The Synergy of Carbon Pricing and Macroprudential Policies in Green Transitions: Insights from a Global Quasi-Natural Experiment

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Abstract:

This study contributes to the growing body of literature on climate policy and financial stability by examining the synergistic effects of carbon pricing and macroprudential policies in driving green energy transitions. Using global quasi-natural experiments and a difference-in-differences approach with time-varying treatment effects, the analysis reveals a significant shift from fossil fuels to renewable energy following the implementation of carbon taxes and emission trading systems (ETS). The findings highlight an inverted U-shaped relationship between carbon tax levels and renewable energy adoption: while higher carbon taxes initially accelerate green transitions, excessively high taxes may hinder progress, potentially due to carbon leakage. A key theoretical contribution of this research lies in exploring the interplay between macroprudential policies and carbon pricing. Stringent macroprudential measures bolster financial system resilience, mitigate transition risks, and incentivise green investments, thereby complementing carbon pricing by fostering a supportive environment for the renewable energy adoption. However, stringent capital requirements could inadvertently stifle progress by disincentivising lending to green sectors due to their delayed financial returns. Conversely, relaxed financial regulations weaken the effectiveness of ETS, which is vulnerable to market distortions. In contrast, carbon taxes retain their efficacy across regulatory environments due to their stable and predictable cost structure. By integrating insights from environmental economics and financial regulations, this study offers critical policy implications for designing cohesive strategies that promote a sustainable and equitable transition to a low-carbon economy.

Keywords: Carbon pricing, carbon tax, ETS, macroprudential policies, renewable energy, green energy transition

1. Introduction

The growing concern over climate change has spurred a global commitment to decarbonisation and the transition to green energy, aiming at reducing greenhouse gas (GHG) emissions and fostering sustainable development. A wide range of initiatives and policy instruments have been implemented at international, national, and subnational levels to support the shift from fossil (brown) to renewable (green) resources. Among these, carbon pricing has been highlighted as the most cost-effective tool for mitigating emission and facilitating the transition to net-zero carbon economies (Boehl et al., 2024; Punzi, 2024; Tvinnereim & Mehling, 2018). By assigning a monetary value to carbon emissions, carbon pricing internalises the environmental costs associated with fossil fuel use, thereby incentivising shifts toward cleaner energy resources and reductions in emissions. Two primary instruments underpin carbon pricing: carbon taxes and emissions trading system (ETS). A carbon tax is a ""Pigouvian tax" (Mankiw, 2009) that sets a price on fossil fuels based on their carbon content, which is subsequently converted into C02 emissions. ETS, on the other hand, operates as a cap-and-trade system in which firms must purchase allowances for every ton of GHG they emit beyond the government-defined limits, with allowances traded at market-determined prices (WorldBank, 2023). While carbon taxes establish a fixed price on carbon, ETS sets an emissions cap and allows the market to determine the price. Finland became the first country to implement a carbon tax in 1990. As of 2024, there are 75 carbon pricing instruments in place globally, covering approximately 25% of GHG emissions worldwide (World-Bank, 2024). According to the World Bank's Carbon Pricing Dashboard, some countries adopt either carbon taxes or ETS at national or subnational level, while others employ hybrid approaches. The adoption of carbon pricing mechanisms is expanding globally, with notable progress from large middle income countries such as Brazil, India, Chile, and Türkiye, which have implemented ETS (World-Bank, 2024).

Carbon pricing is rooted in the economic principle of externalities, as articulated by (Pigou, 2017). When environmental costs are excluded from market prices, polluters lack incentives to reduce emissions. In the short-run, carbon pricing encourages household, firms, and government to adopt cost-effective emission reduction measures. In the long term, the anticipation of sustained and rising carbon prices drive innovation via research and development (R&D) of technologies aimed at lowering the costs of emission reduction (Boyce, 2018). Economic theory posits a downward-sloping demand curve for emissions, meaning higher carbon prices result in lower emissions (Best et al., 2020). Empirical evidence supports the effectiveness of carbon pricing in reducing emissions and promoting technological innovation across various contexts. For instance, Bruvoll & Larsen (2017) find that Norway's relatively high carbon tax, introduced in 1991, significantly reduce emissions per unit of GDP between 1990 and 1999. Andersson (2017) showed that Sweden's carbon taxes, introduced in the early 1990's, led to an 11 percentage-point reduction in C02 emissions from transport sector in an average year compared to a synthetic control, with a 6-percentage-point reduction attributable to the carbon tax alone. Similarly, Murray & Rivers (2015) document a 5-15% reduction in GHG emissions in British Columbia following the implementation of a carbon tax, which gained increasing public support over time. Calel & Dechezleprêtre (2016) demonstrated that the EU ETS drove increased low-carbon innovation among regulated firms without crowding-out other technological advancement. Best et al. (2020) provides cross-country evidence on the effectiveness of carbon pricing in reducing national C02 emissions from fuel combustion.

Despite its theoretical and practical merits, carbon pricing faces substantial technical and political challenges that can undermine its effectiveness (Driscoll, 2021; Levi et al., 2020). One prominent issue is the risk of carbon leakage, where firms relocate production to countries with weaker environmental regulations, thereby offsetting global emission reduction efforts (Böhringer et al., 2017). Another significant limitation is the insufficient coverage and low-price levels of many carbon pricing schemes. A large portion of global emissions remains unpriced, and numerous countries continue to subsidise fossil fuel use through policies effectively acting as a negative carbon price (Boyce, 2018). Furthermore, existing carbon prices remain far below the levels necessary to meet the targets set under the Paris-Agreement (World-Bank, 2024). Various studies theoretically derive optimal carbon pricing from equilibrium models such as GSGE (Gollier, 2024; Poelhekke, 2019; Van der Ploeg & Rezai, 2021), however, these estimations are sensitive to assumptions. Determining the optimal carbon price, often referred to as the "social cost of carbon" (SCC), presents additional technical challenges. (Boyce, 2018) highlight that economic models used to compute the SCC are deeply flawed and inadequate for policy analysis, which weakens the ability of carbon pricing to drive meaningful changes in energy production and consumption.

Another critical concern involves financial instability risks associated with carbon policy shocks. Le (2023) shows that while carbon pricing policies can effectively reduce emissions, they may do so at the costs of economic growth, increased inflation, heightened credit risk, and elevated financial stress. Similarly, (Masciandaro & Russo, 2024) examine the trade-off faced by central banks in addressing climate change. This view is echoed by Chan et al. (2024), who noted that overly stringent carbon taxes could increase default rates in both green and brown sectors, jeopardizing financial stability due to adverse impacts on banks' balance sheets. They emphasise the inherent trade-offs in implementing green macroprudential policies. Policies designed to encourage the green transition may compromise financial stability by raising default rates, whereas those aimed at reducing financial vulnerabilities may hinder the phase-out of polluting sectors and slow the fostering of green industries. They advocate for a balance mix of alternative policies to support the green transition and phase out fossil fuels without compromising financial stability. As such, carbon pricing should be supplemented with complementary measures, including macroprudential policies, to address its limitations and enhance its effectiveness. For instance, D'Orazio & Popoyan (2019) and (Punzi, 2024) underscore the importance of integrating carbon pricing with macroprudential tools to promote a sustainable and stable green transition.

Motivated by the on-going debate about the effectiveness of carbon pricing and its signification implications for financial stability, this study seeks to address the following research questions:

(i) To what extent has the implementation of carbon pricing policies driven the transition from fossil fuels to renewable energy?

(ii) Is a higher carbon tax more effective in accelerating the shift to renewable energy, or does it present diminishing returns?

(iii) How does the effectiveness of carbon pricing vary under different macroprudential policy conditions?

The objectives of this study are three folds. First, it evaluates whether carbon pricing fosters the transition to renewable energy by leveraging the implementation of either carbon taxes or ETS as quasi-experiments and employing a different-in-difference (DID) analysis. While prior research has extensively explored the impacts of carbon pricing on emission reductions – largely focusing on high-income countries – there is limited emphasis on its role in energy transitions, particularly the shifts from fossil fuels to renewable energy. Examining the effects of carbon pricing on renewable energy transitions is especially critical because such transitions represent a long-term and structural solution to climate change, addressing the root causes of emission rather than merely reducing their magnitude. Transitioning to renewable energy creates a pathway toward sustainable decarbonisation by replacing carbon-intensive systems with clean and renewable technologies. By contrast, emission reductions through a carbon pricing alone may sometimes result in temporary or marginal gains, such as efficiency improvements in fossil fuel use, without fundamentally altering the energy infrastructure. Moreover, although a consensus exists in the literature regarding the effectiveness of carbon pricing in reducing C02 emissions, its impacts vary significantly due to differences in policy designs (e.g. regarding carbon tax rates and base as well as tax exemptions) and macroeconomic conditions (e.g. openness, productivity, financial market development) (Köppl & Schratzenstaller, 2023). By providing robust empirical evidence using a comprehensive panel data set of 97 countries across five regions, this study offers a broader and more inclusive understanding of the global dynamics of green energy transitions, accounting for diverse economic and institutional contexts.

Second, the study examines whether higher carbon taxes accelerate green transition more effectively. While much of the existing literature assumes a linear or uniformly positive relationship between carbon taxes and green transitions, this study identified an inverted U-shaped relationship. Higher carbon taxes initially incentivise green transitioning, but their effectiveness diminishes and may become counterproductive if tax exceeds a certain threshold, leading to carbon leakage. This finding addresses a critical gap in the literature by underscoring the importance of optimal tax design to balance motivation and adverse consequences.

Third, the study examines role of macroprudential policies in enhancing the effectiveness of carbon pricing, facilitating an orderly transition to a greener economy while mitigating the potential adverse feedback loops on financial stability and the broader economy. Specifically, it evaluates not only the specific macroprudential tools that facilitate the green energy transition, such as capital requirements or green lending frameworks, but also explores the conditions under which these policies amplify the effectiveness of carbon pricing. For instance, it finds that carbon pricing – particularly ETS – tends to be more effective under tightened macroprudential policies, which strengthen the financial system, incentivise financial institutions to redirect investments toward greener sectors, and mitigate transition risks. By integrating these two frameworks, the study provides a novel interdisciplinary perspective on the financial and policy mechanisms that support the transition to a low-carbon economy.

2. Data and Methodology

This study utilises a panel dataset comprising of 97 countries over the period 2000-2023. The data were sources from multiple repositories. Carbon pricing data were retrieved from the World Bank's Carbon Price Dashboard (https://carbonpricingdashboard.worldbank.org/), which provides comprehensive information on the implementation of specific carbon pricing instruments, revenues, and prices across various jurisdictions, regions, and income groups. Data on energy consumption and the energy mix (fossil fuel vs. renewable sources) were obtained OurWorldinData.org, introduced by Ritchie et al. (2023). Data of macroprudential policies were retrieved from the integrated Macroprudential policy data were extracted from the Integrated Macroprudential Policy Database (iMaPP), which consolidates information on macroprudential tools and aggregate policy indices across countries. iMaPP aggregates inputs from various sources, including the IMF's annual surveys, previous studies, data from the Bank of International Settlement (BIS), the Financial Stability Board, the European Systemic Risk Board, and central bank announcements. Lastly, country-specific control variables were sourced from World Development Indicators database, maintained by the World Bank.

Our empirical analysis proceeds in three steps, corresponding to the study's three core research objectives. *In the first step*, I employ the staggered DID technique, leveraging the implementation of carbon taxes and ETS as global quasi-natural experiments to assess the impact of carbon pricing on renewable energy transition. DID is widely regarded as a robust methodology for evaluating the causal effects of policy interventions. Traditional DIS designs typically involve two groups (treatment and control) and two time periods (pre- and post-treatment), with treated units undergoing the intervention simultaneously. Historically, the two-way fixed effects (TWFE) approach was considered a rigorous method, accounting for unobserved, time-invariant heterogeneity while evaluating the treatment effects. In our context, the treatment group comprises countries that adopted any carbon pricing mechanism during the study period. However, due to varying internal and external factors, countries implemented these mechanisms at different time points, resulting in time-varying treatments. Consequently, the treatment group in each time period consists of country-time observations for those undergoing treatment in that specific period. Given this variation, it is often unrealistic to assume that the treatment effect remains constant over time (Callaway & Sant'Anna, 2021; Li et al., 2024; Sun & Abraham, 2021). Instead, the time-varying treatment effect is modelled as the variance-weighted average of a series of time-specific TWEF-DID estimates across the observation window.

To address the potential estimation bias from TWFE-DID stemming from differences in treatment timing and heterogeneous treatment effects across cohorts or over time, we apply TWFE methodology with heterogeneous treatment effects, as proposed by (De Chaisemartin & d'Haultfoeuille, 2024). This methodology is particularly advantageous as it relaxes the restrictive assumption of homogeneous treatment effects across all units and time periods, allowing for more accurate and nuanced estimation of causal impacts. By accounting for variation in treatment timing and capturing dynamic treatment effects, it provides a robust framework to evaluate policies implemented at different intervals. Furthermore, it mitigates the potential bias that arises in conventional TWFE-DID models when treatment effects vary across cohorts, ensuring that the estimated effects better reflect real-world complexities. We implemented this approach using Stata commands introduced in De Chaisemartin et al. (2024), which offer a streamlined and precise method for operationalizing this advanced analytical framework.

The regression model incorporating TWFE with heterogeneous treatment effects is expressed as follows:

$$\boldsymbol{Y_{i,t} = \alpha_i + \gamma_t + \sum_{k=0}^{K} \delta_k \cdot 1(t - T_i = k) + \beta_l \cdot Z_{i,t} + \varepsilon_{i,t}} \quad (1)$$

Where:

- $Y_{j,t}$: Dependent variable, representing the share of renewable energy in the total energy mix.
- α_i: Country fixed effects, controlling for time-invariant characteristics of countries.
- γ_t: Time fixed effects, accounting for shocks common to all countries in each period.
- $1(t - T_i = k)$: Indicator for the number of periods since treatment (k).
- δ_k: Treatment effect k periods after treatment.
- $Z_{i,t}$: Vector of country-specific control variables.
- $\varepsilon_{i,t}$: Error term.

The selection of control variables is grounded in the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence and Technology), which is widely employed in environmental research to examine anthropogenic factors influencing environmental quality. These factors include energy consumption, population growth, economic development, technological innovation, and political institutions. Following the environment literature, I include GDP per capita, population growth, FDI inflows (% of GDP), energy intensity, total natural resources rents (% of GDP), and R&D expenditure (% of GDP) as a proxy for innovation.

Similar to TWFE-DID design, the validity of TWFE with heterogeneous treatment effects relies on the "*parallel trend assumption*". This assumption requires that the treated and control groups exhibit comparable or parallel time-series trends in the outcome variable before the treatment occurs.

In the second step, we analyse the impact of carbon tax levels on the share of renewable energy using a panel data regression with fixed effects. The empirical modelis specified as follows:

$$\boldsymbol{Y_{i,t} = \tau_1 CT\_price_{i,t} + \tau_2 CT\_price\_sq_{it} + \beta_l Z_{i,t} + \pi_i + \mu_t + \epsilon_{i,t}} \quad (2)$$

Where:

- $CTprice_{i,t}$ *and* $CTprice\_sq_{it}$: Represent carbon tax level of country i in year t and its square term, to capture potential non-linear effects.
- $Z_{i,t}$: Represent the same set of country-control variables as in Equation (1).
- π_i *and* μ_t: Denote country and time fixed effects.
- $\boldsymbol{\epsilon_{i,t}}$: Denote the error term.

Finally, to evaluate the synergistic effects of carbon pricing and macroprudential policies, we estimate the following panel data regression model with fixed effect:

$$\boldsymbol{Y_{i,t} = \theta_1 CP_{it} + \theta_2 MP_{it} + \beta_l Z_{i,t} + \pi_i + \mu_t + \epsilon_{i,t}} \quad (3)$$

Where:

- $CP_{i,t}$: A binary variable indicating whether a country implemented carbon taxes, ETS, or both in year t.
- MP_{it}: Represents the country's macroprudential policy index.

Additionally, we estimate Equation (3) excluding the MP variable but under conditions where macroprudential policies are either tightened or loosened. This allows us to assess whether the effect of carbon pricing differs under varying policy conditions.

Table 1 lists the variables and their definitions, while Table 2 summarises descriptive statistics of all variables used in our empirical analysis. The statistics in Table 2 reveal that, during the 2000-2023 period, the minimum value of renewable energy share is 0%, indicating that some countries still rely entirely on fossil fuels. The maximum value is 74.3%, reflecting the dominance of renewable energy over fossil fuel in certain countries. Although carbon pricing is represented as a binary variable, the descriptive statistics provide insight into the adoption of these environmental policies across countries. Approximately 33.4% of the country-year observations implemented either carbon taxes, ETS, or both. The mean values of ETS and carbon tax (CTAX) are 16.1% and 28.8%, respectively, suggesting that more countries adopted ETS than carbon taxes during the analysed period. For instance, 28 EU member states participated the EU ETS, but only a subset of these countries implemented carbon taxes. The US implemented an ETS in 2009 through the Regional Greenhouse Cas Initiative (RGGI) but has not introduced a national wide carbon tax. Furthermore, there is a notable cross-country variation in income levels (as measured by GDP per capita), population growth, FDI inflows, natural resources rents, R&D expenditures, and energy intensity. These variations underscore the diverse socio-economic and environmental contexts within which carbon pricing policies were adopted.

(Insert Tables 1 and 2 here)

3. Empirical Results and Analysis

3.1. Dynamic effects of carbon pricing on the renewable energy transition

Table 1 summarises the dynamic treatment effects of carbon pricing on the share of renewables in energy production across different time periods after treatment, as estimated using event study and variance estimators suggested by (De Chaisemartin & d'Haultfoeuille, 2024) and (De Chaisemartin et al., 2024). Panel A reports the treatment effects for ten successive post-treatment periods. The effects for the first two periods are 0.2007 and 0.2664, respectively, but they are not statistically significant due to a wide confidence interval, indicating a delayed response in the early years following treatment. Starting from the third year, the treatment effects become statistically significant, showing a steady increase over time and peaking the ninth year with an effect size of 6.386. The p-value for the joint nullity test is 0.000, confirming the treatment effects are statistically significant across all periods.

Panel B presents the average cumulative effect across all treated units, which accumulates to 2.5106 over an average period of approximately 5.18 and is statistically significant. This highlights the long-term positive impact of carbon pricing policies on renewable energy adoption. In contrast, Panel C shows the pseudo-treatment effects for pre-treatment periods derived from the placebo tests, all of which are negative and statistically insignificant. This supports the validity of the parallel trends assumption, though significant p-value for the joint test suggests the need for cautious interpretation and additional diagnostic checks to ensure robustness.

Figure 1 visualises the DID treatment effects over the fourteen periods, ranging from before3, before2, …, 0 (treatment period), after1, …, after 10. The results reveal a growing positive impact of carbon pricing on the share of renewables, with statistically significant effects emerging from the third year and reaching their peak in the ninth year. This pattern underscores the cumulative and delayed nature of the policy's impact, highlighting the importance of allowing sufficient time for carbon pricing mechanisms to drive meaningful shifts in energy production renewables.

(Insert Table 3 & Figure 1 around here)

To gain deeper insights into the distinct effects of the two carbon pricing instruments, we estimate treatment effects of carbon taxes and ETS separately. Table 2 summarises the dynamic treatment effects of carbon taxes, along with their average cumulative effect, while Figure 2 illustrates the simulated treatment effects derived from the event-study approach. The analysis reveals an intriguing temporal pattern: the impact of carbon taxes only becomes significantly positive starting five years after the treatment (t=0), suggesting a lag in the tax policy's effectiveness. This delayed response highlights the time required for the economic and institutional adjustments necessary to facilitate the adoption of renewable energy technologies. The treatment effect of carbon taxes reaches its peak in the eighth year, with an effect size of 3.2087. This significant and pronounced impact underscores the long-term efficacy of carbon taxes in driving the transition toward renewable energy. The average cumulative total effect per treatment unit is 0.73, statistically significant, and accumulates over approximately 4.379 years. The placebo tests _ Placebo_1, Placebo_2, and Placebo_3 - show negative and insignificant pseudo-effects for the pre-treatment periods, providing strong evidence against the presence of pre-treatment trends. This finding reinforces the validity of the parallel trends assumption, ensuring that the observed effects can be attributed to the implementation of carbon taxes rather than other cofounding factors.

(Insert Table 4 & Figure 2 around here)

Table 5 and Figure 3 present the dynamic treatment effects for ETS, which closely minor the patterns observed for carbon pricing in Table 3 and Figure 1. The treatment effects for the ten successive periods are all positive, indicating a consistent upward impact of ETS on the share of renewables in energy production. Statistically significant effects first emerge in the third year (Effect_3 = 1.2622) and progressively intensify, reaching their peak by the ninth year (Effect_9 = 7.367). This pattern underscores the enduring efficacy of ETS as a mechanism to incentivize the transition toward renewables. The average cumulative total effect of ETS over the 5.359 years is 3.376, which is statistically significant. This suggests that ETS, like carbon taxes, requires a sufficient time horizon to exhibit its full potential, likely due to the gradual adjustment processes in energy markets, investment cycles, and policy compliance. Comparing to carbon taxes, ETS demonstrates a more pronounced and sustained impact, achieving a higher peak size. Additionally, the average cumulative effect is significantly greater, suggesting ETS may provide stronger long-term incentives to renewable energy adoption.

The placebo tests for ETS provide additional validation for the robustness of the findings. While the pseudo-effect one year prior to treatment is positive but not statistically significant, the effects two and three years before treatment are negative and also insignificant. These results align with the expected absence of pre-treatment trends, further bolstering the validity of the parallel trends assumption crucial for the interpretation of dynamic treatment effects.

(Insert Table 5 & Figure 3 around here)

While separating the effects of carbon taxes and ETS provide valuable insights into the relative effectiveness of these instruments, it is important to acknowledge potential independencies between them. In practice, many countries adopt hybrid approaches that combine both instruments, albeit at different times or under varying policy framework. This overlap could lead to interaction effects, which could amplify or mediate the outcomes observed for each instrument individually. Future research could explore these hybrid approaches in greater detail, examining ow the interplay between carbon taxes and ETS influence their combined effects. For instance, understanding whether one instrument complements or reinforces the other could offer critical policy insights, particularly for countries contemplating the adoption of both mechanisms.

3.2. The non-linear effect of carbon taxes

In this session, I evaluate whether higher carbon taxes are more effective in accelerating the green energy transition. The question of how expensive $C0_2$ should be - or how high the optimal carbon tax should be- has been an on-going political and economic debate for decades. Neoclassical economists emphasize the role of carbon taxes as an indispensable strategy for efficiently reducing GHG emissions and incentivising a shift from fossil fuels to renewable energy. However, the macroeconomic effects of excessively high carbon taxes have also received considerable attention in the literature. Various studies employ general equilibrium models, such as DSGE models, to theoretically derive optimal carbon pricing (Gollier, 2024; Van der Ploeg & Rezai, 2021). However, these estimations are highly sensitive to underlying assumptions. Theoretically, the optimal carbon price should equal its social cost, which reflects the welfare costs of emissions, defined as the current consumption value in the discounted utility of consumption per unit of additional emission (Poelhekke, 2019). In practice, measuring the monetary benefits of emission reductions remains challenging (Ackerman et al., 2009; Azar, 1998; Pindyck, 2017).

Most existing carbon prices are well below the levels recommended by climate policy analysts (Boyce, 2018). According to the Word Bank's Carbon Pricing Dashboard, the levels of carbon taxes vary significantly across jurisdictions and over time. As of 2024, carbon taxes range from as low as 0.76 $US per metric ton of CO_2 ($/mt CO_2) in Ukraine to $167.17/mt CO_2 in Uruguay (see Figure 4). Countries with low carbon taxes include Japan, Mexico, and Taiwan, where rates are below $10/mt CO_2. In contrast, high carbon taxes exceeding $100/ mt CO_2 are reported in Netherland, Norway, Liechtenstein, and Uruguay. Carbon taxes were first implemented the early 1990s in Scandinavian countries such as Finland, Poland, Norway, Sweden, and Denmark. More recently, countries in America and Africa have introduced carbon taxes, including Chile (2017), Colombia (2017), Argentina (2018), and South Africa (2019). Some countries apply a single carbon tax, while others adopt multiple price levels for different fuel types based on their GHG content, such as gasoline, diesel oil, gas oil, fuel oil, and coal.

(Insert Figure 4 here)

To evaluate the effect of carbon tax levels on renewable energy transition and to estimate its empirical optimal price, we estimate Equation (2) using panel regression with fixed effects. For countries that apply multiple price levels for different energy resources, I use the average price. Table 6 summaries the non-linear effects of carbon taxes on the share of renewable energy based on the quadratic model. Column (1) report the effect of carbon tax on the share of renewable energy in the overall energy mix, while Columns (2), (3), (4), and (5) focus on specific components, including biofuel energy, solar energy, wind energy, and other renewable sources, respectively. As shown in Table 6, the coefficient for the carbon tax is positive, while that for its square term is negative. Both coefficients are statistically significant across all specifications, except in Column (3). Figure 5 illustrates the quadratic response function of renewable energy share to carbon tax levels, revealing a clear inverted U-shaped relationship. These findings suggest that at lower level of carbon taxation, the increased cost of fossil fuels incentivises investment in renewable energy as a cost-effective alternative, consistent with economic theory of externalities (Pigou, 2017). However, as the carbon taxes rise further, the rate of renewable energy adoption slows. Beyond a certain threshold, excessively high carbon taxes may lead to adverse effects. This is due to technical and economic constraints on scaling renewable infrastructure. High energy costs can reduce economic activity, leading to lower overall energy demand, including renewables. Moreover, high carbon taxes may induce carbon leakage, as emission-intensive and trade-exposed industries relocate to regions with less stringent regulations (Böhringer et al., 2017).

(Insert Table 6 and Figure 5 here)

Based on the estimated coefficients (τ_1 *and* 2) of the quadratic model reported in Equation (2), the maximum level of carbon tax (the threshold point) at which the effect of the tax begins to diminish is $68.89/mt CO_2. This threshold is calculated using the following formula:

$$\frac{\partial \boldsymbol{Y}}{\partial \boldsymbol{CT\_price}} = \boldsymbol{\tau_1} + \boldsymbol{2\tau_2} \cdot \boldsymbol{CT\_price}, \qquad where\ \boldsymbol{CT\_price} = -\frac{\boldsymbol{\tau_1}}{\boldsymbol{2\tau_2}}$$

While the estimated optimal carbon price of $68.89, derived from empirical analysis of secondary panel data spanning 2000-2023, is significantly lower than the theoretical optimal levels proposed by (Gollier, 2024) and (Van der Ploeg & Rezai, 2021), it highlights several practical implications. This threshold reflects real world dynamics, including economic, institutional, and technological variations across countries and time periods. Unlike theoretical models, which often assume ideal conditions for optimal carbon pricing, empirical estimates are influenced by historical implementation challenges, market imperfections, and country-specific factors such as energy infrastructure, political will, and societal readiness for green transitions. The relatively lower optimal price in this study may indicate that, historically, many countries lacked the capacity to fully leverage higher carbon taxes due to inadequate support mechanisms for renewable energy or resistance from key stakeholders. It also suggests that empirical estimates, while reflecting past conditions, may understate the price required in the future in the future to meet ambitious climate goals, especially as technologies evolve and global condition strengthens. Thus, policymakers must balance empirical insights with forward-looking strategies to design adaptive and scalable carbon pricing mechanisms.

3.3. The role of macroprudential policies on the effectiveness of carbon pricing

The literature has extensively explored the macroeconomic and financial instability implications of carbon pricing, as well as the critical role of the banking sector in facilitating the green transition (Boehl et al., 2024; Chan et al., 2024; Punzi, 2024). Punzi (2024) highlights that while carbon pricing policies increase the cost of fossil fuels and incentivise the adoption of cleaner technologies, they also elevate the default risk for entrepreneurs in the carbon-intensive sectors. This heightened risk can negatively impact banks' balance sheets and have adverse macroeconomic consequences. Similarly, Campiglio (2016) emphasize that carbon pricing alone is insufficient to bridge the investment gap in low-carbon technologies due to market failures in credit creation and allocation. These findings underscore the need for a comprehensive policy mix, where carbon pricing is complemented by monetary and macroprudential policies. Additionally, transitioning to a low-carbon economy requires substantial economic resources to be directed toward the green sector. Macroprudential policies, such as capital requirements and risk weighting, can play a pivotal role in relocating financial flows toward renewable energy projects and other low-carbon activities.

This section examines the synergistic effects of carbon pricing and macroprudential policies on the green transition. To analyse this interaction, I estimate Euquation (3), focusing on two key variables: a carbon pricing dummy variable and macroprudential policy indicators. I utilised the IMF's iMaPP database, which provides dummy-type indicators of tightening and loosening actions across various macroprudential policy instruments. The total index is constructed by aggregating 17 components representing different banking operation requirements. These components include: Countercyclical capital buffer (CCB), Capital conservation buffer (CCB), Capital requirements for banks (Capital), Limits on leverage (LVR), Loan loss provision requirements (LLP), Limits on growth or the volume of aggregate credit (LCG), Loan restrictions (LoanR), Limits on foreign currency (LFC), Limits on loan-to-value ratios (LTV), Limits to debt-service-to-income ratio (DSTI), Tax and levies applied to specified transactions (Tax), Measures taken to mitigate systemic liquidity and funding risks (Liquidity), Limits to the loan-to-deposit (LTD), Limits to on net or gross open foreign exchange positions (LFX), Reserves requirements (RR), Systematically important financial institutions (SIFI), and Other macroprudential measures (OT).

The estimated parameters are summarised in Table 7. Column (1) presents the effect of the macroprudential policy aggregate index, while Columns (2) – (9) detail the significant effects of key macroprudential instruments, including Capital, LVR, LLP, Liquidity, LTD, SIFI, and OT, respectively. The findings reveal that the aggregate effect of macroprudential policies, along with most individual components, is positive and statistically significant. However, capital requirement exhibits a negative and significant impact on the green transition. Stronger macroprudential policies contribute to financial market stability by mitigating financial risks and vulnerabilities, thus complementing carbon pricing in fostering an enabling environment for the green energy transition. Carbon pricing, while effective in curbing emissions, can disproportionately affect low-income households and small businesses. Macroprudential measures help offset these adverse distributional impacts by ensuring continued credit availability to vulnerable sectors during the transition. For instance, targeted credit programmes and liquidity buffers can address potential liquidity shortages that might hinder the adoption of renewable technologies (Campiglio, 2016). Furthermore, sharp increase in carbon pricing may induce market volatility and uncertainty, delaying investment in renewable energy. Macroprudential policies stabilise the market by conducting climate stress tests to assess the resilience of financial institutions to carbon pricing-induced shocks (Bolton et al., 2020). The negative coefficient on Capital, however, suggests that stringent capital requirements may impede the transition. This result is consistent with (Chan et al., 2024), who argue that compound capital depreciation shocks and carbon pricing shocks elevate climate-related financial risks during the fossil fuel phase-out. Strict capital rules can reduce banks' willingness to finance long-term renewable projects with delayed financial returns. This finding supports the need for a green-differentiated macroprudential policies, such as preferential capital requirements for green corporate and municipal financing. For instance, the Central Bank of Hungary has implemented green capital requirements since 2021 (Chan et al., 2024). Similarly, differentiated reserve requirements have been adopted by the Bank of China and the Bank of Philippines to support green investments.

(Insert Table 7 here)

Table 8 provides further results on the effectiveness of carbon pricing under tightened and loosen macroprudential policies. Columns (1), (3), and (5) confirm the consistent positive effects of carbon pricing, ETS, and carbon tax under tightened macroprudential conditions. However, Columns (2) and (4) indicate that under loosened macroprudential policies, carbon pricing, especially ETS, their effectiveness, as evidenced by their significant coefficients. In contrast, the effect of carbon taxes remains robust under both tightened and loosened conditions. The divergence in the effectiveness of ETS and carbon tax under varying macroprudential policy conditions stem from differences in their mechanisms and interactions with financial stability measures. ETS effectiveness relies on well-functioning financial system and stable regulatory environments. Studies show that under relaxed macroprudential policies, speculative trading in carbon markets can lead to price volatility, distorting the price signals needed to drive emissions (Martin et al., 2014; Newell et al., 2014). Unstable credit conditions and speculative bubbles further undermine ETS by reducing its predictability, discouraging long-term renewable energy investments. Looser financial regulations may also perpetuate lending to carbon-intensive industries, neutralising the incentivises ETS create to the green transition. In contrast, carbon taxes maintain their impact regardless of financial conditions because their straightforward implementation does not rely on market dynamics.

(Insert Table 8 here)

4. Conclusions and Implications

As carbon pricing emerges as a cornerstone solution to global climate change, understanding its efficacy and the conditions that facilitate its successful implementation is of paramount important. By leveraging carbon taxes and ETS as global quasi-natural experiments and employing a DID approach with time-varying treatment effects on a panel dataset of 97 countries, this study reveals a significant shift from fossil fuels to renewable energy following the adoption of carbon pricing mechanisms. However, the finding highlights a delayed and long-term responses, emphasizing the time required for economic and institutional adjustments to enable the adoption of renewable energy technologies. A particular notable finding is the identification of an inverted U-shaped relationship between carbon tax levels and renewable energy adoption. While higher carbon taxes initially incentivize green transitions, excessively high tax levels can have unintended consequences, such as carbon leakage, which may hinder progress. This result underscores the complex dynamics of carbon pricing and the need for carefully calibrated carbon tax levels to balance incentives and potential risks.

The makes a significant theoretical contribution by integrating insights from environmental economics and financial regulation to explore the role of macroprudential policies in enhancing the effectiveness of carbon pricing. Stringent macroprudential measures are shown to strengthen financial system resilience, incentivize green investments, and mitigate transition risks, thereby creating an enabling environment for renewable energy adoption. However, stringent capital requirements may inadvertently impede this process by disincentivising lending to the green sectors, given their delayed financial returns. Furthermore, while ETS mechanisms are vulnerable to market distortions under relaxed financial regulations, carbon taxes remain effectiveness across varying regulatory conditions due to their straightforward and less market-dependent implementation. By addressing a critical gap in the literature at the intersection of climate policy and financial regulation, this study bridges two pivotal research domains. First, it provides a more comprehensive framework for understanding the conditions under which carbon pricing mechanisms succeed or falter, accounting for heterogeneity in their design and implementation across jurisdictions. Second, it highlights the necessity of complementing carbon pricing with macroprudential policies to ensure a cohesive strategy that aligns environmental goals with financial stability.

The practical contributions of this research are equally significant. Policymakers can draw on these findings to design a more effective carbon pricing frameworks that account for institutional and market conditions, ensuring that these mechanisms drive meaningful progress toward low-carbon economies. Additionally, the study underscores the importance of tailored macroprudential measures, such as differentiated capital requirements or green lending incentives, to mitigate the potential trade-offs between financial stability and environmental objectives.

Despite its contributions, this study is not without limitations, which provide avenue for future research. First, while the study disentangles the effects of carbon taxes and ETS, it is challenging to fully isolate these mechanisms from other climate and energy policies, such as energy-sector regulations or renewable support schemes. Future research could explore additional natural experiments to better understand the individual and combined effects of these instruments. Second, the analysis reveals a delayed response to carbon pricing due to economic and institutional adjustments, but specific institutional factors driving these delays remain underexplored. Future studies could investigate these factors to enhance the interpretability of the findings. Third, carbon leakage is identified as a potential consequence of high carbon taxes, but the study does not examine global spillover effects in depth. Adopting a multi-regional framework in future research could provide a clearer understanding of how emission reduction in one jurisdiction may offset by increases elsewhere through trade and investment flows. Lastly, the uses of the IMF's iMaPP database provide valuable insights into the role of macroprudential policies. However, the aggregate index and individual policy instruments may not fully capture the comprehensive interactions between financial regulations and climate policies. Qualitative aspects such as enforcement and compliance are not directly addressed. In low-income countries, where central banks hold significant power, implementing macroprudential policies may be less challenging. However, enforcing these policies in developed economies remains a significant huddle that warrant further investigation.

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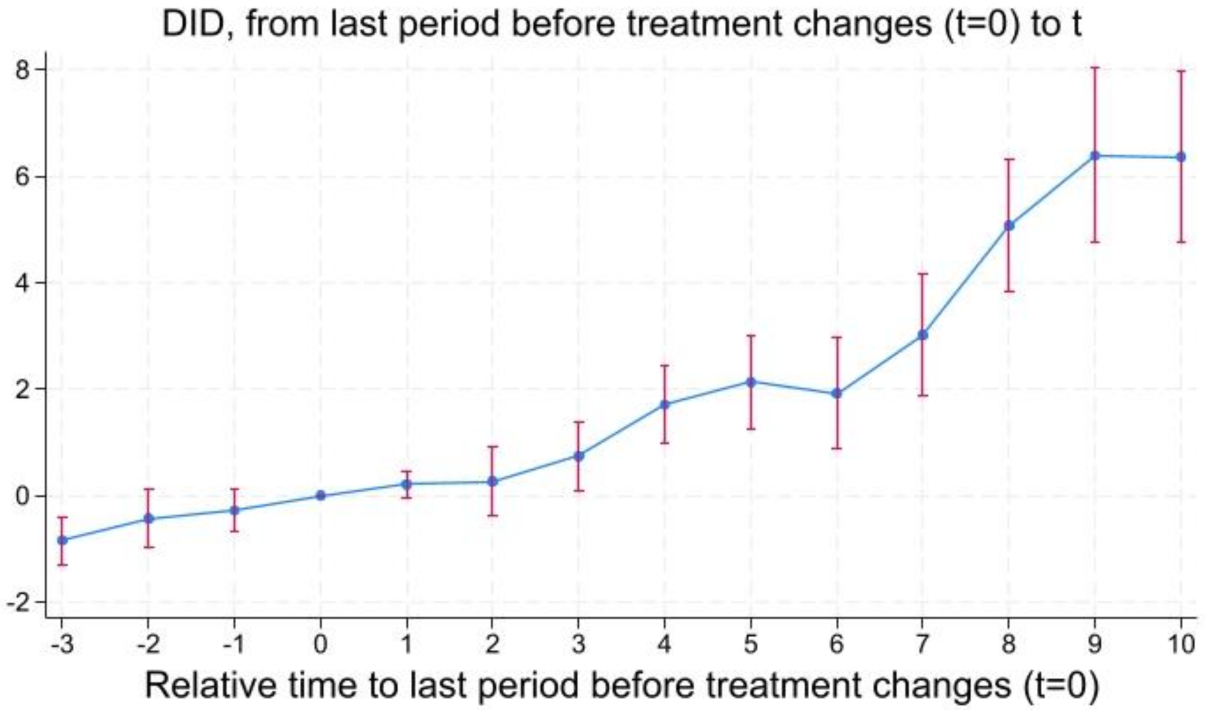
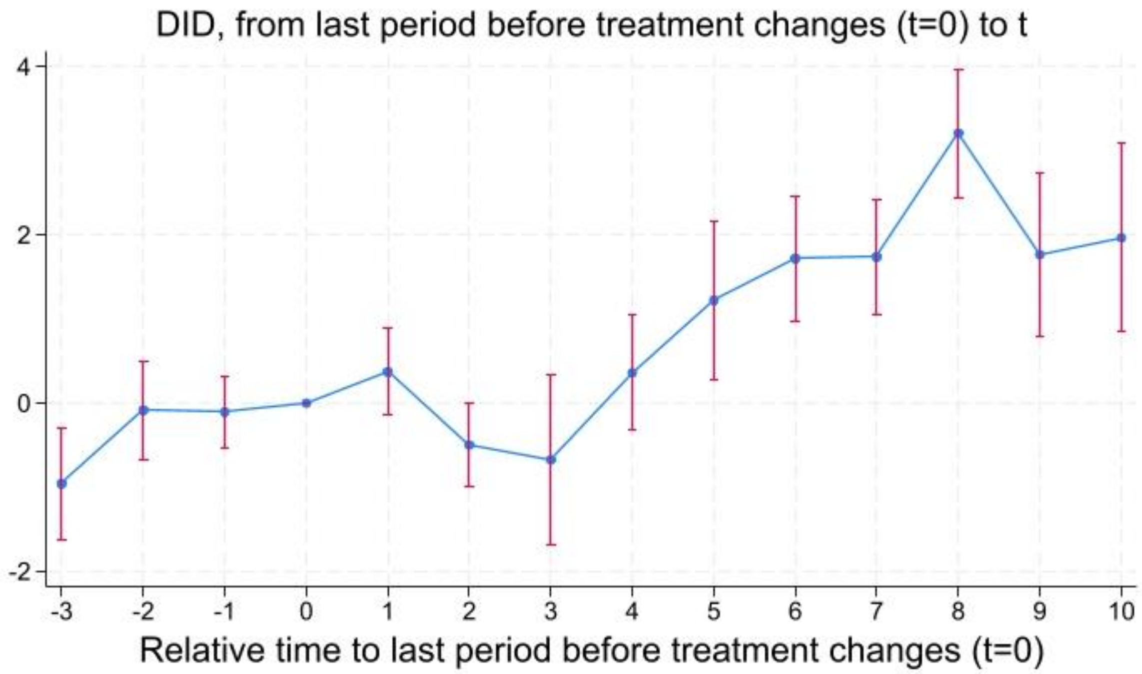
LIST OF FIGURES AND TABLES

Figure 1 – Treatment effects of carbon pricing based on event study estimators



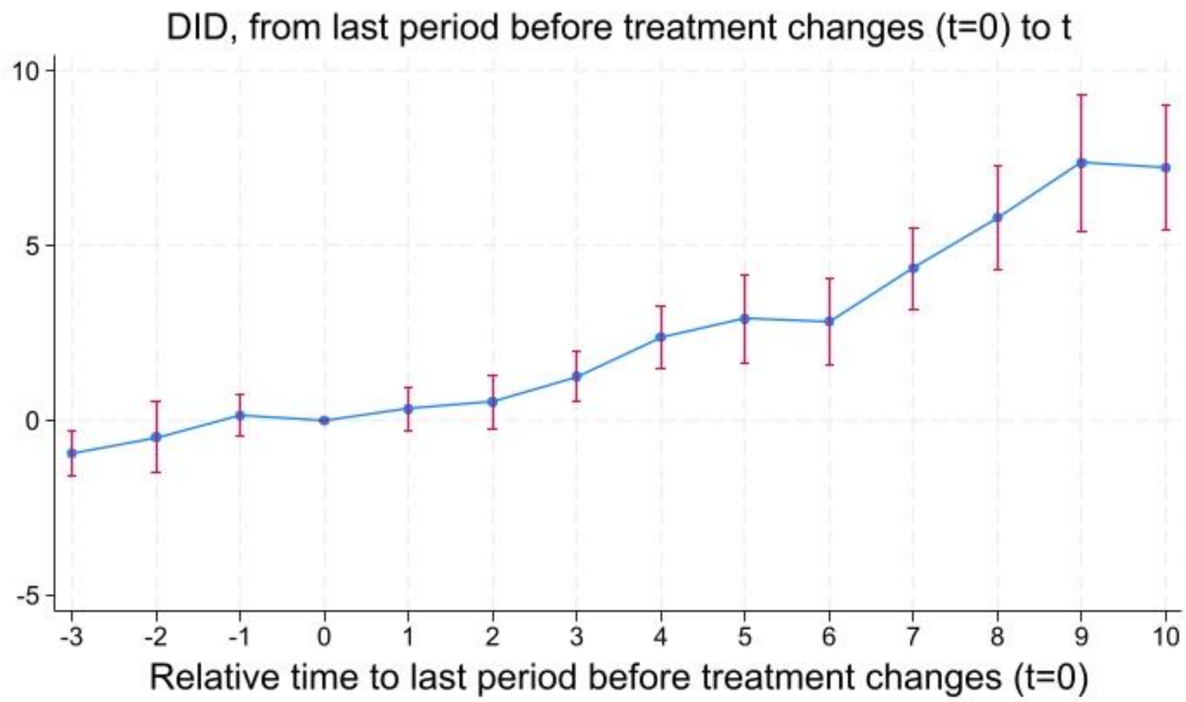
Notes: The treatment effects were estimated following De Chaisemartin et al. (2024)'s event study and variance estimators.

Figure 2 –Treatment effects of carbon taxes based on event study estimators



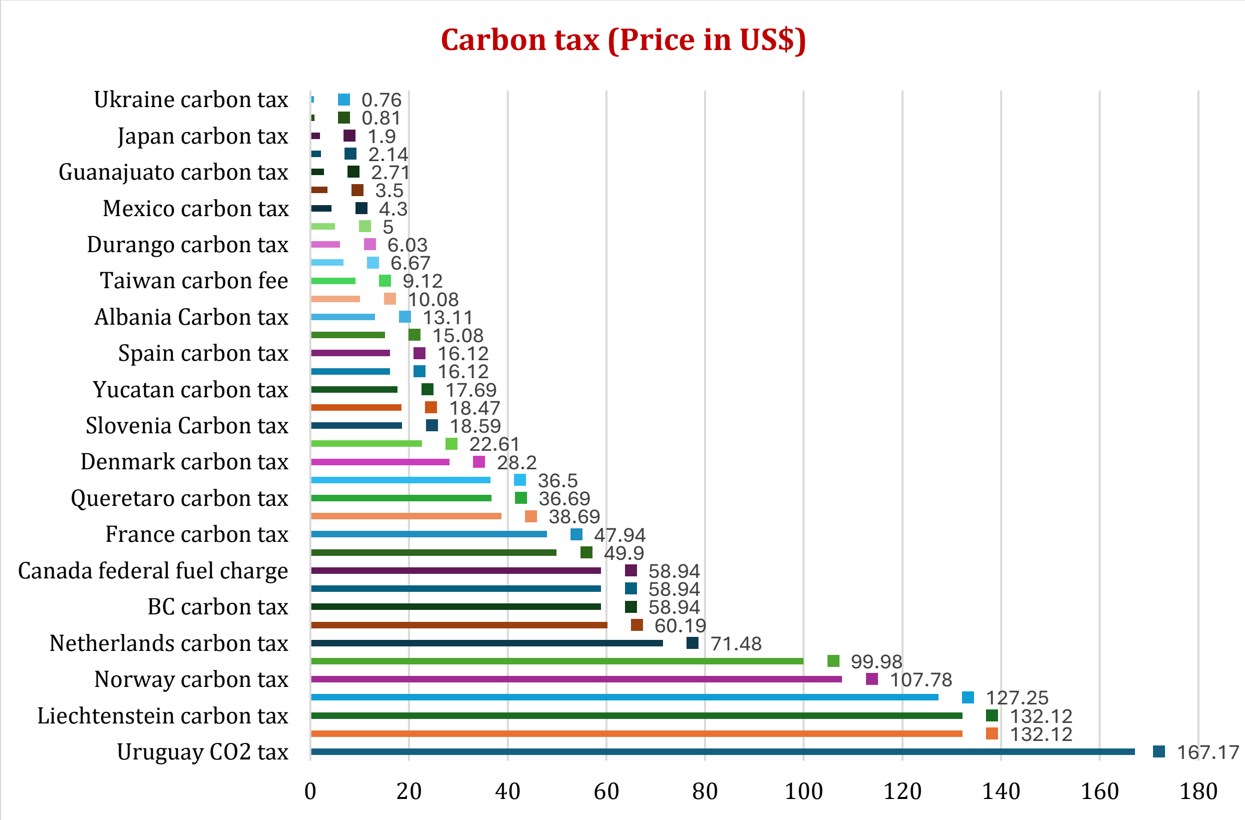
Notes: The treatment effects were estimated following De Chaisemartin et al. (2024)'s event study and variance estimators.

Figure 3 –Treatment effects of ETS based on event study estimators



Notes: The treatment effects were estimated following De Chaisemartin et al. (2024)'s event study and variance estimators.

Figure 4 – The levels of carbon tax across countries in 2025 (($/mt CO_2)



Sources: Author complied from World Bank's Carbon Pricing Dashboard. Prices are on 1 April 2024.

Figure 5 – The non-linear effect of carbon tax levels on the share of renewable energy

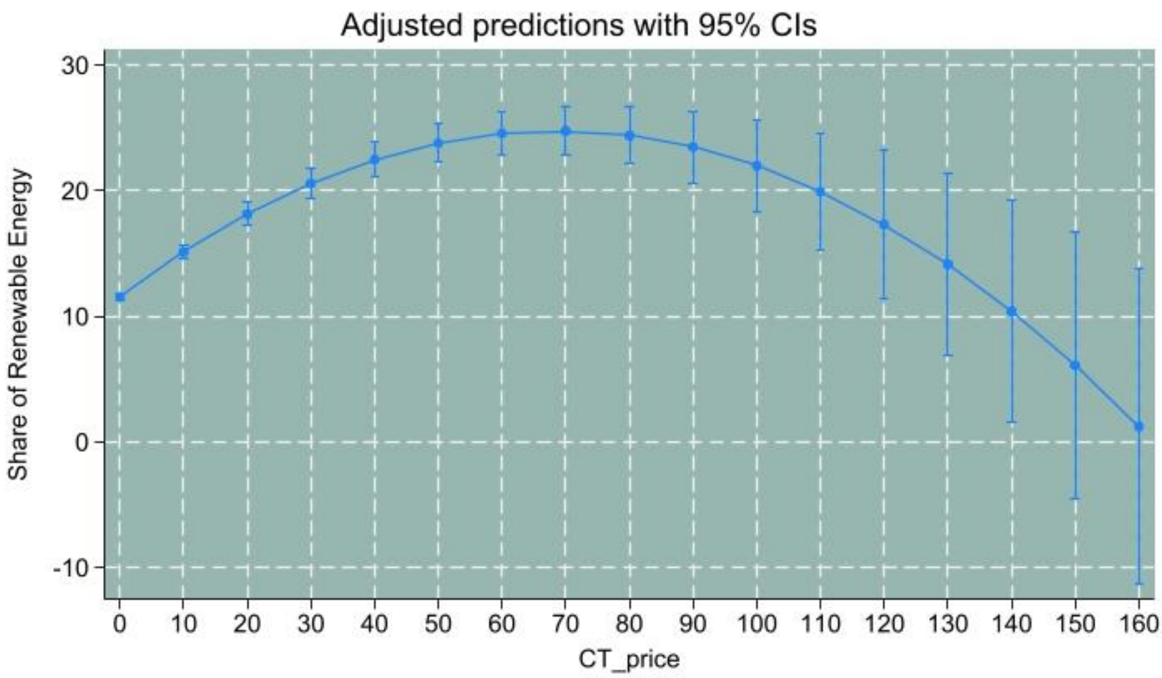


Table 1 – Variable Definition

Variables	Definition	Sources
Dependent variables		
Renewables	Share of renewable energy in the total energy use (Renewables = Biofuel + Solar + Wind + Other renewable energy)	OurWorldinData.org introduced by Ritchie et al. (2023)
Biofuel	Share of biofuel energy in the total energy use	
Solar	Share of solar energy in the total energy use	
Wind	Share of wind energy in the total energy use	
Other	Share of other renewable energy in the total energy use	
Independent variables		
CP	Dummy variable takes the value of 1 if a country implemented either carbon tax or ETS or both, and 0 otherwise	World Bank's Carbon Price Dashboard: https://carbonpricingdashboard.worldbank.org/
CTAX	Dummy variable takes the value of 1 if a country implemented carbon tax, and 0 otherwise	
ETS	Dummy variable takes the value of 1 if a country implemented ETS, and 0 otherwise	
CT_price	Carbon tax price levels, measured by USD per ton of CO2	
MP	Macroprudential policy index is the sum of 17 sub-indices	Macroprudential Policy database (iMaPP)
Control variables		
GDP_per_cap	GDP per capita in current US$ (in logarithm)	World Development Indicators
Population	Annual percentage growth rate of population growth	
FDI	Net foreign direct investment (BoP, current US$) over total GDP (current US$)	
Resources	Total natural resources rents (% of GDP)	
R&D	Total research and development expenditure (% of GDP)	
C02_intensity	Carbon intensity of GDP (kg CO2e per 2021 PPP $ of GDP)	

Table 2 – Descriptive Statistics of Variables

Variable	Obs	Mean	Std. dev.	Min	Max
Renewables	1,533	13.365	13.432	0.000	74.300
Biofuel	1,208	0.595	0.909	0.000	7.490
Solar	1,521	0.515	1.095	0.000	9.370
Wind	1,533	1.523	3.001	0.000	25.770
Other	1,533	1.548	2.334	0.000	21.580
CP	2,328	0.334	0.472	0.000	1.000
CTAX	2,328	0.161	0.368	0.000	1.000
ETS	2,326	0.288	0.453	0.000	1.000
CT_price	2,250	4.541	17.639	0.000	156.000
MP	2,088	0.667	1.877	-13.000	13.000
GDP_per_cap	2,309	9.115	1.396	4.961	11.803
Population	2,328	1.104	1.682	-10.930	21.700
FDI	2,184	-0.020	0.150	-2.658	2.093
Resources	2,119	6.426	10.653	-0.810	65.320
R&D	1,531	2.943	23.747	0.010	577.920
C02_intensity	2,162	0.558	0.511	0.050	5.120

Table 3 – The effect of carbon pricing on renewable energy transition: event-study estimators and variance estimators

Panel A - Estimation of treatment effects: Event-study effects (p-value = 0.000)						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*Switchers*
Effect_1	0.2007	0.1271	-0.0483	0.4498	264	30
Effect_2	0.2664	0.3334	-0.3870	0.9198	247	29
Effect_3	0.7355	0.3285	0.0915	1.3794	212	29
Effect_4	1.7026	0.3754	0.9668	2.4383	194	26
Effect_5	2.1263	0.4485	1.2474	3.0053	169	26
Effect_6	1.9184	0.5317	0.8763	2.9606	172	26
Effect_7	3.0107	0.5886	1.8570	4.1643	140	25
Effect_8	5.0647	0.6388	3.8127	6.3167	126	24
Effect_9	6.3860	0.8377	4.7441	8.0279	97	21
Effect_10	6.3641	0.8277	4.7418	7.9864	85	20
Panel B - Average cumulative (total) effect per treatment unit						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*SwitchxPeriods*
ATT	2.5106	0.3740	1.7775	3.2437	618	256
Panel C - Testing the parallel trends and no anticipation assumptions						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*Switchers*
Placebo_1	-0.2849	0.1985	-0.6739	0.1042	253	28
Placebo_2	-0.4368	0.2749	-0.9756	0.1020	231	27
Placebo_3	-0.8449	0.2282	-1.2922	-0.3976	191	25

Notes: The estimation of treatment effects and cumulative total effect were estimated following De Chaisemartin et al. (2024)'s event-study estimators and variance estimators. Average number of time periods over which a treatment's effect is accumulated is 5.1875. The *Switchers* column indicates the number of units that contribute to the treatment effect in that period (i.e. the units that transition from untreated to treated status during a specific period). These "switchers" serve as the treated group, while units that have not yet been treated or never treated act as the control group for the estimation in that period.

Table 4 - The effect of carbon tax on renewable energy transition: event-study estimators and variance estimators

A - Estimation of treatment effects: Event-study effects (p-value = 0.000)						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*Switchers*
Effect_1	0.3686	0.2634	-0.1478	0.8849	406	15
Effect_2	-0.4989	0.2543	-0.9975	-0.0004	385	13
Effect_3	-0.6736	0.5130	-1.6791	0.3318	321	12
Effect_4	0.3621	0.3510	-0.3259	1.0500	268	9
Effect_5	1.2219	0.4830	0.2753	2.1685	244	9
Effect_6	1.7192	0.3824	0.9698	2.4687	244	9
Effect_7	1.7366	0.3530	1.0447	2.4285	200	8
Effect_8	3.2088	0.3906	2.4432	3.9744	165	5
Effect_9	1.7658	0.4970	0.7918	2.7398	125	4
Effect_10	1.9670	0.5726	0.8447	3.0893	95	3
B - Average cumulative effect per treatment unit						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*SwitchxPeriods*
ATT	0.7309	0.2883	0.1658	1.2960	729	87
C - Testing the parallel trends and no anticipation assumptions						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*Switchers*
Placebo_1	-0.1064	0.2200	-0.5376	0.3247	400.0000	15
Placebo_2	-0.0847	0.2982	-0.6692	0.4998	374.0000	13
Placebo_3	-0.9572	0.3408	-1.6252	-0.2891	308.0000	12

Notes: The estimation of treatment effects and cumulative total effect were estimated following De Chaisemartin et al. (2024)'s event-study estimators and variance estimators. Average number of time periods over which a treatment's effect is accumulated is 4.3793. The *Switchers* column indicates the number of units that contribute to the treatment effect in that period (i.e. the units that transition from untreated to treated status during a specific period). These "switchers" serve as the treated group, while units that have not yet been treated or never treated act as the control group for the estimation in that period.

Table 5 – The effect of carbon tax on renewable energy transition: event-study estimators and variance estimators

A - Estimation of treatment effects: Event-study effects (p-value = 0.000)						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*Switchers*
Effect_1	0.3238	0.3081	-0.2800	0.9277	239	34
Effect_2	0.5325	0.3971	-0.2458	1.3107	212	33
Effect_3	1.2623	0.3566	0.5632	1.9613	196	33
Effect_4	2.3907	0.4527	1.5034	3.2780	199	33
Effect_5	2.9112	0.6436	1.6498	4.1726	185	33
Effect_6	2.8392	0.6262	1.6120	4.0665	182	33
Effect_7	4.3518	0.5968	3.1821	5.5215	157	32
Effect_8	5.8130	0.7590	4.3254	7.3006	152	32
Effect_9	7.3676	1.0004	5.4069	9.3284	121	29
Effect_10	7.2273	0.9137	5.4364	9.0181	110	28
B - Average cumulative effect per treatment unit						
	Estimate	*SE*	*LB CI*	*UB CI*	*N*	*SwitchxPeriods*
Av_tot_eff	3.3756	0.5056	2.3846	4.3666	720	320
C - Testing the parallel trends and no anticipation assumptions						
Placebo_1	0.1417	0.3100	-0.4658	0.7492	229	32
Placebo_2	-0.4732	0.5101	-1.4729	0.5265	200	31
Placebo_3	-0.9347	0.3198	-1.5614	-0.3079	171	28

Notes: The estimation of treatment effects and cumulative total effect were estimated following De Chaisemartin et al. (2024)'s event-study estimators and variance estimators. Average number of time periods over which a treatment's effect is accumulated is 5.359. The *Switchers* column indicates the number of units that contribute to the treatment effect in that period (i.e. the units that transition from untreated to treated status during a specific period). These "switchers" serve as the treated group, while units that have not yet been treated or never treated act as the control group for the estimation in that period.

Table 6 - The non-linear effect of carbon tax on renewable energy transition

VARIABLES	Renewables	Biofuel	Solar	Wind	Others
	(1)	(2)	(3)	(4)	(5)
CT_price	0.3858***	0.0274***	0.0242***	0.2333***	0.1148***
	(0.0327)	(0.0047)	(0.0067)	(0.0171)	(0.0105)
CT_price_sq	-0.0028***	-0.0002***	-0.0001	-0.0020***	-0.0009***
	(0.0004)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
GDP_per_cap	0.4954*	0.5549***	-0.0591	0.4720***	0.6702***
	(0.2822)	(0.0479)	(0.0579)	(0.1479)	(0.0902)
Population	-0.3576	-0.0899**	-0.1448***	-0.3029**	0.1766**
	(0.2548)	(0.0402)	(0.0523)	(0.1335)	(0.0814)
FDI	-0.2587	0.1870**	0.0524	-0.5682*	0.0212
	(0.5910)	(0.0837)	(0.1213)	(0.3097)	(0.1888)
Resources	0.059	-0.0378***	-0.0166	-0.0187	0.0183
	(0.0496)	(0.0108)	(0.0102)	(0.0260)	(0.0158)
R&D	4.3316***	0.1728***	1.0906***	1.4935***	1.0451***
	(0.3403)	(0.0516)	(0.0698)	(0.1783)	(0.1087)
C02_intensity	-3.0963***	0.1378	-0.6656***	-0.6839**	-0.2271
	(0.5700)	(0.0922)	(0.1170)	(0.2987)	(0.1822)
Constant	2.5863	-5.1590***	-0.1455	-5.0264***	-6.6370***
	(2.7504)	(0.4697)	(0.5646)	(1.4411)	(0.8789)
Year FE	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y
Observations	1,104	950	1,104	1,104	1,104
R-squared	0.3777	0.3152	0.3058	0.3197	0.3517

Notes: This table presents the estimation results of Equation (2). The dependent variable is the share of renewable energy in the energy mix (1) and its components including share of biofuel energy (2), solar energy (3), wind energy (4), and other renewable energy (5). CT_price indicates carbon tax levels, and CT_price _sq is its square term. *, **, and *** denote significance at 10%, 5%, and 1% level. Standard errors in parentheses.

Table 7 - The synergistic effects of carbon pricing and macroprudential policies on the green energy transition

VARIABLES	MP_total	Capital	LVR	LLP	Liquidity	LTD	SIFI	OT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CP	1.9947***	2.0098***	2.0211***	1.9769***	1.9543***	2.0629***	1.9715***	1.9933***
	(0.4402)	(0.4330)	(0.4375)	(0.4354)	(0.4478)	(0.4209)	(0.4424)	(0.4288)
MP	0.0967*	-0.4105**	1.0412**	-0.5580***	0.4149*	1.7461***	0.5585**	1.0577***
	(0.0570)	(0.1783)	(0.4949)	(0.2068)	(0.2449)	(0.4241)	(0.2770)	(0.2458)
GDP_per_cap	-0.2536	-0.126	-0.2677	-0.1305	-0.2298	-0.2166	-0.2088	-0.2561
	(0.6921)	(0.7074)	(0.6933)	(0.7168)	(0.6970)	(0.7002)	(0.7008)	(0.6783)
Population	-0.8373	-0.795	-0.7604	-0.8225	-0.7832	-0.8521	-0.8181	-0.8495
	(0.5883)	(0.5821)	(0.5933)	(0.5916)	(0.5785)	(0.5877)	(0.5882)	(0.5726)
FDI	0.3442	0.3142	0.2661	0.3436	0.2527	0.3513	0.3935	0.5255
	(0.4169)	(0.4258)	(0.4131)	(0.4034)	(0.4128)	(0.4182)	(0.4110)	(0.3540)
Resources	0.0133	0.0165	0.0214	0.02	0.03	0.0165	0.021	0.0176
	(0.0928)	(0.0894)	(0.0888)	(0.0911)	(0.0881)	(0.0903)	(0.0922)	(0.0897)
R&D	4.7237***	4.6590***	4.7480***	4.6408***	4.7143***	4.8398***	4.6683***	4.5375***
	(1.4731)	(1.4801)	(1.4966)	(1.5012)	(1.4555)	(1.4418)	(1.4820)	(1.4553)
C02_intensity	-3.8561*	-3.8122*	-3.8338*	-3.7977*	-3.8173*	-3.8872*	-3.9092*	-3.7807*
	(2.2028)	(2.1860)	(2.1620)	(2.1691)	(2.2377)	(2.2114)	(2.1674)	(2.1468)
Constant	10.4302	9.3335	10.4743	9.3983	10.1405	9.9686	10.1235	10.6245
	(6.6350)	(6.7603)	(6.5840)	(6.8152)	(6.7625)	(6.7518)	(6.6653)	(6.5362)
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,107	1,107	1,107	1,107	1,107	1,107	1,107	1,107
R-squared	0.2926	0.2936	0.295	0.2943	0.2944	0.2935	0.2929	0.3079

Notes: This table presents the estimation results of Equation (3). The dependent variable is the share of renewable energy in the energy mix. Variables of interest is macroprudential policy index (MP_total), and its components, including capital requirements for banks (Capital), a limit on leverage (LVR), loan loss provision requirements (LLP), measure taken to mitigate systemic liquidity (Liquidity), limits to the loan-to-deposit (LTD), systematically important financial institutions (SIFI), and other macroprudential measures not captured in the above categories (OT). *, **, and *** denote significance at 10%, 5%, and 1% level. Standard errors in parentheses.

Table 8 – The effectiveness of carbon pricing under tightened and loosen macroprudential policies

VARIABLES	Tight	Loose	Tight	Loose	Tight	Loose
	(1)	(2)	(3)	(4)	(5)	(6)
CP	1.0854**	1.4997				
	(0.5446)	(1.7533)				
ETS			2.7922***	2.9124		
			(0.6091)	(1.8942)		
CTAX					2.5523***	3.5457**
					(0.5896)	(1.6719)
GDP_per_cap	-0.8913*	-0.151	-1.2889**	-1.0026	-0.6742	0.1192
	(0.5034)	(1.5309)	(0.5019)	(1.6065)	(0.4875)	(1.1979)
Population	-0.9699**	-0.4898	-1.0560***	-0.652	-0.7423*	-0.1955
	(0.4011)	(0.9347)	(0.3921)	(0.9315)	(0.3988)	(0.9198)
FDI	0.8028	-13.0620**	0.7781	-12.7966*	0.5552	-13.1844**
	(0.6637)	(6.5477)	(0.6508)	(6.4775)	(0.6552)	(6.3820)
Resources	0.1116	-0.1673	0.1173*	-0.1886	0.106	-0.0885
	(0.0684)	(0.3355)	(0.0665)	(0.3321)	(0.0665)	(0.3283)
R&D	3.9243***	5.3102***	3.5538***	4.7962***	4.1323***	5.6195***
	(0.5655)	(1.5905)	(0.5614)	(1.6231)	(0.5518)	(1.5153)
C02_intensity	-4.6160***	-3.3712*	-4.6465***	-4.2142**	-4.3863***	-2.7419
	(1.0088)	(1.9969)	(0.9880)	(1.9910)	(0.9934)	(1.9696)
Constant	19.6989***	11.293	23.2175***	20.0212	17.0332***	7.5199
	(4.8139)	(14.3536)	(4.7964)	(15.4766)	(4.7175)	(11.4516)
Year FE	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y	Y
Observations	488	123	488	123	488	123
R-squared	0.2042	0.2904	0.2349	0.3062	0.2309	0.3258

Notes: This table presents the effects of carbon pricing, ETS and carbon taxes on green energy transition under tightening and loosening policy actions (Tight vs. Loose). *, **, and *** denote significance at 10%, 5%, and 1% level. Standard errors in parentheses.