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Pricing Carbon, Preventing Leakage: A Comparative Analysis of Steel Decarbonization in the European Union, United States, and China

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ABSTRACT

Steel manufacturing is an important pillar of the world economy, accounting for about 7-9% of annual carbon dioxide emissions. This paper discusses the role of climate policy in providing emission reductions in the steel sector without compromising industrial competitiveness and carbon leakage. It discusses the EU's Emissions Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM) within the framework of the USA's subsidy-based model and China's state-led industrial strategy. This paper uses comparative policy analysis and case studies of ArcelorMittal, Nucor, U.S. Steel, and China Baowu Steel Group to show that companies operating in environments with stronger climate policies are more likely to invest consistently in low-carbon technologies. The EU's combination of carbon pricing and border adjustments provides the strongest and most coherent incentives, but China's coordinated industrial planning shows that state-led investment can also accelerate technological change. In the United States, a hybrid model that combines carbon accountability with continuous investment incentives could be applied to accelerate steel decarbonization. Rising carbon dioxide (CO_2) emissions present a significant global challenge, increasing pressure on countries to decarbonize carbon-intensive industries.

Keywords: Steel decarbonization; Carbon Border Adjustment Mechanism (CBAM); European Union Emissions Trading System (EU ETS); steel sector emissions; U.S. climate policy; comparative climate governance

1. Introduction

Steel production is fundamental to the global economy, enabling infrastructure, transportation, manufactured goods, and the transition to clean energy systems. However, steel is one of the most energy-intensive and carbon-intensive industries globally; traditional coal-fired, blast-furnace-based steelmaking accounts for almost 10% of global annual CO_2 emissions (IEA, 2020;

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World Steel Association, 2023). As steel remains indispensable to our modern economies, addressing its emissions will be essential for achieving global climate goals. Yet, countries compete to lower industrial emissions while maintaining the competitiveness of their domestic producers.

While the European Union (EU) has developed a climate framework based on carbon pricing and border adjustments, the United States has favored subsidies, voluntary corporate targets, and state-level efforts instead of a national carbon price (European Commission, n.d.; Hufbauer et al., 2022). In addition, China, the world's largest steel producer, steers its strategy through national industrial policy and emissions mandates rather than solely carbon pricing. (IEA, 2021; IEA, 2022; World Steel Association, 2023).

A crucial factor in measuring carbon intensity in industries has complicated this equation by creating potential for carbon leakage, where producers move their activities to regions where environmental regulations are not as stringent to avoid carbon costs or mandates (World Bank, 2023). When such an event happens, domestic carbon emissions might decline, but total global emissions do not decrease; they just shift location. Therefore, policymakers need mechanisms to encourage emissions reductions without motivating firms to relocate.

To effectively tackle industrial steel emissions, the European Union has implemented a dualistic climate policy system composed of a carbon price and a trade-based tool. The EU Emissions Trading System (ETS) enforces that businesses purchase permits to offset their carbon emissions, giving them an economic incentive to invest in innovative, clean alternatives and production methods (European Commission, 2021). The Carbon Border Adjustment Mechanism (CBAM) strengthens this system by extending carbon price-based adjustments to specific imports, which mitigates carbon leakage risks.

This paper asks the following:

1. What are the key differences between the European Union’s United States’, and China’s approaches to steel decarbonization? What do these differing strategies reveal about the relationship between climate policy, industrial competition, and carbon leakage?

This analysis examines corporate decisions, emissions intensity, and investments in clean technology by ArcelorMittal, Nucor, U.S. Steel, and China Baowu Steel Group to evaluate how different policy regimes shape business decision-making in the steel sector. Arguing that the EU's use of border-adjustable carbon pricing makes for a more stable approach to carbon mitigation than the U.S. subsidy approach or China's policy, which, in practice, takes cues from national industry strategies. By comparing and contrasting the different policy regimes, it

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illustrates the compromises that must be made when leaders seek to reduce emissions and retain competitive advantages.

2. Literature Review

2a. The Steel Industry and Global Emissions

According to the International Energy Agency (IEA), steel production accounts for a substantial share of global CO_2 emissions due to reliance on coal-based blast-furnace processes (IEA, 2020). As steel demand continues to grow and is projected to increase steadily through 2050, mitigating these emissions poses a significant challenge, yet remains essential to achieving the international climate objectives articulated in the Paris Agreement. Producing one tonne of steel results in approximately 2.18 tonnes of CO_2 emissions (World Steel Association, n.d.), underscoring the urgency of transitioning to cleaner production processes. A synergistic approach, combining technological innovations such as hydrogen-based steelmaking with more stringent policy frameworks, offers the most viable path toward reducing the industry's carbon footprint.

2b. Carbon Leakage and International Climate Policy

A central issue in climate policy design is carbon leakage. The World Bank characterizes this phenomenon as the relocation of manufacturing activities to countries with more lenient or absent climate regulations, thereby circumventing regulatory constraints and avoiding the economic consequences of carbon pricing (World Bank, 2023). Rather than reducing global emissions, such practices merely shift them geographically (World Bank, 2023). The uneven international application of carbon pricing systems thus exposes a significant deficiency in global climate governance, creating economic incentives for production relocation that undermine the effectiveness of even well-designed domestic policies (World Bank, 2023).

In the short term, reducing short-lived climate pollutants (SLCPs), including methane and black carbon, also presents an important near-term mitigation opportunity. The Climate and Clean Air Coalition (n.d.) notes that despite their brief atmospheric lifespan, SLCPs can substantially accelerate global warming and that targeted mitigation efforts could reduce the rate of global temperature rise by up to 0.6°C while yielding significant public health co-benefits.

2c. Corporate Response to Carbon Regulation

A key theme in the literature is that climate policies significantly influence corporate decision-making. Research from the Organisation for Economic Co-operation and Development (OECD, n.d.) reveals that firms respond directly to policy signals when making investment and production decisions. Strong regulatory frameworks encourage long-term investments in cleaner

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technology, while weaker policies allow companies to delay action or prioritize short-term cost savings (OECD, n.d.). Carbon pricing mechanisms such as the ETS have created strong financial incentives for firms to reduce emissions, invest in low-carbon technologies, and restructure production methods, whereas less consistent policy environments tend to produce slower or more fragmented decarbonization progress (European Commission, n.d.).

3. Methodology

This study adopts a comparative case study approach to examine how firms operating under different climate policy regimes respond to decarbonization incentives. This approach compares policy frameworks and firm-level responses across multiple countries to identify how regulatory environments influence corporate investment and emissions reduction strategies. The European Union was chosen because it has implemented both the ETS and CBAM, combining carbon pricing with a trade-based mechanism designed to address carbon leakage (European Commission, n.d.). The United States provides a useful comparison because its federal approach relies more heavily on subsidies and industrial incentives, including those provided through the Inflation Reduction Act (IRA), rather than a national carbon pricing system. China was included because it is the world's largest steel-producing country and offers a contrasting model in which steel decarbonization is influenced by state-led industrial policy, national emissions targets, and government planning (IEA, 2021; IEA, 2022; World Steel Association, 2023).

To evaluate firm-level responses, the paper analyzes four major steel producers: ArcelorMittal, Nucor, U.S. Steel, and China Baowu Steel Group. These firms were selected because they represent different production models, geographic markets, and policy environments. ArcelorMittal provides an example of a multinational steel producer with operations subject to European climate policy and investments in lower-carbon steelmaking technologies (ArcelorMittal, n.d.). Nucor represents a U.S. producer that relies heavily on electric arc furnace (EAF) steelmaking and recycled scrap, while U.S. Steel represents a producer with a greater historical reliance on integrated blast-furnace production that is also investing in newer steelmaking technologies (Nucor, n.d.; United States Steel Corporation, n.d.). China Baowu Steel Group provides a non-Western comparison because its decarbonization efforts take place within China's state-led industrial policy framework and include investments in lower-carbon metallurgical technologies (IEA, 2022; World Steel Association, 2023). By combining policy analysis with firm-level case studies and emissions data, this approach allows for a global evaluation of how differing policy frameworks influence corporate behavior and steel decarbonization outcomes.

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4. Key Policies

4a. European Union: The Emissions Trading System and Carbon Border Adjustment Mechanism

The European Union has developed a comprehensive policy framework for reducing industrial emissions while addressing carbon leakage. The EU Emissions Trading System (ETS) is a cap-and-trade mechanism that sets a ceiling on total emissions and allows firms to buy and sell emissions allowances (European Commission, n.d.). By placing a direct price on carbon, the ETS incentivizes companies to reduce emissions and invest in cleaner technologies. Firms that emit less than their allowance can sell surplus permits, while those that exceed their limits must purchase additional allowances, creating a market-driven mechanism for emissions reduction (European Commission, n.d.).

While the ETS effectively reduces emissions within the EU, it raises concerns about carbon leakage, as firms may be incentivized to relocate production to regions with weaker regulation (European Commission, n.d.). To address these concerns, the EU introduced the Carbon Border Adjustment Mechanism (CBAM), which applies a carbon cost to certain imported goods based on their emissions intensity (European Commission, n.d.). This policy is particularly relevant to the steel industry, as it aligns carbon costs across domestic and imported products, preventing leakage while supporting fair competition in global markets (European Commission, n.d.).

4b. United States: Subsidies and the Inflation Reduction Act

In contrast to the EU, the United States does not have a national carbon pricing system (U.S. Department of Energy, 2023). U.S. climate policy has instead used subsidies, tax credits, loans, and other financial incentives to support emissions reductions and clean technology development (U.S. Department of Energy, 2023). The Inflation Reduction Act (IRA), for example, established and expanded financial incentives supporting clean energy and industrial decarbonization (U.S. Department of Energy, 2023; U.S. Environmental Protection Agency, n.d.). While these incentives can help lower the financial barriers associated with adopting cleaner technologies, this approach differs from a carbon pricing system that directly attaches a cost to greenhouse gas emissions (U.S. Department of Energy, 2023). As a result, the U.S. approach provides financial support for decarbonization without creating the same uniform carbon-price signal faced by firms operating under the EU ETS (European Commission, n.d.; U.S. Department of Energy, 2023).

4c. China: State-Led Industrial Policy and Steel Decarbonization

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China, the world's largest steel producer, approaches steel decarbonization through a different policy model than either the European Union or the United States. Rather than relying primarily on border-adjustable carbon pricing or subsidy-driven voluntary action, China's strategy is shaped by state-led industrial policy, national emissions targets, and production controls. The steel sector has been incorporated into China's broader climate agenda, including the national goal of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060 (IEA, 2021; IEA, 2022). In practice, the approach has translated into pressure on steel firms to improve energy efficiency, reduce excess capacity, expand electric arc furnace production, and invest in lower-carbon technologies (IEA, 2025).

China's national emissions trading system currently focuses primarily on the power sector rather than fully regulating steel in the same way as the EU ETS. As a result, Chinese steel decarbonization remains driven more by administrative guidance, industrial planning, and state-led investment than by a comprehensive carbon price (IEA, 2021; IEA, 2022). Large firms such as China Baowu have responded by investing in hydrogen-based steelmaking research and other low-carbon metallurgical technologies (World Steel Association, 2023). However, because China's approach is less directly tied to a uniform economy-wide carbon cost, the pace and consistency of emissions reductions remain dependent on central government priorities, enforcement, and broader industrial policy goals (IEA, 2022).

4d. Policy Gaps and Challenges

While progress is notable, many issues are outstanding. Stringent carbon border policies (such as CBAM) can lead to trade tensions, especially as countries are differently equipped to cope with increased production standards; developing countries can face constraints in this aspect (Hufbauer et al., 2022). Further questions about whether these carbon border adjustments are consistent with established trade rules exist, and varied policies across countries for industrial decarbonization maintain inconsistency within global climate governance (Hufbauer et al., 2022). The patchy use of carbon prices, subsidies, and industrial policy amongst the largest steel-producing countries further hinders the fight to slash emissions while ensuring a competitive global market (World Bank, 2023).

5. Case Study Findings

The four case studies demonstrate that differences in national climate policy produce distinctly different corporate responses to decarbonization. Rather than following a single pathway, firms adapt their investment strategies, production methods, and long-term planning according to the incentives created by their respective policy environments (OECD, n.d.). Together, the cases illustrate three contrasting models of industrial decarbonization: the European Union's market-

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based carbon pricing framework, the United States' subsidy-driven approach, and China's state-led industrial strategy (European Commission, n.d.; U.S. Department of Energy, 2023; IEA, 2021; IEA, 2022).

5a. EU Firm: ArcelorMittal

Operating under both the ETS and CBAM, ArcelorMittal faces strong and increasing financial pressure to reduce emissions (European Commission, n.d.). In response, the company has taken more aggressive steps toward decarbonization than its U.S. counterparts, including investments in hydrogen-based steelmaking and carbon capture technologies as part of its long-term strategy (ArcelorMittal, n.d.). These actions illustrate how carbon pricing directly shapes corporate decision-making: with a clear and rising cost attached to emissions, ArcelorMittal is incentivized to reduce its carbon footprint not only for environmental reasons but also to maintain economic competitiveness (European Commission, n.d.; ArcelorMittal, n.d.). CBAM further reinforces this approach by ensuring that imported steel faces equivalent carbon costs, reducing the competitive disadvantage that would otherwise result from domestic emissions compliance. (European Commission, n.d.).

5b. U.S. Firms: Nucor and U.S. Steel

U.S.-based producers Nucor and U.S. Steel operate in a policy environment without a national carbon price, relying instead on voluntary commitments and subsidy-driven incentives (U.S. Department of Energy, 2023; U.S. Environmental Protection Agency, n.d.). Corporate strategies consequently vary more significantly than among EU peers. Nucor has adopted a comparatively cleaner production model through its near-exclusive reliance on electric arc furnace (EAF) technology, which uses recycled scrap steel and produces substantially fewer emissions than integrated blast furnace methods, positioning it as a lower-emissions producer independent of regulatory pressure (Nucor, n.d.). U.S. Steel, by contrast, continues to depend more heavily on traditional blast furnace production and has demonstrated slower progress in transitioning to low-carbon technologies (United States Steel Corporation, n.d.). While both companies have stated emissions goals for 2050, the absence of binding regulatory enforcement raises questions about whether those targets will be met under current trajectories (Nucor, n.d.; United States Steel Corporation, n.d.).

This divergence highlights a key structural difference between the two policy systems. Without a carbon price, U.S. firms do not uniformly face pressure to reduce emissions, which allows them to prioritize short-term cost considerations over long-term decarbonization (OECD, n.d.). The result is uneven progress at both the firm and sectoral levels (OECD, n.d.).

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5c. Chinese Firm: China Baowu Steel Group

China Baowu Steel Group offers an important contrast to both EU and U.S. firms because it operates under a state-led decarbonization model rather than a fully market-based carbon pricing regime (IEA, 2021; IEA 2022). As the world's largest steel producer, Baowu has become central to China's effort to reduce emissions from heavy industry while maintaining industrial output and global competitiveness (World Steel Association, 2023). The company has invested in hydrogen metallurgy, low-carbon metallurgical technologies, and other innovations intended to reduce the emissions intensity of steel production (World Steel Association, 2023).

At the same time, Baowu's transition illustrates the limits of a policy system driven more by industrial planning and state direction than by a consistently rising carbon price. Unlike ArcelorMittal, which faces direct carbon costs under the EU ETS and CBAM, Baowu operates in an environment where decarbonization is shaped by government mandates, capacity controls, and long-term national planning goals (IEA, 2021; IEA, 2022). This approach can support large-scale coordination and investment, but it does not create the same transparent and immediate firm-level market pressure for emissions reduction found in the EU model (IEA, 2022; European Commission, n.d.). Baowu therefore represents a third pathway in steel decarbonization: one driven by state-led industrial strategy rather than primarily by either border-adjusted carbon pricing or subsidy-based voluntary incentives.

6. Comparative Insight

The case studies of ArcelorMittal, Nucor, U.S. Steel, and China Baowu demonstrate that climate policy influences corporate decarbonization not only by incentivizing investment but also by shaping the consistency and urgency of that investment. The combination of the Emissions Trading System (ETS) and Carbon Border Adjustment Mechanism (CBAM) in the European Union offers a predictable economic incentive for firms to reduce emissions while protecting domestic producers from carbon leakage. This, in turn, gives companies operating under this framework a stronger financial incentive to invest in technologies such as hydrogen-based steelmaking, carbon capture, and other low-carbon production methods (European Commission, n.d.; ArcelorMittal, n.d.).

But the United States relies more on subsidies and voluntary corporate commitments, which encourage innovation but apply less steady pressure for emissions reductions (U.S. Department of Energy, 2023; OECD, n.d.). The divergent strategies of Nucor and U.S. Steel illustrate how companies in the same national policy environment can take substantially different decarbonization paths when emissions reductions are not backed by a common carbon price (Nucor, n.d.; United States Steel Corporation, n.d.). The third model is China, where state-driven

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industrial planning, production targets, and public investment have driven technological development at a faster pace without a comprehensive steel-specific price on carbon (IEA, 2021; IEA 2022). This approach has enabled significant investment, but its success is very dependent on continued government coordination and long-term policy objectives (IEA, 2022; World Steel Association, 2023).

These comparisons suggest that durable industrial decarbonization requires both strong economic incentives and stable policy signals. Although no single policy framework fully addresses every challenge associated with industrial decarbonization, the evidence presented in this study suggests that the European Union's integration of carbon pricing with border adjustments currently offers the most comprehensive strategy for reducing emissions while preserving industrial competitiveness in a free market economy.

7. Policy Implications and Recommendations for the United States

The comparative analysis highlights several implications for future U.S. climate and industrial policy. First, adopting a carbon border adjustment mechanism similar to the European Union's Carbon Border Adjustment Mechanism (CBAM) could help reduce carbon leakage by applying a carbon cost to imports, thereby reducing incentives for firms to shift production to less-regulated jurisdictions and helping ensure that domestic emissions reductions are not simply displaced geographically (World Bank, 2023). Second, such a policy could improve the competitiveness of domestic producers like Nucor and U.S. Steel by equalizing carbon costs between domestic and imported goods, thereby creating a more equitable environment for firms that have already invested in cleaner production methods (European Commission, n.d.; Hufbauer et al., 2022).

Third, clearer carbon pricing signals would likely be associated with broader adoption of low-carbon technologies across the steel industry. As the Organization for Economic Co-operation and Development (OECD) notes, firms respond most effectively to policy signals when those policies impose clear economic consequences for emissions (OECD, n.d.). Subsidies can lower the cost of adopting new technologies, but on their own, they do not create a consistent penalty for carbon-intensive production (OECD, n.d.). For this reason, the most effective U.S. approach would likely be a hybrid model combining carbon border measures or carbon pricing with continued investment subsidies: subsidies lower the cost of clean technology adoption, while carbon pricing may provide stronger and more predictable incentives for emissions reduction (Hufbauer et al., 2022).

At the same time, the comparison with China suggests that state-backed investment, industrial coordination, and long-term planning can also support decarbonization. China's experience indicates that government-directed investment and production targets can mobilize large-scale

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change in heavy industry, even without a steel-specific carbon pricing system equivalent to the EU ETS (IEA, 2021; IEA, 2022). While the United States is unlikely to replicate China's state-led model directly, it can still draw an important lesson from it: industrial decarbonization appears to require not only market incentives but also sustained public investment, clear long-term policy signals, and coordination across energy, manufacturing, and trade policy.

Taken together, these findings suggest that the United States would benefit most from a hybrid strategy that combines elements of both the EU and Chinese approaches. Federal subsidies under the Inflation Reduction Act already support clean energy development and industrial innovation (U.S. Department of Energy 2023; U.S. Environmental Protection Agency, n.d.). The absence of a national carbon price may limit their effectiveness in driving consistent emissions reductions across heavy industry (OECD, n.d.). A policy framework that combines investment incentives with stronger carbon accountability measures, such as a border adjustment or sector-specific emissions standard, could reduce leakage, strengthen industrial competitiveness, and accelerate the transition to cleaner steel production.

Despite these advantages, important challenges remain. Carbon border policies may be perceived as protectionist and could trigger disputes under international trade law, particularly among developing countries that lack the financial and technological capacity to rapidly transition to lower-carbon production standards (Hufbauer et al., 2022). Political feasibility is another significant barrier, as the United States has historically faced substantial opposition to nationwide carbon pricing. To ensure that carbon border adjustments are both environmentally effective and globally equitable, any future U.S. policy would need to be paired with complementary measures, including investment support for domestic producers and financial or technological assistance for lower-income trade partners.

8. Conclusion

The steel industry remains essential to global economic growth, infrastructure development, and the transition to clean energy, yet it is also one of the largest sources of industrial carbon emissions. The comparative evidence presented in this paper indicates that climate policy plays a central role in shaping how steel firms approach decarbonization, although the mechanisms through which governments encourage emissions reductions vary considerably across countries.

This study also has several limitations related to the research process. It relies primarily on publicly available company reports, policy documents, and secondary sources, which created challenges in comparing firms across countries because emissions and investment data were not always reported in consistent ways. This issue was especially true for China, where publicly available firm-level data were more limited, making it harder to integrate China Baowu into the

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same type of comparison as ArcelorMittal, Nucor, and U.S. Steel. In addition, because the paper uses a small case study sample, its findings should be interpreted as suggestive rather than fully generalizable. Future research could build on this project by examining a larger set of steel firms, using more standardized emissions data, and tracking policy and firm-level changes over a longer period of time.

The European Union's Emissions Trading System (ETS) and Carbon Border Adjustment Mechanism (CBAM) represent the most comprehensive effort to combine carbon pricing with trade regulation, addressing both domestic emissions and the risk of carbon leakage. By contrast, the United States has relied more heavily on subsidies and voluntary corporate commitments, producing more uneven results across firms. China offers a third model, in which state-led industrial policy, public investment, and long-term planning shape steel decarbonization even without a steel-specific carbon pricing regime equivalent to the EU's. Together, these cases suggest that decarbonization outcomes are shaped not only by whether governments intervene but also by the type of policy pressure and support they provide to industry.

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