms' innovations and green innovations. Also, this study applied the 'Propensity Score Matching based DID (PSM-DID)' to overcome the policy endogeneity issues. Also, this study used the two-step System GMM to cross-validate the original findings of benchmark DID regression.

In objective two, this study investigates the impact of RGGI on firms' market competitiveness. This study applied the 'Synthetic Control Model' as a benchmark model and used the Placebo Fake unit and the Fake time tests as robustness tests. This study also applied the regression-based treatment effect model, the DID, and PSM-DID to cross-validate the original findings. This study also used alternative measures of market competitiveness as it is relatively new in the innovation literature. In objective three, this study again separated the effects of innovations and green innovations on firms' market competitiveness. This study used the panel data regression (fixed effect model) as a benchmark model and applied a two-stem System GMM for the robustness test. The summary of the findings and hypotheses testing, along with discussions of the findings, are presented in the next chapter.

CHAPTER 6: DISCUSSIONS OF FINDINGS

6.1 Introduction

This chapter explains the results of Chapter 5 and summarizes the main results of the study objectives and hypotheses. In this chapter, the findings of this study are further explained with the findings of previous studies and practical operational aspects of RGGI in regulated and unregulated sectors. This chapter is split up into three subsections. The first section presents an overview of the results, which are in line with the study's objectives. The second section also summarized the results of each hypothesis test in the study. The third section expands on the discussion of the investigation's findings.

6.2 Summary of Findings

This section mainly summarized the findings of the result analysis chapter. This study examines three relationships among the three objectives. Therefore, the results are summarized separately for each objective of this study.

6.2.1 Objective 1: To examine the impact of the US RGGI implementation on innovation

In objective one, this study examined the impact of regional greenhouse gas initiatives (RGGI) on firm-level innovation from 2000 to 2019. Experts concluded that each environmental policy has a direct impact on regulated facilities. A well-designed environmental policy also has indirect effects on sectors that are not regulated and encourages firms to take proactive steps toward environmental compliance to avoid sudden regulatory pressures. Thus, this study separately investigated the direct effect of RGGI on firm innovation in the regulated sector and the policy spillover effect of RGGI in the non-regulated sector. This study examined each relationship between RGGI implementation and firm-level innovation and found that the coefficient of interest (the "RGGI and year dummy" interaction term in Table 5.3) was 4.022 and statistically significant with a 99% level of confidence. The expected coefficient value is higher when all inclusions (such as control variables, sector variables, and time-fixed effects) are included in the model. It indicates that implementing RGGI stimulates firms' innovation in the regulated sector, supporting the "weaker" version (Porter hypothesis). For the unregulated sector, the coefficient value was also positive but statistically insignificant.

6.2.2 Objective 1(a): To examine the impact of the US RGGI implementation on green innovation

This study distinguishes green patents from annual registered total patents and limits the firm's innovation activities to green innovation only. According to the Porter Hypothesis, flexible environmental policies are superior to restrictive (e.g., command-and-control) types of regulation because they provide firms with a greater incentive to innovate. It is commonly known as the 'narrow' version of the Porter Hypothesis (Qi & Cheng, 2022; Wang & Lin, 2022). RGGI is flexible but mandatory, and authorities are paying their profits for low-carbon development within participating states. For example, RGGI authorities are spending significantly on energy efficiency, which accounted for 40% of RGGI's auction profit in 2019 and 54% of the total historical investment. More than 250,000 households and 1,400 companies in the area are estimated to save $553 million in energy costs for their lifetimes, preventing more than 1.5 million metric tons of CO_2. Another 18% of 2019 RGGI investments will go to renewable energy, 15% to GHG reduction, and 19% to direct bill assistance, with the remaining 14% going to cumulative investments and 10% to direct bill assistance to citizens. More than 2.51 million short tons of CO2 will not be released due to these investments in clean technology and direct bill help.

As a result of RGGI's efforts, the power sector has undergone substantial changes, making it easier for firms to adopt cleaner technologies, driving the power sector towards greater efficiency, and transforming it into a low-carbon industry using market mechanisms. Also, in recent literature, scholars have noted the relationship between market-based control and the green innovation of companies as an extension of the Porter hypothesis (Bel & Joseph, 2018; Calel, 2020; Y. Q. Liu et al., 2022; L. Zhang et al., 2019). This study investigated the relationship between the adoption of the RGGI and the green innovations of firms. This study found a positive but statistically insignificant relationship between adopting the RGGI and firms' green innovation in regulated and unregulated sectors. This finding remains consistent in the robustness tests.

6.2.3 Objective 2: To evaluate the impact of the US RGGI on the market competitiveness

The "strong version" of Porter's theory also said that a company's innovations make up for higher regulatory costs, and that environmental management through regulations could make a company more competitive. From this perspective, this study investigated the impact of RGGI on firms' market competitiveness. The implementation of RGGI appears to significantly boost the market competitiveness of firms in the regulated sector, but a statistically significant negative relationship with the non-regulated sector was found. These results are further tested using placebo-fake unit and time tests, regression-based treatment effect models such as DID and PSM-DID, and alternative measurement proxies for firms' market competitiveness. The results were found to be consistent in all the cases.

6.2.4 Objective 3: To measure the relationship between innovations and market competitiveness

Scholars are interested in two common ideas about a firm-level innovation effect, such as the "Schumpeterian view," which says that large companies in a concentrated market are more likely to motivate for innovations (Chassagnon & Haned, 2015; Forcadell et al., 2019; Kogan et al., 2017; Pereira, 2021). On the other hand, the "Arrowian views or escape-competition effects"- that more competition leads to more significant innovation, which means more competition persuades firms to innovate to survive the competition (Mulkay, 2019; Sanyal & Ghosh, 2013). However, Schumpeter (1934) stated that increased market rivalry hinders innovation. Large companies are more innovative because they are more stable, have more internal finances to invest in innovation, and can easily protect their ideas. K. J. Arrow (1962) introduced the counterargument that competition is better for innovation. Specifically, the author considered that corporate innovation is helpful for firms to reduce production costs and achieve innovative profits in a competitive environment, which motivates managers to conduct corporate innovation activities.

In objective three, this study again separated the effects of innovations and green innovations on firms' market competitiveness. This study found that firms' innovations promote market competitiveness, which is statistically significant at a 99% confidence level. This study also examined the moderating effect of US RGGI implementation on the relationship between innovation and market competitiveness of US F500 firms, and the coefficient value was negative and statistically significant at the 99% confidence level. This finding also indicates that the implementation of the RGGI (or market-based system for carbon trading in a broader sense) failed to promote firms' market competitiveness through innovation during the study period.

Furthermore, this study also examined the moderating effect of firm innovativeness on the relationship between innovation and market competitiveness of US F500 firms from 2000 to 2019. In contrast to the moderating effect of RGGI, this study found a relatively strong moderating effect of firm innovativeness on the relationship between innovation and market competitiveness. The coefficient value is positive and highly statistically significant. These results are verified through a series of robustness tests, including dynamic panel estimation, and remain consistent. Therefore, this study can conclude that an innovative firm or US F500 company with higher innovation activity than the average firm's innovation can increase market competitiveness through innovation.

6.2.5 Objective 3(a): To measure the relationship between green innovations and market competitiveness

This study examined the link between green innovation and market competitiveness and found a significant positive relationship. Also, this study found that implementing the RGGI weakens the relationship between firm-level green innovation and market competitiveness. Similarly, the legacy of green innovations (a firm with higher green innovation activities than the mean of total firms' green innovations) is positively moderated to increase the firms' market competitiveness through green innovation. It is statistically significant at a 99% confidence level and remains consistent with different inclusions. Also, this study cross-validated each finding with multiple robustness tests.

6.3 Summary of hypotheses tested

This section summarized all the results of hypothesis testing. Based on the 'weak and strong versions' of the Porter hypothesis, this study tested a total of 10 hypotheses and found supporting evidence for six hypotheses and rejected the other four. In addition,

Table 6.1 illustrates the decision to accept or reject each hypothesis for each model applied in this section. Finally, the results are interpreted in a manner consistent with previous research.

H_1: The RGGI has a significant and positive impact on innovation in the regulated sector

The results show that the implementation of US RGGI promotes the innovation of firms in the regulated sector, i.e., RGGI positively impacts the innovation of firms in the electric power sector. According to the 'weak' version of the PH, well-structured and properly managed environmental regulation spurs firms' innovations. This study measured firms' innovation using their yearly total number of registered patents and a policy interaction term generated using a dummy variable. This study used the DID quasi-experimental framework as a benchmark model (reported in Table 5.3) from model 1 to model 6. This study found that the coefficient of interest was 4.022, which is statistically significant at 1% significance level. This result was also cross-validated by using PSM-DID and found a positive and significant relationship (coefficient of interest varied between 8.584 and 9.160 in each model reported in Table 5.5) in the regulated sector. Also, this study used a two-step system GMM and found the coefficient of interest varied from 5.464 to 8.042 (reported in Table 5.6), which is positive and statistically significant. It indicates that US RGGI positively and significantly impacts firms' innovation in the regulated sector. Thus, this study supports the 'weaker' version of the Porter hypothesis.

H_{1a}: RGGI has an impact on innovation in the non-regulated sectors

The results show that the implementation of US RGGI does not significantly promote the innovation of firms in the unregulated sectors, i.e., RGGI has a positive but statistically insignificant impact on the innovation of firms in the unregulated sectors of within the participating states compared to unregulated states. However, this is not part of the 'weak' version of PH, with many recent studies examining the impact of regulatory spillovers on active environmental initiatives in unregulated sectors or firms. Also, firms' proactive environmental efforts have shown that more environmental regulations can lead to more innovation to avoid higher costs of compliance. Therefore, by following the same measures, this study found that the coefficient of interest was positive (reported in Table 5.3) but statistically insignificant. The findings remain consistent in the PSM-DID (reported in Table 5.5) and the tow-step SGMM (reported in Table 5.6). It suggests that the US RGGI has a positive but insignificant effect on firms' innovation in the unregulated sector. Thus, this study rejects the hypothesis that "the US RGGI has significant and positive effects on firms' innovation in the unregulated sector".

H_2: The RGGI has a positive and significant impact on green innovation in the regulated sector

In recent literature, many scholars have investigated the effects of market-based environmental controls on firms' green innovation by emphasizing the 'narrow' version of PH. Flexible regulatory approaches give enterprises more incentives to develop and are thus superior to authoritarian types of regulation. RGGI authorities are investing their proceeds from the auction trade for green growth in the participating states. Therefore, this study examined the impact of RGGI on firms' green innovations in the regulated sector and found the coefficient of interest (RGGI×YD) ranging from 0.085 to 0.238 (reported in Table 5.8) but statistically not significant. Also, the results remain steady in the case of PSM-DID (reported in Table 5.10) and two-step SGMM (Table 5.11). Consequently, this research could not find sufficient evidence that a "weak" form of the Porter hypothesis existed throughout the study period. Consequently, this study can reject the hypothesis that RGGI has a significant and positive effect on green innovation in regulated sectors.

H_{2a}: The RGGI has an impact on green innovation in non-regulated sectors

This study also investigated the regulatory spillover effects in unregulated sectors, i.e., the impact of RGGI on firms' green innovations in the unregulated sectors. Following the same procedure as the previous hypothesis test, this study found that the coefficient of interest between Model 1 and Model 6 (reported in Table 5.8) ranged from 1.614 to 1.890. It was positive but statistically insignificant. Also, the results remain steady in the case of PSM-DID (reported in Table 5.10) and two-step SGMM (Table 5.11). It suggests that the US RGGI has no substantial influence on unregulated sectors. Consequently, this study can also reject the hypothesis that RGGI has a positive and significant effect on the green innovation of firms in the unregulated sector.

H_3: The RGGI positively affects the market competitiveness in the regulated sector

Under the "strong" form of PH, ecological legislation can boost a firm's competitiveness. Recent literary scholars have argued that market competitiveness may be a better option for measuring the impact of flexible regulation on firm-level competitiveness. Thus, this study used the Synthetic Control Mothed (SCM) to investigate the effect of RGGI on firms' market competitiveness. The main idea is that SCM-optimized covariate weight and calculating the best-matched predictor's balance and optimal covariate weights leads to better comparative output in the synthetic control method. According to Figure 5.12, the market competitiveness of RGGI enterprises is around 0.0004 to 0.0016 points greater than synthetic RGGI firms from 2010 to 2019. According to the year-wise predictions of post-treatment periods (shown in Appendix S), all the post-intervention treatment effects are positive except in 2019. The average treatment effect (ATE) is positive, and the value is 0.008. It is strong evidence that the RGGI has accelerated the firm's ability to compete in the electricity production and transmission sector market during the study period. Also, this study applied the regression-based treatment effect model such as DID and PSM-DID (results reported in Table 5.14) and found a consistent value of the coefficients of interest. The results are also cross-validated with the help of a ‘Placebo test using fake units and time’. Similar results were evident when alternative measurements of the market competition were used in this study. Finally, this study acknowledges the existence of a ‘strong’ version of the Porter hypothesis in the RGGI-regulated sector during the study period.

H_{3a}: The RGGI has an impact on the market competitiveness in non-regulated sectors

This study also investigated the spillover effect of RGGI on the market competitiveness of firms in the unregulated sectors. This study follows the same procedure as the last hypothesis test. According to the year-wise predictions of post-treatment periods (reported in Appendix Y), all the post-intervention treatment effects are negative. The graphical average treatment effect is also portrayed in Figure 4 (reported in Appendix X). This study found that the average treatment effect over the post-treatment periods is -0.0571. This finding is consistent with robustness tests like the last hypothesis. In other words, this study can conclude that the US RGGI implementation failed to accelerate the market competitiveness of firms in the non-regulated sector during the study period. Finally, this study failed to acknowledge the existence of a ‘strong’ version of the Porter Hypothesis in unregulated sectors.

H_4: Firm-level innovation promotes the market competitiveness of US firms

The continuous improvement of the creative ability of the companies is essential for their success and survival. Technology innovation has been recognized as an advantage in the market. Also, innovation helps the firm improve energy efficiency, which influences the firm's competitiveness. From this perspective, this study investigated the relationship between firms' innovations and market competitiveness. This study used a panel fixed effect model (without lags) as a benchmark model (reported in Table 5.19). Results were also consistent when the same model was run with two lagged periods (results reported in Table 5.20). Moreover, this study also checked the persistence of the benchmark results with two-step SGMM (with and without lags) and found similar results (reported in Table 5.23 and Table 5.24). Finally, this study acknowledges that firms' innovations stimulate firms' market competitiveness.

H_5: Firm-level green innovation promotes the market competitiveness of US firms

This study followed the same procedure to measure the impact of green innovation on the market competitiveness of US F500 firms and found similar results (model output reported in Table 5.21 and Table 5.22). It indicates that the green innovations of the firms increase the ability of a firm to compete in the market. This study also checked the consistency of the finding with two lagged periods and two-step SGMM for both lagged and without lags (reported in Table 5.23 and Table 5.24); the result remains steady in each case. Finally, this study found specific scientific evidence to support this hypothesis that firms' green innovations can increase the market competitiveness of firms.

H_6: RGGI moderates the relationship between innovation and market competitiveness of US firms

Environmental regulation has dual effects, such as increasing compliance costs in the short term and improving technological advancement through innovation activities that will enhance business performance in the long run. As a result, this study explored the role of RGGI in influencing the link between innovation and market competitiveness in companies. This study found a negative and significant coefficient of interest (result reported in Table 5.19), which is robust in lagged periods estimation (results reported in Table 5.20). Also, this study found consistent results when applying the two-step SGMM with and without lag periods (reported in Table 5.23 and Table 5.24). This indicates that implementing the US RGGI undermines the ability of companies to increase their market share through innovation activities.

H_7: RGGI measures the relationship between green innovation and market competitiveness of US firms

This study also examined the moderating effect of RGGI on the relationship between green innovations and the market competitiveness of US companies. The section only replaced the firms' total registered patents with total green patents to measure the relationship between firms' green innovations and market competitiveness. Like previous hypothesis testing, this study considered the same inclusion of covariates and time-fixed effects. Also, this study found similar negative and statistically significant values for the coefficient of interest (results reported in Table 5.21). Benchmark results were found to be consistent in each robustness test. This indicates that the implementation of US RGGI weakens the firm's ability to increase its market share through green innovation activities.

Table 6.1: Summary of hypotheses tested

Hy	**Description**	**Benchmark Model**							**Robustness**							
		Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**SCM**	**DID**	**PSM-DID**	**SGMM**	**Placebo U**	**Placebo T**	**Alt. Proxy**	**LBE**	**Status**
H_1	The RGGI has a significant and positive impact on innovation in the regulated sector	Y	Y	Y	Y	Y	Y			Y	Y					Y
H_{1a}	RGGI has an impact on innovation in the non-regulated sectors	N	N	N	N	N	N			N	N					N
H_2	The RGGI has a positive and significant impact on green innovation in the regulated sector	N	N	N	N	N	N			N	N					N
H_{2a}	The RGGI has an impact on green innovation in non-regulated sectors	N	N	N	N	N	N			N	N					N
H_3	The RGGI positively affects the market competitiveness in the regulated sector							Y	Y	Y		Y	Y	Y		Y
H_{3a}	The RGGI has an impact on the market competitiveness in non-regulated sectors							N	N	N		N	N	N		N
H_4	Firm-level innovation promotes the market competitiveness of US firms	Y	Y	Y	Y	Y	Y				Y				Y	Y
H_5	Firm-level green innovation promotes the market competitiveness of US firms	Y	Y	Y	Y	Y	Y				Y				Y	Y
H_6	RGGI moderates the relationship between innovation and market competitiveness of US firms						Y				Y				Y	Y
H_7	RGGI measures the relationship between green innovation and market competitiveness of US firms						Y				Y				Y	Y

Note: H_y=hypotheses; LBE= lagged-based estimation; Y= supported the hypothesis, N= reject the hypothesis; model 1 to model 6 represent the same inclusions as presented in Tables 5.3, 5.8,5.19, and 5.22; SCM= synthetic control model; DID= difference-in-difference; PSM-DID=propensity score matching-based DID; SGMM= two-step system generalized method of moments; Placebo U= placebo test using fake treatment units; Placebo T= placebo test using fake treatment times; Alt. Proxy= robustness test based on an alternative measure of firms' market competitiveness.

6.4 Discussion of the findings

This section describes, further analyzes, and interprets the results of this study, in line with previous empirical studies and the practical effectiveness of RGGI, mainly as a market-oriented carbon trading policy in the US. Here, this study explains the results of each objective separately.

6.4.1 Impact of US RGGI Implementation on Innovation in Regulated Sectors

In objective one, this study examined the impact of the US RGGI on the innovation of firms in both regulated and unregulated sectors separately. This study used the DID treatment effect model as a benchmark regression to measure the actual effect. Finally, this study found that US RGGI positively and significantly impacts firms' innovation in the regulated sector. Thus, this study supports the 'weak' version of the Porter hypothesis. Although each ETS has some distinct characteristics that affect firm innovation differently, and unlike other similar major ETSs, RGGI is based solely on auction-based principles. However, the results of previous research help to better understand the impact of market-based environmental regulations on firm innovation. The RGGI, like the EU ETS and the CN-ETS, consists of the following functions: coverage, cap setting, permit allocation, allowance trading, monitoring, reporting, tracking, and compliance. However, the study's results may vary depending on the level of study (e.g., macro or micro), sample selection criteria (regulated or unregulated), measurement proxy, applied econometric model, and so on. Nonetheless, previous results are crucial to understanding global ETS initiatives and their impact on firm-level innovation.

Scholars have used the 'weak version' of the Porter hypothesis as a theoretical framework, particularly when they investigated the impact of market-based environmental legislation on innovation. In the extensive literature, both macro and micro levels have been investigated. For example, the authors investigated innovations at the provincial and city levels and found a negative relationship between CN-ETS implementation on innovation. (Liu, Ma, et al., 2020; Shi et al., 2018). One possible reason for their negative results is the duration of the coverage study. They covered up to 2015 when CN-ETS was implemented in 2013 and 2014 (Chongqing Pilot ETS and Hubei Pilot ETS were implemented in 2014). On the other hand, they measured innovation by total registered patents which must have influenced the results because patent registration is a time-consuming endeavor that takes a year or two to complete the patent registration process. In the case of ER, many recent studies have emphasized the country, province, sector and industry level, and in most cases the authors adopt the 'weak' version of the Porter hypothesis (Dou & Han, 2019; Fu & Jian, 2021; Hille & Mobius, 2019; Li et al., 2020; Martinez-Zarzoso et al., 2019; Nie et al., 2022; Qiang et al., 2022). Note that this study considers ER as a command-and-control regulation, which differs from market-based regulation in terms of flexibility and market participant nature. Although the 'weak' version of Porter's hypothesis has been acknowledged in macro-level research, the firm-level situation is also complex, thus, this study measured the relationship between ETS implementation and firm innovation.

At the micro-level, much of the recent research has emphasized the impact of ER on firm innovation. For instance, scholars acknowledged the supportive evidence of the ‘weak’ version of PH (i.e., a positive and statistically significant relationship between the ER and firms’ innovations) in China and Pakistan (Javeed et al., 2021; Liu & Gu, 2020; Liu & Xie, 2020a; J. T. Zhang et al., 2022). Another study found a positive relationship between Chinese voluntary environmental regulation and firms’ innovation (Bu et al., 2020). The ‘Chinese Air Pollution Reduction Governance Policy’ has recently significantly promoted firms’ innovation (W. Mbanyele & F. R. Wang, 2022). Also, few authors investigated the relationship between the Chinese SO2 emission trading scheme and firms' innovations and acknowledged the supportive existence of the 'weak' version (Ren et al., 2020b; Ta et al., 2020). Therefore, environmental regulations have a positive effect on firms' innovation. Furthermore, market-based carbon trading scheme such as CN-ETS was investigated to reveal their impact on firms' innovation through panel data and quasi-natural experimental methods (e.g., DID) and found a positive relationship (J. Hu et al., 2020; Qi & Cheng, 2022; Shen et al., 2021; X. Yang et al., 2020). Therefore, both command-and-control and market-based environmental policies have significant effects on firm-level innovation, based on recent literature findings.

Similar to recent findings in the literature, this study also found evidence supporting the 'weak version' of the Porter hypothesis in the regulated sector in RGGI participating states. The results of this study are significant for four reasons. First, the impact of each market-based carbon regulation should be different due to the different start dates of the diverse regimes. Second, unlike EU-ETS and CN-ETS, the RGGI started with a fully functioning auction compared to freely grandfathering allowances (Borghesi & Montini, 2016). Allocation of free allowance or over-allocation has a negative impact on innovation efforts (Martin et al., 2013). Thus, RGGI has brought about a significant change in the power sector, making it easier for firms to switch to technology advances, drive the power sector more efficiently, and turn it into a low-carbon emitting industry through market mechanisms. Third, the US RGGI differs due to constant thresholds (exemptions for installations, e.g., ≥25 MW). In contrast, the EU-ETS has different sector-based thresholds, and the CN-ETS has different thresholds for different provinces. Lastly, most previous studies (especially for CN-ETS) specifically covered a short period of post-policy intervention. But this study covered ten years after the implementation of RGGI, which may differ from the results of this study. Finally, the finding is consistent with most previous studies where the authors tested the 'weak' version of the Porter hypothesis and acknowledged its existence.

6.4.2 Effects of policy spillovers on firm-level innovation in non-regulated sectors

A cap-and-trade program encourages innovation more strongly for capped than uncapped firms. The influence of ETS on innovation probably extends beyond the regulated ETS sectors to other unregulated sectors. Environmental policies can hinder firms' performance, so firms that anticipate future regulations are more inclined to comply with today's requirements. If policy spillovers occur, the innovation effect of the ETS will be greater than the sum of the firm-level estimates given above. The impact will extend beyond the ETS entity to unregulated entities and the impact on individual ETS entities may be larger than the estimates presented above. Knowledge flows and spillovers may be created by the nature of innovation, particularly for companies operating in the same technological field as the regulated companies, but this takes time. By contrasting regulated and unregulated firms, one can conservatively estimate the program's overall impact.

However, emissions leakage can occur in regional enterprises, whereby reductions in emissions in regulated areas are nullified by increases in emissions elsewhere when firms move operations or production output to non-regulated areas (Lee & Melstrom, 2018). Emissions leakage, in which concurrent increases in emissions in unregulated areas balance decreases in the policy zone, is one of the primary issues (Chan & Morrow, 2019). For instance, the RGGI lowered yearly CO2 emissions by 4.8 million tonnes in regulated states, but uncontrolled states saw an increase of 3.5 million tonnes. Thus, it is essential to analyze the potential impact of RGGI on unregulated firms that face higher energy prices because they purchase electricity from regulated firms.

Consequently, this study also investigated the effect of US RGGI on firms' innovation in the unregulated sector and found that US RGGI has a positive but insignificant impact on firms' innovation in the unregulated sector. Thus, this study rejects the hypothesis that "the US RGGI has significant and positive effects on firms' innovation in the unregulated sector". Very few studies have directly measured policy spillover effects on the unregulated sector. However, in the case of EU-ETS, the regulated sectors are more likely to innovate than the non-regulated sectors in Italy (Borghesi et al., 2015). Another similar study was done by Martin et al. (2016) and found that the EU-ETS has no significant effect on firms' innovation in the unregulated sector.

Similarly, the spillover effect of CN-ETS on innovation in China's non-environmental industries is found to be negative and significant (Feng et al., 2017). They empirically reveal that CN-ETS inhibits enterprise innovation in non-environmental sectors, which are not covered by CN-ETS (Feng et al., 2017). They also reject the existence of a 'weak version' of the Porter hypothesis, particularly in Chinese non-environmental industries. Therefore, the results of this section are relevant to previous similar studies and reject the existence of policy spillover effects on firms' innovation in the unregulated sector.

6.4.3 Impact of the US RGGI on the firm's green innovation

This study examines the impact of RGGI on firms' green innovation between 2000 and 2019 by separating two panels for regulated and non-regulated firms. Also, the DID regression is used as a baseline model to investigate the impact of RGGI intervention. This study revealed that RGGI positively influenced firm-level green innovation in regulated firms. Also, firms in the unregulated sector without paying for green initiatives were positively affected when authorities set up RGGI. However, the results are not statistically significant. The results also remain constant and are insignificant for different inclusions used in individual model. These results are unaffected by the inclusion of control variables and time or sector fixed effects or dynamic effects in the case two-step system GMM. Therefore, this study can conclude that RGGI did not significantly affect the green innovation of firms in the regulated sector (i.e., electricity generation companies) and the non-regulated sector. Overall, the analysis of the results showed that RGGI failed to significantly promote green innovation of firms (in the regulated sector) and was unable to play a motivating role in proactive concern for green innovation in the non-regulated sectors, and its analytical robustness test supports this argument. Thus, this analysis refutes the "weak" and "narrow" forms of Porter's hypothesis that well-managed, flexible environmental legislation may promote green innovation among firms.

However, the theory of ‘Green Paradox’ suggests that environmental regulation can have unintended consequences and reduce innovation and competitiveness (Sinn, 2008). For example, if regulations are too strict or uncertain, they can reduce the incentives for firms to invest in new technologies, or they can discourage investment in certain sectors or regions (Tavares & Robaina, 2021). For example, in the context of China, it was found the existence of the theory of ‘green paradox’ (Y. A. Wang et al., 2019; Zhang et al., 2017). The literature already recognizes that environmental perfections are complicated to ascertain because of the ‘rebound effect’, ‘green paradox’ and ‘crowding out’ effect of ‘green or eco-innovation’ over a product's life cycle (Liu et al., 2018; van den Bergh, 2013). Hence, it is already accepted in the global environmental policy literature that the impact of environmental policies varies across factors and contexts.

Moreover, the positive relationship between RGGI implementation and green innovation of electric power generating firms (regulated firms) is not due to RGGI; instead, two possible factors may influence it. First, the market pulls and technological push[9], as the study found that the average age of regulated and unregulated firms was over

[9] The "market pull" strategy aims to provide items in response to market demand. The "technology push" strategy aims to attract market interest in new goods based on innovative solutions.

66 years and 43 years, respectively, indicating that firms may be forced to change technology to ensure permanence and optimal energy efficiency. Second, to achieve cost efficiency, the RGGI has significant effects on coal-to-gas switching (Kim & Kim, 2016). Huang and Zhou (2019) argued that the CO2 emissions target was not met because coal was switched to natural gas or natural gas was switched to non-fossil fuel. It was because coal was used less, and emissions were leaked. They also argued that lower natural gas prices triggered the so-called coal-to-gas switching. Hence, the firms might have a long-term strategic standpoint for technological switching from coal to gas to improve their cost-efficiency. Therefore, this study cannot confirm that this positive effect in regulated and unregulated sectors is only due to RGGI deployment, although it is not statistically significant.

In contrast, RGGI authorities have raised \$5 billion to date by selling CO2 permits and reinvesting most of these revenues in GHG emission-reducing activities. These supports can reduce the risks of green innovation for regulated firms by increasing consumer awareness. However, in unregulated sectors or in non-participating states, this support may have the opposite effect, putting pressure on green innovation without providing any direct incentives for low carbon initiatives. For instance, over 260,000 households and 1,400 companies engaged in RGGI-funded initiatives, saving \$1.3 billion in energy costs for its lifetime. Therefore, this support can reduce the impact of high regulatory compliance costs on citizens, can also create environmental awareness of citizens, which can reduce the risk of green innovation in the regulated sector but increase in the unregulated sectors. Recent research by the EU-ETS reveals that dispersal compensation does not cover increased energy prices and reduces the negative effects of greater exposure to carbon leakage (Ferrara & Giua, 2022). It can be one of the crucial causes of the insignificant impact of the RGGI on firms' green innovation in unregulated sectors. Another possible reason is that the RGGI authorities are reluctant to expand its coverage and have stuck with single-sector coverage since 2009. Another important issue is the political dilemma of environmental reform, which may make company management reluctant as the federal government announced its withdrawal from the Paris Agreement in mid-2017 and yet decided to rejoin under the new government.

Some previous findings also support the findings of this study where the authors empirically examined the relationship between ETSs (especially in EU-ETS and CN-ETS) and firms' green innovation but failed to establish a link or even conclude with an inhibited relationship. Regarding promoting the adoption of low-carbon technologies, the EU ETS cannot drive companies' investments in carbon-reducing technologies or encourage their adoption (Lofgren et al., 2014). Likewise, a significant negative relationship has been noticed in the electric sector (Bel & Joseph, 2018; Z. C. Zhang et al., 2019). Likewise, Yi et al. (2019) concluded that Chinese ERs do not offer adequate impetus for firms' green innovation. CN-ETS was found by Lyu et al. (2020) to be a short-term impediment to the advancement of low-carbon technological innovation. Likewise, another recent study by Z. F. Chen et al. (2021) used the panel-based DID method from 1990 to 2018 for Chinses listed firms and posited that the CN-ETS has no significant effect on firms' green innovation. Although the CN-ETS and the US RGGI are designed to be cap-and-trade in nature, the RGGI differs significantly due to the prescribed cap threshold. Specifically, CN-ETS induces different cap thresholds for different provinces, whereas RGGI considers a uniform cap threshold.

In contrast, regional ETS encourage companies to shift their operations from regulated to non-regulated areas to reduce CO2 emissions from regulated facilities and generate emissions from unregulated facilities. Another way is outsourcing alterations. Companies may outsource more operations if the related cost is less than the cost of lowering CO2 (Sadayuki & Arimura, 2021). However, regulated companies have 36.2

percent more low-carbon patents than non-regulated companies (Popp, 2019). The study's findings are that RGGI has an insignificant effect on the green innovation of firms in non-regulated sectors. This result is consistent with other similar studies in the context of EU-ETS and CN-ETS. For instance, the EU-ETS does not differentiate between regulated and non-regulated enterprises in terms of the effect of low-carbon innovation (Martin et al., 2013). Another study looked at the impact of CN-ETS on the low-carbon technology transition of Chinese listed companies. It found no correlation between the adoption of CN-ETS and the development of low-carbon technologies (W. Wang et al., 2020). Similarly, the US RGGI has failed to encourage firms in the unregulated sector to innovate green technologies.

However, RGGI has successfully reduced member states' CO2 emissions and fossil fuel consumption (EIA, 2021). However, experts argue that these emissions reductions are mainly achieved by reducing coal imports and emissions leakages, rather than "coal to gas fuel switching" (Huang & Zhou, 2019). Furthermore, RGGI does not significantly improve energy efficiency and increases retail electricity prices in Member States, reducing electricity demand due to higher carbon compliance costs (Rocha et al., 2015). In the same vein, the dented electricity demand is not because of RGGI but because of energy-efficiency improvements (Narassimhan et al., 2018) and technological improvements, mainly efficient electrical appliances' energy efficiency (Huang & Zhou, 2019). Therefore, this study can conclude that RGGI authorities invest in low-carbon development but fail to significantly stimulate firm-level green innovation in regulated and unregulated sectors.

6.4.4 Impact of US RGGI implementation on market competitiveness

This study also examines the effects of RGGI deployment on the market competitiveness of firms in both regulated and unregulated sectors. A positive and significant relationship was found between RGGI implementation and market competitiveness of firms in the regulated sector. However, this study found an inverse relationship in the unregulated sector, indicating that US RGGI implementation failed to accelerate the market competitiveness of firms in the unregulated sector during the study period. Following the “strong version” of PH, environmental legislation enhances a firm's competitiveness. Based on eco-innovation theory, this study recognizes the existence of a 'stronger version' of PH in the RGGI-regulated sector but not in the unregulated sector.

Market-based, i.e., flexible regulation influences the firm's operational activities in two ways. On the one hand, it pressures companies to reduce emissions by increasing compliance costs. This increases their overall costs, hampers their productivity, and ultimately reduces their market competitiveness. Specifically, the US RGGI establishes a carbon emission control system, a quota management system, carbon emission trading, emission reporting, verification, and penalties based on strict monitoring. In addition to establishing mandated criteria for firms, the participating states also established an industry admissions system. Companies that do not satisfy the standards must limit their harmful emissions during manufacturing. In practice, pollution control and emission reduction expenditures are necessary to maintain low carbon levels, raising business expenses and impeding productivity gains, diminishing their competitiveness in their markets.

Alternatively, agencies in participating states optimize revenues by subsidizing energy conservation and pollution abatement costs. First, member states establish special funds supporting low-carbon growth that primarily support companies headquartered in participating states with investment subsidies, renewable energy development, energy efficiency improvements, and direct bill support for citizens. After the introduction of RGGI, considering its environmental and social costs, authorities developed an acceptable energy pricing strategy by distributing RGGI revenue among citizens and providing specific incentives to use improved materials, renewable energy, and technological advances. These preferential measures can increase revenues for enterprises in regulated jurisdictions and compensate for additional costs generated by regulatory policies.

The results of this study are consistent with other previous similar studies. Many recent studies examined the existence of 'strong' versions of the Porter hypothesis and acknowledged the presence of the Porter hypothesis. Most studies have emphasized the relationship between environmental regulation (this study treats it as a command-and-control regulation) and firm performance, profitability, and productivity. Ecological regulation positively affects a firm’s performance (Javeed et al., 2020; Lei et al., 2022; Y. L. Yang et al., 2021; Y. Zhang et al., 2022). More specifically, few authors concluded with empirical findings that environmental regulation affects firms’ financial and economic performance (Gu et al., 2022; Xing et al., 2020), environmental energy performance (Lin & Chen, 2020), profitability (Ahmad et al., 2019), and total factor productivity (D. Q. Shi et al., 2022). However, a flexible market-based environmental regulation was generally accepted and more effective than command-and-control-based regulation. Therefore, it is essential to compare the existence of the Porter hypothesis based on the results of market-based environmental emission reduction schemes.

Many scholars have recently emphasized the relationship between market-based regulation and firm performance. For example, the EU-ETS promotes the performance of industrial companies in Spain (Canon-de-Francia & Garces-Ayerbe, 2019). Similarly, the impact of EU ETS on net imports of cement and steel sectors in Europe is found to be positive (Boutabba & Lardic, 2017). EU ETS had a minor direct influence on global competitiveness, but it had a major indirect impact on the European pulp and paper sector

(Lin et al., 2019). The Chinese experimental ETSs, in contrast, have failed to prevent a deleterious effect on competitiveness (Zhang & Duan, 2020). However, they used employment to measure the firms' competitiveness and covered only the study period from 2005 to 2015; CN-ETS was induced in 2013 and 2014. Thus, they measured the immediate impact of the CN-ETS on employment, which was commonly used to measure labor market competitiveness (Dubel & Pawlowska, 2020; Goto & Mano, 2012). In recent days, experts have argued that market competition may be a good option for measuring the impact of flexible controls on firm-level competition. In this vein, this study measured the impact of RGGI on firms' market competitiveness and found a positive and statistically significant relationship that is consistent with other previous empirical findings and favors the 'strong' version of Porter's hypothesis. However, the policy (RGGI) spillover effect in the unregulated sector was inversely affecting firms' market competitiveness.

6.4.5 Relationship between innovation activities and market competitiveness

Innovation is a key driver of a firm's competitiveness in the market. It can lead to the development of new products, processes, and business models that can give a company a competitive advantage over its rivals. Additionally, a company that can continuously innovate may be able to stay ahead of market trends and changes, allowing it to maintain its competitive position over the long term. On the other hand, a lack of innovation can make a company less competitive, as it may struggle to keep up with its rivals and may not be able to offer as many unique products or services. Overall, innovation is an important factor in determining a firm's competitiveness in the market.

The impact of environmental regulation on firms' market competitiveness can be both positive and negative, depending on various factors such as the type and stringency of the regulation, the level of technological sophistication of the firm, and the industry in which it operates. Innovation helps bring many benefits to the organization. For example, innovations increase a firm's value creation by increasing market share, profits, sales, and provide first-mover advantage by creating new market opportunities. Also, innovations help to reduce costs by improving productivity and efficiency. In addition, firms' continuous innovation activities help to enhance non-financial assets such as corporate reputation and image, and improve product quality, which increases customer satisfaction. From this perspective, this study examined the relationship between firms' innovative activities and market competitiveness. Using panel data regression, this study found that innovation helps increase firms' market competitiveness from 2000 to 2019. Thus, this study acknowledges that firms’ innovations stimulate market competitiveness of US firms.

However, counterarguments are also true that innovation creates some negative effects on the firm's market competitiveness. The negative impacts are: i) increasing the costs of compliance with environmental regulations, which can make it more difficult for firms to compete on price, ii) slowing innovation, as firms may have less resources available to invest in research and development, iii) reducing a firm's flexibility in responding to market changes and customer needs. Overall, the impact of environmental regulation on firms' market competitiveness will depend on the specific circumstances of each case and can vary greatly between industries and countries.

The findings of this study are consistent with previous studies where the authors have examined the relationship between innovation and competitiveness. Research on the macro-level (national level) link between innovation and competitiveness has shown positive results (Khyareh & Rostami, 2021; Lewandowska, 2020). However, most previous studies have emphasized the relationship between firm-level innovation and competitiveness. For instance, Wang and Lin (2008) concluded that Chinese enterprises could improve their core competitiveness through technological innovation. Firms' innovations were identified as an important determining factor of the competitiveness of Polish enterprises (Sachpazidu-Wojcicka, 2017). Srivastava et al. (2017) conducted additional exploratory research in which they analyzed the innovation competence index score and the overall competitiveness performance index of Indian Agro-food processing enterprises. Their study identified a strong link between the firm's innovation ability and competitiveness.

In the recent literature, innovation was identified as a driver of external competitiveness in Italian small and medium enterprises (Brancati et al., 2021). Another study found a positive potential link between corporate innovation and corporate competitiveness in UK IT firms (Sukumar et al., 2020). However, none of the studies investigated the relationship between firm innovation (measured by successfully registered patents) and the firm's market competitiveness when they measured the impact of innovation on firm performance and competitiveness. This research contributes to the body of knowledge that firms' innovations enhance firms' ability to compete in the market. Moreover, the results of this study are significant for two reasons. First, how the amount of firm-level innovation (measured by the total number of patents) affects the firm's ability to compete in the market with 20 years of panel data. Second, this study reveals empirical evidence for high revenue generating firms because innovation is highly costly for firms.

6.4.6 Relationship between green innovation and market competitiveness

Green innovation is a very costly endeavor of the firm which reduces the firm's ability to invest in new potential opportunities. On the other hand, a successful green innovation improves product or process quality and improves firm efficiency, creating a corporate green reputation and green image. In addition, green initiatives help companies show better concern for the environment (by producing less hazardous products and services), which helps them face environmental regulatory strictures, social (increasing public awareness of the environment) and economic benefits. As a result, it helps to increase market demand and enhance the ability of organizations to compete in the market. From this perspective, this study also investigates the relationship between the firms' green innovation and market competitiveness. This study found that the firms' green innovations make them more capable of being competitive on the market.

Past research has shown a relationship between green innovation and a firm's ability to compete successfully. Research on business issues often uses the phrases "competitive advantage" and "competitiveness" interchangeably without defining the distinction between the two (Morioka et al., 2017). Some research has shown that competitive advantage and competitiveness help evaluate an organization's growth and development. Intensely competitive companies have an edge over their rivals (Delery & Roumpi, 2017). When a company has a significant competitive advantage, it is more competitive, which indicates that there is no obvious separation between "competitive advantage" and "competitiveness," and the study on competitiveness is always inseparable from the idea of competitive advantage (Zong & Wang, 2022).

According to Porter (1991c), competitive advantage is a relatively straightforward measure of an organization's favorable position to be more profitable than its competitors. On the other hand, Baranzini et al. (2000) defined competitiveness as the capabilities of a firm to maintain or enhance both global and domestic market shares and profitability. According to El Amrani et al. (2021), a company's market competitiveness is determined by its capacity to provide products and services that are more innovative and effective than those offered by rivals. Similarly, Cui et al. (2021) defined market competitiveness as achieving market goals, such as enhancing market advantage, market share, market position, profitability, etc. Following the previous studies by Fresard (2010), J. Hu et al. (2021), and Nguyen et al. (2021), this study considers that market competitiveness is a firm’s ability to business activities within a market context considering the demands of products and services rendered to the market by complying with additional environmental compliance costs due to the implementation of the RGGI.

The results of this study are also consistent with some previous studies. For example, environmental innovations have increased firm competitiveness in Spain's Balearic Islands by satisfying customer needs, improving service quality, and greening the firm's image (Jacob et al., 2010). Similarly, another recent study found that firms' green innovations positively contribute to competitive advantage through the corporate green image of manufacturing enterprises in China (Waqas et al., 2021). Another research revealed that green innovation significantly influences manufacturing competitiveness in Ecuador (C. P. Padilla-Lozano & P. Collazzo, 2022). In Iranian oil refining companies, the author states the positive role of green innovation in reaching competitive advantages (Barforoush et al., 2021). Environmental process innovation has been proven to help attain low costs and differentiation, but environmental product innovation can only strengthen the competitiveness of Chinese manufacturing firms (Liao, 2016; Tu & Wu, 2021). In Brazil, the relationship between product innovation and green processes and achieving competitive advantage was significant but moderate in the electrical and electronic sectors (Arenhardt et al., 2016). In addition, Taiwanese firms' environmental performance and competitiveness are boosted by greening their suppliers (T.-Y. Chiou et al., 2011). In the case of eco-innovation, authors also found a positive relationship between firms’ competitive advantage in the Australian wine-producing firms (Ratten, 2018) and the Malaysian automotive industry (Fernando et al., 2021). However, to the best of the research's limited knowledge, no study directly measures the relationship between firms’ green innovation and market competitiveness. But the measuring of competitiveness is not as simple as it seems. Competition is challenging since it cannot be directly observable (OECD, 2021). Thus, this study cross-validated the benchmark result with multiple robustness texts and found no inconsistency. Therefore, this study concluded that firms' green innovation stimulates US firms' capacity to compete in the market.

Overall, this study critically evaluates the previous similar finding those examined the impact of market-based carbon emission trading systems on firm-level innovation activities and market competitiveness. They also found similar results. However, this study also evaluates innovation activities and market competitiveness. The result reveals that the firm's innovation activities significantly enhance the firm's ability to compete in the market. This study also examines the moderating effects of RGGI and the firm's innovativeness between innovation activities and market competitiveness. The findings reveal that RGGI weakens the relationship between innovations or green innovation and market competitiveness. However, this study found a statistically significant positive effect on the firm's innovativeness, indicating that innovative firms retain existing market opportunities more than less-innovative firms. At this point, this study recommends a specific policy implication that the RGGI authorities can extend their coverage to ensure better performance regarding green innovation for achieving sustainable CO2 emission targets.

6.5 Chapter conclusions

This chapter mainly presented the summary of the findings in line with the objective and hypothesis of the study. After that, this section critically explains the previous chapter's results and justifies the conclusions with the support of relevant recent literature. Although this study separated the market-based carbon process into paid and freely auction-based policies, it used an extensive literature survey based on the theoretical background, such as eco-efficiency theory or Porter's hypothesis. Overall, this section illustrates the similarities and differences in previous literature, which can help to understand the current position of RGGI regulatory agencies and the management of US firms toward reducing negative externalities through innovation activity. The next section will explain its implications, limitations, and conclusions.

CHAPTER 7: CONTRIBUTION, IMPLICATIONS, AND CONCLUSION

7.1 Introduction

This chapter presents the key contributions and implications of the study and policy recommendations. The current chapter is divided into three sections. The first section presents the implications of this study, including theoretical and practical implications. The second section summarizes the key policy recommendations of this study. Limitations and future research directions are presented in section four, followed by a section that concludes the thesis.

7.2 Significant Implications of the Study

This empirical research initiative provided a more nuanced understanding of the impact of US RGGI on firms' innovation, green innovation, and market competitiveness of US firms. The findings carry significant theoretical and practical implications, including policy recommendations and implications.

7.2.1 Theoretical implications

This study offers a theoretical contribution to the existing knowledge on implementing market-based environmental regulation and its impact on firms' innovation activities and market competition. First, this study explored the impact of RGGI, designed as market-based regulation, on firms' innovation. Few previous studies examine the effect of US environmental regulation on firms' innovation. Also, a few studies have investigated the impact of market-based environmental regulation on firms' innovation, but most have focused on the EU-ETS and CN-ETS. Still, the results of previous studies are inconclusive. Previous studies have overlocked the impact of RGGI on innovation in US firms. Based on the classification of market-based environmental policies, RGGI is working on fully auction-based permit distribution instead of freely distributed permits in the case of EU-ETS and CN-ETS. Thus, the present study's findings will enrich the existing literature examining the ‘weak’ version of the Porter Hypothesis.

Second, most previous studies reveal the effects of environmental regulation through panel data and DID methods in regulated facilities compared to unregulated facilities. This study also explores the impact of RGGI on the innovation of firms in the unregulated sector by comparing RGGI participating firms to firms in non-participating RGGI states. This measure is vital for two reasons: 1) to measure the effect of policy spillovers on the unregulated sector, and 2) to explore whether RGGI authorities have been able to create threats to the expansion of untreated sectors and non-participating states. In addition, findings on the relationship between RGGI implementation and innovation in the unregulated sector will enrich the policy spillover literature on market-based environmental regulation.

Third, authors in recent studies have examined the relationship between the implementation of market-based carbon regulations and firms' green innovation. They also consider this relationship as an extended test of the 'weak' and the 'narrow' version of the Porter hypothesis. Thus, the present findings contribute to the green innovation literature in terms of the evaluation of environmental policy (ETS regime). Fourth, this study investigated the impact of RGGI deployment on firms' green innovation initiatives in the unregulated sector to explore firms' proactive green initiatives and policy spillover effects. Thus, the findings on the relationship between RGGI implementation and firms' green innovation in the unregulated sector enrich the policy spillover literature of market-based environmental regulation.

Fifth, the 'strong' version of the Porter hypothesis suggests that flexible, structured environmental regulation can increase firm competitiveness. Based on this theoretical rationale, this study examines the impact of RGGI deployment on the market competitiveness of firms in the regulated sector. Most studies in the recent past have emphasized EU-ETS and CN-ETS; however, most authors have focused either on firms' competitive advantage or competitiveness. Moreover, most major ETS systems are criticized for free permit allocation or over-allocation. At the same time, this study focuses on firms' market competitiveness to measure the impact of RGGI. However, due to some differences between the policy features of the RGGI and other contemporary ETS regimes and the application of multiple proxies to measure firms' market competitiveness, the results of the present study may differ somewhat in understanding the impact of the RGGI. Nevertheless, this study found a positive and significant effect of RGGI implementation on the market competitiveness of firms in the regulated sector, which is a new addition to the market-based policy evaluation literature (since RGGI is a fully payment-based policy). Sixth, the present study also revealed policy spillover effects in the non-regulated sector, enriching the policy spillover literature of market-based environmental policy.

Seventh, this study measured the impact of innovation on market competitiveness and found a positive and statistically significant relationship among US firms. In fact, according to the 'Derwent Innovation Index,' most of the top 100 innovative companies originate in the US (Derwent-Index, 2019). The sample selection criteria for this study considered most US innovative firms. Thus, the findings of this study contribute to the innovation literature by revealing empirical evidence of highly innovative firms in the United States. Eighth, this study explores the moderating role of RGGI in the relationship between firm innovation and market competitiveness. Remarkably, this study finds a negative and significant moderating effect, indicating that the implementation of the US RGGI weakens firms' ability to increase their market share through innovation. This relation also contributes to the present body of knowledge. Nineth, this study compared the ability of firms to grasp the market opportunities through innovation efforts between the innovative and low-innovative firms. In this study, a firm is considered innovative if they register more patents than the average of total firm patents, otherwise considered a low-innovative firm. This study found positive and significant results indicating that innovative firms retain existing market opportunities more than less-innovative firms. Thus, this is also an exciting contribution to the current literature.

Tenth, this study also measured the impact of green innovation on firms' market competitiveness and found positive and statistically significant relations among the US firms. Most selected sample companies are ranked among the top 100 innovative companies worldwide. Thus, the findings of this study contribute to the green innovation literature by revealing empirical evidence of highly innovative firms in the US. Eleventh, this study also examines the moderating role of RGGI between the firms' green innovation and market competitiveness. Remarkably, this study also finds a negative and significant moderating effect, indicating that implementing the US RGGI weakens firms' ability to increase their market share through green innovation. This relation also contributes to the present body of knowledge.

Twelfth, this research compared the firm's ability to retain the market opportunities through innovation efforts between the green-innovative and low-green-innovative firms. In this study, a firm is considered green innovative if they register more green patents than the average total green patents, otherwise considered a low green-innovative firm. This study found positive and significant results indicating that green-innovative firms retain existing market opportunities more than low-green-innovative firms. Thus, this is also an interesting contribution to the current literature. Finally, from a methodological perspective, this study applied the 'synthetic control method' to assess the impact of the RGGI on firms' market competitiveness, which is the first attempt at the impact of the ETS regime on firms' competitiveness.

7.2.2 Practical implications

In addition to theoretical contributions, this study also offers some specific practical contributions and guidelines to industry practitioners. First, this study measured the impact of RGGI on firms' innovation, green innovation, and market competitiveness, which can help practitioners understand the actual effect of market-based regulation in the US called RGGI. Second, this study separately measures the direct impact of RGGI on regulated sectors and policy spillover effects on non-regulated sectors, which can help practitioners understand the overall situation of US firms' innovation and green innovation initiatives. Third, this study controlled for specific firm-specific characteristics such as firm age, size, Tobin's Q, firm profile, operating capacity, firm growth, business capacity, and leverage and found no significant effect on the benchmark results.

Consequently, firms operating in pervasive institutional transitions, especially those in the participating states, should match their innovation objectives with the institutional forces. Specifically, a firm can exploit institutional incentives to promote incremental innovations and translate institutional pressures into motivations toward radical innovations. Policymakers must consider the different roles of institutional incentives and forces in influencing incremental and radical innovations when considering regulations' incentive-based or command-and-control designs (Stewart, 2010). A systems approach is called for to view the interplays of an innovation system's combined mix of institutions, regulations, and policies (Edler & Fagerberg, 2017). These findings help firms' management rethink their innovation and green innovation initiatives, particularly how they can improve them.

Fourth, market-based regulations are considered an effective way to reduce carbon emissions by promoting green innovation of firms. This gives companies some unique advantages for green development, and many companies try to use the opportunity to go green and create a green image (Chen, 2010; Xie, 2019). They also revealed that successful implementation of green process innovation activities requires a balance of absorptive capacity. These requirements not only help companies overcome the technical challenges of green process innovation but also allow them to enhance their green image and gain a competitive advantage. Therefore, decision makers can identify these valid approaches for managing green process innovation, thus effectively enhancing their organization's green image.

Fifth, this study found that a firm's innovation activities (innovation and green innovation) stimulate the firm's ability to increase market competitiveness. Implementing a green innovation strategy could be a new path for manufacturing new ventures to achieve performance growth (X. E. Zhang et al., 2022). By implementing a green innovation strategy, new venture manufacturing can innovate products and services to attract more benefits from environmentally-sensitive customers (Lisi et al., 2020). Additionally, it enhances corporate social reputation and customer loyalty, builds brand leverage and benefits from premium income brought by the product's environmental protection features (Lisi et al., 2020). Meanwhile, a green innovation strategy can build differentiated competitive advantages by promoting enterprises to improve operation quality and reduce production costs, which increases the possibility of performance improvement (X. E. Zhang et al., 2022). Thus, the results of this study can help decision makers to choose the right approach for green development of firms to manage the regulatory and market demand push-pull to maintain or improve their current market competitive position.

Sixth, this study also measured the moderating role of a firm's innovativeness and found that innovative firms can better capture existing market opportunities than less-innovative firms. These findings can reassure the firm's decision-makers that innovation and green innovation improve their current position in the market and secure their position in the long run. Also, this study found that implementing RGGI weakens the ability of regulated firms to secure market positions relative to non-regulated firms. Therefore, policymakers and industry practitioners must work together to find a win-win solution.

7.3 Policy recommendation

Based on empirics, this study paves the way for policy solutions. First, expand the coverage of the RGGI, which currently covers power plants of twenty-five megawatts or more in member states. Thus, increased coverage of more economic sectors, at least energy-intensive sectors, could improve the situation, making a significant difference, especially in green innovations as like innovation. Second, prior studies confirmed the emissions leakage (the regulated regions' reduction can be offset by an increase in emissions in the unregulated regions) as the RGGI is a sub-national climate policy. This emissions leakage may impact the price of CO2 allowances and the firm's environmental compliance cost, which may restrict the firm's green innovation attempt. The ideal solution is a national cap-and-trade program to avoid emissions leakage. However, due to the relative political freedom of the policy-making power of each state, it is not easy to persuade. From this perspective, this study expects that leaders of RGGI participating states can negotiate to widen the area coverage or at least the states where they are importing a high volume of energy.

Third, this study found a positive and statistically significant influence of the RGGI on firms' innovation. Also, this research explored a strong positive of firms' innovation on market competitiveness. However, this study also confirmed that the implementation of RGGI has weakened this relationship and revealed that innovative firms are more capable of holding market advantage than low-innovative firms. These results shed light on whether RGGI stimulated innovation at these companies throughout the research period. Similar results were revealed for green innovation. Two possible reasons could also influence the RGGI and firms' innovations relation. On the one hand, technological push, which forced firms to make technological changes or technology upgradations. For example, this study found that the average age of regulated companies was 66.45 years, indicating that companies are old enough that changes in technology to ensure optimal energy efficiency become apparent.

On the other hand, to achieve cost efficiency, the RGGI significantly affects coal-to-gas switching (Kim & Kim, 2016). Huang and Zhou (2019) argued that the CO2 emissions target was not met because coal was switched to natural gas or natural gas was switched to a non-fossil fuel. It was because coal was used less, and emissions were leaked. They also argued that lower natural gas prices triggered the so-called coal-to-gas switching. Hence, the firms might have a long-term strategic standpoint for technological switching from coal to gas to improve their cost-efficiency. Therefore, this study hardly confirms this positive effect on green innovation of the regulated sector due to the establishment of RGGI. However, it is not statistically significant, and further research or joint (policy agents and industry practitioners) strategic solutions are needed to get the best results for RGGI deployment.

In contrast, the RGGI earned \$5 billion by selling CO_2 permits and reinvesting most of this revenue in GHG emissions-reducing activities. These assistances might have lowered the risk of green innovation for the regulated companies by increasing consumer awareness. However, in unregulated sectors, this support may have the opposite effect. Over 260,000 households and 1,400 companies engaged in RGGI-funded initiatives, saving \$1.3 billion in energy costs for its lifetime. Recent research from EU-ETS reveals that the dispersed compensation budget does not compensate for the increased energy prices, and the adverse impacts diminish in sectors more susceptible to carbon leakage risk (Ferrara & Giua, 2022). It may be one of the crucial causes of the insignificant effect of the RGGI on firms' green innovation in unregulated sectors. Also, the political dilemma of environmental reform may make the company's management reluctant that the federal government was ready to back away from the Paris Agreement in the middle of 2017 and rejoin it under a new government.

Forth, although the RGGI authorities are committed and spending more than 85 percent of their auction proceeds on developing renewable energy, improving energy efficiency, technological progress, and direct utility bill assistance. However, the policymaker should reevaluate the effectiveness of this spending and pay more attention to how firm-level green innovation can be stimulated. Finally, a reciprocal approach, such as a mix of subsidies or special fund allocations and market-based rules, can significantly impact enterprises' green actions (Bai et al., 2019; Li & Zeng, 2020). Thus, when combined with present policies, subsidies for firms' green innovation and special funds will improve firms' green efforts.

7.4 Limitations of the study and future research scope

Some limitations of this study are inevitable, which the present research keeps for future researchers. First, the RGGI is induced in ten specific states only, and each state has legislative autonomy. Thus, this study was conscientious to the fact that a state's characteristics may affect firms' innovative activity. In this context, this study introduced and regressed by controlling the 'state's fixed effect' and found no significant difference with benchmark regression. Nonetheless, specific state-level differences (e.g., incentives, voluntary initiatives, and differences in consumers' environmental concerns) might have influenced firms' green innovations and kept them for future researchers.

Second, some subsidiaries of a large company may have been involved in the innovation process or patent application (Capaldo & Petruzzelli, 2014). This study settled this issue by limiting the USA to an 'innovator's address', and the firm's origin. Thirty-eight companies that changed their headquarters location from regulated to non-regulated states were excluded from this study. Then, this study selected companies listed on the US stock market to confirm business activities but could not consider the proportion of industrial activities within the regulated state and left this issue for future researchers.

Third, as R&D is the prime input of firms' innovation, the disclosure trend of green R&D is still not enough to conduct good academic research. Thus, the gradual development of firm-level green information will carry out much research in this field. Forth, in-depth industry-wise analysis with no limits to listed and non-listed or comparative impact on private and public or 'large firm' and 'small and medium firm' or 'state-owned' and 'listed' can also enrich the empirical understanding of the relationship between this policy and firms' green behavior.

Fifth, distributed proceeds for business entities should reduce regulatory compliance costs and promote firms' ability to implement green innovations. Also, direct energy bill assistance can increase citizens' ability to pay more for green goods or services and improve their green awareness. This study found no studies examining the impact of RGGI, specifically direct bill subsidies, on consumer green awareness and demand or market pull in RGGI participating states. Thus, the effect of direct bill support on citizen green awareness could be interesting research in the future.

7.5 Conclusion

This study aims to examine the impact of US RGGI on innovation, green innovation, and market competitiveness of US firms. Also, the current study sets an extended objective to measure the impact of firms' innovative activities on firms' market competitiveness. First, this study examines the impact of RGGI on firms' innovations. To measure this effect, this study selected regulated sectors (e.g., the electric power sector) to measure the direct effect of RGGI on the innovation of regulated firms. To measure the impact of policy spillovers or firms' proactive initiatives on innovation, this study selected non-regulated sectors based on firms' high financial performance (e.g., United States Fortune 500 companies). Based on the quasi-natural experimental framework, this study used the DID method as a benchmark model and applied PSM-DID and two-step SGMM to cross-validate the initial results. This study found that RGGI implementation significantly enhances firm innovation in the regulated sector but is statistically insignificant in the unregulated sector.

Furthermore, the US RGGI, designed as a market-based environmental regulation, specifically focused on sustaining the current upward trend in greenhouse gas emissions. RGGI has also worked on the cap-and-investment nature, which sets an upper limit through purely auction-based emissions and requires a firm to buy allowance permits from the market if a specific limit is exceeded. RGGI agencies earn profits from this market system and redeploy these funds to low-carbon technological development or green technological advancements. From this perspective, this study focuses on green innovation from firms' innovation. Then, this study separates firms' total registered green patents from total annual registered patents to measure firms' green innovation. This study found a positive but statistically insignificant relationship between the RGGI's implementation and firms' green innovation in the regulated and non-regulated sectors. This finding remains consistent in the robustness tests.

In objective two, this study evaluated the impact of the US regional greenhouse gas initiative on a firm's market competitiveness. To measure this impact, the current study applied the synthetic control method and found that implementing the RGGI stimulates firms' market competitiveness significantly in the regulated sector but found a statistically significant negative relation in the case of non-regulated sectors. This study further examines the empirical findings using the Placebo fake unit and time tests, regression-based treatment effect models such as DID and PSM-DID, and alternative measuring proxy for firms' market competitiveness. The results were found to be consistent in all the cases.

In objective three, this study again separated the effects of innovations and green innovations on firms' market competitiveness. This study found that firms' innovations promote market competitiveness, which is statistically significant at a 99% confidence level. This study measures the moderating effect of the RGGI and found that the RGGI weakens the relationship between firms' innovation and market competitiveness. However, this study found strong moderating effects of the firms' innovativeness between the firms' innovations and market competitiveness. In other words, this study found that an innovative firm (a firm with higher innovation activities than the mean of total firms' innovation) can enhance its market competitiveness through innovations.

Besides, this study investigated the effects of firms' green innovation on market competitiveness and found a significant positive relationship. Also, this study found that implementing the RGGI weakens the relationship between firms' green innovation and market competitiveness. Similarly, the legacy of green innovations (a firm with higher green innovation activities than the mean of total firms' green innovations) is positively moderated to increase the firms' market competitiveness through green innovation. It is statistically significant at a 99% confidence level and remains consistent with different inclusions. Also, this study cross-validated each finding with multiple robustness tests.

This chapter also highlights the relevant literature to further discuss this research's findings. Also, these sections point out some specific theoretical and practical implications of the study along with policy recommendations that help academicians to get a clear picture of RGGI implementation on firms' innovation, green innovation, and market competitiveness. Also, industry practitioners and regulatory bodies can get some improvement recommendations based on the study findings, which help them to modify the current position of regulations for better performance in the future.

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