Harvard Project on Climate Agreements

Good Spillover, Bad Spillover? Industrial Policy, Trade, and the Political Economy of Decarbonization

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The Harvard Project on Climate Agreements is a Harvard-University-wide initiative established in 2007 to identify and advance scientifically sound, economically sensible, and politically pragmatic public policy options for addressing global climate change. Drawing upon leading thinkers from around the world, the Harvard Project conducts research on policy architecture, key design elements, and institutional dimensions of international and domestic climate-change policy. The Harvard Project is directed by Robert N. Stavins, A.J. Meyer Professor of Energy and Economic Development, Harvard Kennedy School. For more information, see the Harvard Project's website: www.hks.harvard.edu/hpca.

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ABSTRACT

Spillover effects can impede or advance climate action. They have enabled some of the greatest successes in climate change mitigation, yet also threaten to undermine accelerating decarbonization efforts. Because they are difficult to define and quantify, they are routinely neglected in the theoretical framing of climate policy instrument choice. Some spillover effects have been extensively studied, while others remain opaque, with scarcely understood causal mechanisms and interactions. Several international bodies have recently begun to elevate spillover effects in their work, but reveal the lack of an overarching conceptual framework in their approach and are politically constrained in the solutions they can propose. This Discussion Paper suggests a typology of spillover effects, and correlates these with two climate policy approaches that differ substantially in their political economy: interventions that impose a private cost on emissions, and interventions that socialize the cost of climate change mitigation. Drawing on recent policy developments on both sides of the Atlantic, the Discussion Paper goes on to show how spillover effects have influenced past instrument choices, and how those choices will in turn result in new and – in some cases – unintended spillover effects. As Europe, the United States and other major economies chart industrial policy trajectories that threaten to fragment international flows of goods, services, capital, and ideas, they risk exacerbating harmful and impeding beneficial spillover effects, increasing the cost and time horizon of decarbonization. The paper therefore concludes with options for improved understanding of spillover effects and enhanced policy coordination in their management to enable a virtuous sequence of climate policy diffusion and implementation.

Keywords: Spillover effects, European Green Deal, Net Zero Industry Act, Inflation Reduction Act, carbon pricing, CBAM, international trade, political economy

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GOOD SPILLOVER, BAD SPILLOVER: INDUSTRIAL POLICY, INSTRUMENT CHOICE, AND THE POLITICAL ECONOMY OF DECARBONIZATION

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1. INTRODUCTION

1.1 Climate Action in a Fragmenting World

Global climate action faces intensifying headwinds. With a rapidly diminishing carbon budget and persistent inertia of physical and socioeconomic systems, it is becoming increasingly doubtful that humanity will succeed in curbing runaway climate change (Armstrong McKay *et al.*, 2022; Fransen *et al.*, 2023). Despite an aspiration to achieve convergence of domestic climate efforts under the Paris Agreement over the long term, coordination shortfalls and the need to accommodate vastly different geophysical and socioeconomic starting points have contributed to entrenched heterogeneity of nationally determined climate action (Mehling, Metcalf, and Stavins, 2018; Roelfsema *et al.*, 2020). Growing obstacles to cooperation, including fraying prospects for multilateralism amidst rising geopolitical tensions (ICC, 2023; IMF, 2023), further undermine the prospects for a collective solution to what is perhaps the definitive collective action problem.

Barriers to climate action are not limited to the international sphere, however. Accelerating investment needs in climate change mitigation and adaptation are imposing mounting strains on public budgets, exacerbated by price inflation and rising capital costs. Not only has this delayed achievement of pledged climate finance transfers (UNFCCC Standing Committee on Finance, 2022; Buchner *et al.*, 2023; OECD, 2024a), but concerns about the fiscal strain and distributional burden of ambitious

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decarbonization efforts are also altering the political economy of climate action, as populist movements expand their influence in response to changing electoral priorities, and policy makers resort to protectionist industrial policies for decarbonization or shift their focus to other issues altogether, such as immigration and national security (Driesen, Mehling, and Popp, 2024).

In short, the window for transformative climate action is narrowing just as its urgency is greatest (IPCC, 2023; UNEP, 2024). In such a context, one would think that building on past successes (Lamb *et al.*, 2022; Stechemesser *et al.*, 2024) takes precedence over policy experiments with unknown outcomes. Yet the world is nonetheless witnessing a dramatic paradigm shift in the choice of policies to address climate change, with leading actors including the United States and the European Union turning to industrial policy strategies to advance decarbonization alongside a wide range of other policy objectives (Allan, Lewis, and Oatley, 2021; Meckling, 2021; Nahm, 2021). In the process, decades of consensus on the benefits of greater trade liberalization and economic integration have largely given way to a surge in market interventions, many of which seek to actively reverse contested outcomes of globalization (Cherif and Hasanov, 2019).

Industrial policy and its means – designed to shape the structure or the economy by selectively promoting and protecting certain industries, technologies, or sectors – have always been controversial (Pack and Saggi, 2006; going back to Hamilton, 1791; Mill, 1848) and elicited criticism for their susceptibility to government failure and political capture, distortion of market signals, and misallocation of resources (von Hayek, 1945; Krugman, 1983; Krueger, 1990). Lately, however, they have seen growing support even from earlier sceptics (Krugman, 1993), with proponents justifying industrial policy as a means to address various externalities, improve economic coordination, and provide public goods (Liu, 2019; Juhász, Lane, and Rodrik, 2024). Politically, industrial policy has often had other motivations, such as the need to respond to economic shocks, counter geopolitical adversaries, and secure popular support for climate action.

For better or for worse, the generational challenge of climate change mitigation is now inseparably tied to the rise of industrial policy. Often labelled “green industrial policy” (Rodrik, 2014; Altenburg and Assmann, 2017), this convergence of industrial policy and decarbonization reflects a growing view that state intervention is not only called for to correct the market failures underlying climate change, but also to help create markets and an enabling context that fosters green innovation, guides investment, and promotes systemic transformation while managing the social impacts and evolving workforce needs of the energy transition (Mazzucato, 2013; Lamperti *et al.*, 2019). To achieve these objectives, however, a majority of industrial policies contain protectionist elements (Evenett *et al.*, 2024; Juhász and Lane, 2024) that threaten to distort the global economy and are more likely to generate unintended outcomes, including “spillover” effects.

1.2 A Growing Interest in Spillover Effects

What are the implications of this evolving policy paradigm for the prospects of successful decarbonization? With so many concurrent objectives, not all of which are necessarily aligned, what unintended effects might the observed surge in industrial policy have for the achievement of committed climate objectives? Such questions are at the center of this Discussion Paper, which aims to shed light on them by focusing on a topic that has recently witnessed growing interest, yet still defies a comprehensive theoretical or conceptual framing: the spillover effects of climate and industrial policies. Scholars are increasingly acknowledging the relevance of spillover effects for the success or failure of environmental progress (Zhong *et al.*, 2024), while international research initiatives have even sought to quantify such effects (OECD/EC-JRC, 2021; Sachs, Lafortune, and Fuller, 2024) and created an index to rank the spillover performance of countries (SDSN, 2024a).

So far, the discussion of spillover effects has been largely limited to civil society and academia. Most recently, however, this has begun to change, with policy makers beginning to show awareness of spillover effects and their impact on public policy objectives. Often, the reference to spillover effects is implicit only. In its legislative proposal for a directive on corporate sustainability due diligence, for instance, the European Commission estimated that "up to 80-90% of the environmental harm of EU production may occur ... outside the Union" (European Commission, 2022). Announcing the creation of a White House Task Force on Climate and Trade, meanwhile, U.S. Special Presidential Envoy for Climate John Podesta cited research claiming that "for every ton of carbon pollution reduced at home because of the Inflation Reduction Act, we'll slash up to 2.9 tons of carbon pollution outside of the U.S." (White House, 2024).

Reference to spillover effects has been more explicit in international policy debates. Two prominent policy efforts, the Climate Club launched by the Group of Seven (G7) and the Inclusive Forum on Carbon Mitigation Approaches (IFCMA), have recently included spillover effects in their respective work programs. Under its mitigation pillar, the Climate Club calls for a "[s]trategic dialogue on causes and relevance of spillovers from mitigation policies! aimed at identifying risks to climate action and identifying possible cooperative solutions (Climate Club, 2023), whereas the IFCMA features an Inclusive Multilateral Dialogue that focuses on, *inter alia*, "maximising positive spillovers, such as technology transfers, and minimising negative ones, such as carbon leakage and trade distortions" (OECD, 2024b). In the latest contribution to this debate, a task force of international organizations led by the World Trade Organization has dedicated an entire chapter of a landmark report to spillover effects, admonishing coordination to manage spillover effects (WTO *et al.*, 2024).

Policy interest in spillover effects was noticeably accelerated by the global COVID-19 pandemic, which heightened awareness for the many transmission channels – such as financial flows, trade in goods and services, migration or knowledge transfers – mediating transboundary disruptions to supply chains, labor mobility, tourism, and remittances. It also underscored the need for greater coherence between national, regional and global policy responses, spurring demand for international rules and governance standards (OECD/EC-JRC, 2021). In the context of climate action, however, this interest is also owed to the increased stakes of decarbonization and its pursuit through industrial policies, which aim to advance multiple concurrent objectives and are often themselves a response to spillover effects.

As this Discussion Paper argues, spillover effects may hold the key to successful decarbonization, yet they are barely understood and lack a unifying conceptual framework. Because they are challenging to measure or predict, they are also routinely underestimated, leading to their neglect in policy design and instrument choice. A central proposition of this paper is, in fact, that the current surge in industrial policies risks exacerbating negative spillover effects while impeding positive ones. At the same time, it proposes that improved policy design and targeted cooperation may also help manage spillover harm while leveraging spillover benefits, allowing a progression in climate action through a virtuous cycle of policy sequencing.

Drawing on a review and synthesis of research from different areas of knowledge, the objective of this paper is therefore to advance the understanding of spillover effects in the context of climate action so these can better feature in the evaluation of policy options and influence the choice of policies that give rise to such effects in the first place. To this end, Section 2 discusses why spillover effects matter for decarbonization, referencing two widely studied examples; Section 3 offers a taxonomy of spillover effects, and examines their political economy implications; Section 4 presents a case study on industrial policies currently advanced in the United States and the European Union; Section 5 explores how international cooperation can be leveraged to manage spillover effects, and offers proposals for improved management through coordinated action. Section 6 concludes.

2. WHY SPILLOVER EFFECTS MATTER FOR DECARBONIZATION

In its most recent assessment report, the Intergovernmental Panel on Climate Change (IPCC) identified solar energy as the mitigation option offering the largest potential contribution to net greenhouse gas (GHG) emission reductions by 2030 (IPCC, 2023). What may thus be the single most important lever to address climate change – the widespread availability of affordable solar photovoltaic (PV) technology for electricity generation – is owed to a well-documented sequence of spillover effects: from the initial observation of the photoelectric effect in Europe to the invention of the first practical solar PV modules in the United States and their early adoption in niche markets, to scaled up deployment in countries like Germany creating the demand pull that led to an eventual concentration of manufacturing capacity in China, each stage was enabled by public policies and accompanied by spillover effects that contributed to the diffusion and extraordinary cost declines of solar PV technology (Mazzucato, 2013; Nemet, 2019; Pillai, 2015; Ziegler, Song, and Trancik, 2021; Kolesnikov *et al.*, 2024).

Such spillover effects are difficult to anticipate and often unintended, which is why they are commonly neglected in academic research. Several economic analyses of the feed-in tariff under the German Renewable Energy Act (EEG, 2000), for instance, found the policy instrument to be "a very expensive way of reducing CO_2 emissions", and indicated a strong preference for reliance on carbon pricing instead (Marcantonini and Ellerman, 2015; similarly Abrell, Kosch, and Rausch, 2019). Importantly, these studies relied on retrospective data for Germany only, and expressly excluded the innovation and learning effects induced by its domestic demand; these, in turn, were critical in driving the economies of scale, advancements in manufacturing processes, and global competition that accelerated progress along the technology learning curve and resulted in rapidly declining costs for solar energy. Expanding the scope of the analysis to capture innovation spillover effects – especially over time and across borders – dramatically alters the results, however: a more recent analysis of innovation in solar energy technology that deployed a dynamic structural model of international competition among solar panel manufacturers estimated that "86% of the marginal solar adoption attributable to innovation induced by German subsidies occurs outside Germany" (Gerarden, 2023).

In other words, mainstream analyses that narrowly focused on one market failure and neglected temporal and geographic spillover effects would have justified abandoning the German feed-in tariff in favor of relying solely on the European Union Emissions Trading System (EU ETS). In hindsight, however, that same feed-in tariff has been described as the single most important factor in driving down technology cost to make solar energy competitive with conventional energy sources, given that it established the first significant market for solar energy and thereby spurred the subsequent growth in Chinese manufacturing (Buchholz, Dippl, and Eichenseer, 2019; Huang *et al.*, 2016). By contrast, the EU ETS – while eventually successful at driving operational changes such as fuel switching (Delarue Erik, Voorspools Kris, and D'haeseleer William, 2008) and creating an expectation of tightening constraints (Bayer and Aklin, 2020) – has been shown to have, at best, modest impacts on technological innovation (Calel and Dechezleprêtre, 2016; Martin, Muûls, and Wagner, 2016; Calel, 2020), with exploratory interviews suggesting that feed-in tariffs proved a far more significant driver of innovation in renewable energy technology (Hoffmann, 2007; Rogge, Schneider, and Hoffmann, 2011).

As this example highlights, if consequential benefits of policy options are neglected because they follow from unknown spillover effects, valuable opportunities for decarbonization progress may be left to chance and remain unexploited. Not all spillover effects are beneficial, however. An unintended outcome of globalization and decades of liberalized trade has been an offshoring of economic activity and employment, erosion of local industries, and increased dependency on foreign manufacturing hubs, often at the expense of domestic economic resilience. Hence, although they contributed to falling technology costs, the spillover effects which induced relocation of solar manufacturing capacities from Germany to China were met with widespread public disapproval at the time. Seeking to learn from that experience, newer industrial policies to promote growth of domestic clean technology manufacturing make greater use of localization targets and content requirements, and have been accompanied by more aggressive deployment of trade defence measures such as countervailing duties and antidumping tariffs (Noll, Steffen, and Schmidt, 2024).

Another spillover effect that has garnered considerable attention is emissions leakage, which involves relocation of emissive activities as a result of uneven climate policy ambition (Felder and Rutherford, 1993; IPCC, 2022). Because leakage offsets emission reductions in one region with increased emissions in other parts of the world, it can substantially undermine progress on decarbonization and even lead to an overall increase in global emissions (Hoel, 1991, 1994; Babiker, 2005). While related concerns have proven largely baseless in the past (Aldy and Pizer, 2015; Dechezleprêtre and Sato, 2017; Caron, 2022), dramatically accelerated climate action – as envisioned under the Paris Agreement – could precipitate a future increase in emissions leakage (Branger and Quirion, 2014; Carbone and Rivers, 2017). Indeed, despite limited evidence of past leakage in the EU ETS (Branger, Quirion, and Chevallier, 2016; Healy, Schumacher, and Eichhammer, 2018; Naegele and Zaklan, 2019; Verde, 2020;

Dechezleprêtre, Nachtigall, and Venmans, 2023), concerns about the potential for future leakage as carbon prices increase alongside a decline in free allowance allocation declines (Antoci *et al.*, 2022) have prompted this spillover effect to remain an influential factor in the European climate policy debate, and have even prompted adoption of a controversial Carbon Border Adjustment Mechanism (CBAM; for further detail, see Section 4 below).

As the share of emissions in international trade – currently estimated at around 20-25% of global emissions (Davis and Caldeira, 2010; Hasanbeigi and Darwili, 2022) – grows relative to declining overall emissions, emissions leakage could thus become one of the greatest impediments to steep decarbonization around the globe, especially in sectors that are difficult to abate, such as heavy industry. Already, offshoring of the most emissive activities has allowed countries such as Switzerland or Singapore to reduce their own territorial emissions below those associated with goods they import from abroad (Karstensen, Peters, and Andrew, 2018). While such displacement has been largely due to more favorable factor endowments, such as lower costs of labor and raw materials, coupled with a protectionist bias in trade policy that amplifies emission transfers (Shapiro, 2021), it illustrates how countries can report progress towards their climate targets without securing commensurate reductions in global emissions.

It also risks perpetuating a historical pattern in which affluent countries have outsourced polluting activities to less affluent regions with weaker environmental standards (Pethig, 1976; Siebert, 1977), in the process shifting the burdens of natural resource depletion, local air and water pollution, waste, and associated health impacts (Levinson, 2010; Kanemoto *et al.*, 2014) while transferring accountability for the accompanying emissions (IPCC, 2006; Kanemoto *et al.*, 2012; Moran, Hasanbeigi, and Springer, 2018). For the time being, emission transfers between developed and developing countries appear to have stabilized (Baumert *et al.*, 2019; Wood *et al.*, 2020), yet they may soon be exceeded by transfers between developing countries (Meng *et al.*, 2018). Indeed, a recent empirical assessment found that trade along China's Belt and Road Initiative (BRI) already accounts for the majority – nearly three quarters – of all emissions embedded in internationally traded goods (Li and Khan, 2024).

Whether emissions are displaced by climate policies or other causes, the challenge remains: in a context of nationally determined climate action, such as that created by the Paris Agreement, emissive activities could become concentrated in a diminishing number of countries that continue to use fossil fuels in the near and medium term – stimulated by falling prices in global energy markets due to declining demand in more ambitious jurisdictions (Bohm, 1993; Felder and Rutherford, 1993) and an acceleration of fossil fuel extraction due to expectation of future policy constraints (Sinn, 2012) – to produce goods for the international market. Even the mere perception of such relocation risks can give rise to formidable opposition against increased climate ambition because they entail a loss of economic benefits such as employment and investment, a deteriorating trade balance, and reduced fiscal revenue (World Bank, 2019).

As shown in this section, spillover effects can both account for a significant share of the climate benefits arising from policy decisions, as well as undermine and potentially reverse their desired outcomes. Case studies discussed later in this Discussion Paper (see Section 4) suggest that spillover effects often exceed the direct policy impacts, in some cases even by an order of magnitude. Therefore, understanding the different types of spillover effects and their implications for climate action – also with a view to informing future policy choices – is not merely of academic interest, especially in the current context of shifting policy paradigms and the widespread deployment of industrial policies with increase market interventions and restrictions on international trade. Lack of systematic attention to spillover benefits and harms is due, in part, to the absence of a unifying conceptual framework, but given their potential implications for climate action such epistemic uncertainty does not justify their neglect. While this Discussion Paper cannot dispense with such uncertainties altogether, the following section proposes a taxonomy of spillover effects as a frame of reference for improved scholarly engagement with the topic.

3. UNDERSTANDING SPILLOVER EFFECTS

3.1 Reviewing the Conceptual Landscape of Spillover Effects

In general usage, the term "spillover" can be traced back almost a century, with a leading dictionary defining it as follows: "[t]hat which spills over; the process of spilling over; (an) incidental development; a consequence, a repercussion, a by-product" (Oxford English Dictionary, 2024). Its broad scope and indeterminate nature, meant to capture both intended and unintended consequences across widely divergent context, defies conceptual precision or a conclusive definition. Unsurprisingly, therefore, "to date research on spillover effects has generated mixed and at times conflicting results, and studies are spread across disconnected literatures from diverse disciplines." (Truelove *et al.*, 2014). Some of these "disconnected literatures from diverse disciplines" are surveyed in the following paragraphs.

At first glance, spillover effects share considerable overlap with the economic concept of externalities, first introduced by Alfred Marshall as "external economies" (Marshall, 1890) and further elaborated by Arthur C. Pigou as "incidental services or disservices" that result in a divergence between private and social costs and benefits (Pigou, 1920). A form of market failure, externalities thus describe how the choices of one economic actor can generate unintended effects for others (Bator, 1958; Buchanan and Stubblebine, 1962; Jaffe, Newell, and Stavins, 2005). By expressing them in terms of costs or benefits, the concept of externalities enables calculating such effects with mathematical precision. Indeed, an effort by the U.S. federal government to estimate the marginal damage of greenhouse gas (GHG) emissions – a negative externality (Stern, 2007) – has resulted in a metric, the Social Cost of Carbon (SCC), that is used in regulatory impact assessments in the United States (Executive Office of the President, 2021; Interagency Working Group on Social Cost of Greenhouse Gases, 2021; for an overview: Nordhaus, 2017). Difficulties establishing parameters such as climate sensitivity, damage functions, and the applicable discount rate have highlighted the conceptual challenges faced in calculating this metric (Pindyck, 2017; Weitzman, 2014; Rennert *et al.*, 2022; Ricke *et al.*, 2018), however, with SCC values applied across consecutive administrations varying by an order of magnitude due to different geographic scopes of damages considered (Carleton and Greenstone, 2022). In other words, consideration or neglect of spillover effects again has a significant effect on outcomes.

Another type of externality frequently described in the economic literature is even commonly referred to as a "spillover": the positive externality of knowledge or innovation spillovers, which occur when advancements achieved by one economic actor through research and development (R&D) as well as learning by doing influence productivity and technological capabilities in other actors without financial return to the originator. As a non-rivalrous good, knowledge, once created, can benefit others at little to no additional cost, generating this positive spillover effect (Arrow, 1962). Because innovation is a driver of economic growth, with increasing returns to scale and positive impacts on the broader economy, policy interventions can be justified to correct the market failure (Romer, 1990; going back to Schumpeter, 1926). More recently, empirical studies have demonstrated the impact of research and development as well as patent spillovers on productivity, especially within geographic clusters (Griliches, 1992; Jaffe, Trajtenberg, and Henderson, 1993; Irwin and Klenow, 1994). Knowledge spillovers enabled through international flows of goods, services, capital and ideas can then enable technology diffusion across borders (Coe and Helpman, 1995; Keller, 2004; Melitz and Redding, 2023).

Economic theory is not the only branch of economics that has relevance for the spillovers conceptualization of spillover effects. In the study of financial markets, the term "spillover" has been used to describe how economic shocks or regulatory changes can influence relevant behavior across markets, for instance in the form of contagion across interconnected financial systems (Masson, 1998). In the literature on development and health economics, researchers have proposed a fourfold typology of spillover effects, a term they use to describe indirect effects of treatment programs. Although conceding that the "labels … are somewhat arbitrary" and primarily used to group similar types of spillover effects, they distinguish: externalities, as described above; general equilibrium effects from interventions affecting equilibrium prices through shifts in the supply and demand of products in the market; context equilibrium effects from interventions affecting social norms or behaviors; and social interactions, where treatment benefits are mediated indirectly through peer effects (Angelucci and Di Maro, 2016). A similar distinction between the direct and spillover effects of policies or treatment programs can also be found in more recent scholarship on methods of applied and empirical economics (Vazquez-Bare, 2023b, 2023a).

Spillover effects that convey through peer effects and changes in social norms are also widely explored in other fields of behavioral science, such as social psychology, education and communications studies, where the term has been defined as the "extent to which engaging in one behavior influences the probability of conducting a subsequent behavior" (Nilsson, Bergquist, and Schultz, 2017). In the environmental domain, spillover effects have been observed when individuals engaging in one behavior adopt a more environmentally conscious orientation and subsequently engage in other environmentally beneficial behaviors, or instead see their motivation for such behavior decrease (Thøgersen and Crompton, 2009; Truelove *et al.*, 2014). Carlsson *et al.* (2021) and Lanzini *et al.* (2014), for instance, provide examples of how social information campaigns and other interventions aimed at reducing energy use can have broader behavioral spillover effects, encouraging more sustainable behaviors in areas outside of energy conservation. Contributing to this body of work, Dolan et al.

(Dolan and Galizzi, 2015) propose a distinction between promoting, permitting or purging spillovers, and Nilsson *et al.* (2017) study how such spillover effects can manifest across time and contexts.

Aside from such behavioral spillover effects, research on spillovers in the environmental domain has most often focused on geographical spillovers, studying how these manifest across jurisdictions by virtue of physical flows – such as pollutants crossing national borders or affecting the global commons – or trade flows, with consumption in one region spurring unsustainable production patterns in another. For instance, Schmidt-Traub *et al.* (2019) provide example of international spillover effects in their work on the Sustainable Development Goals (SDGs), where spillover effects occur when actions in one country impose costs or deliver benefits to others, often without these impacts being accounted for in market prices. In their typology, they distinguish between environmental spillovers, socioeconomic spillovers, spillovers related to finance and governance, and security spillovers. This typology and a set of methods to assess international spillovers are used by the Sustainable Development Solutions Network (SDSN) for periodic updates to a spillover index and ranking of countries according to their "spillover performance" (SDSN, 2024b, 2024a) published as part of an annual flagship report (Sachs, Lafortune, and Fuller, 2024).

Similarly, a report by the Organisation for Economic Co-operation and Development (OECD) and European Commission Joint Research Centre (JRC) focuses on geographic spillovers, emphasizing the transboundary nature of spillover effects, which can be either intended or unintended and are transmitted through environmental, social, or economic pathways (OECD/EC-JRC, 2021). In this report, spillover effects are broadly defined as "synergies and trade-offs across dimensions" and specifically related to the implementation of national and international policies. To ensure that policy design and implementation consider the impacts of policies "here and now", "elsewhere", and "later", the report proposes institutional mechanisms for integrated planning and strategic visioning, greater coordination and collaboration across sectors and levels of government, and improved monitoring, evaluating and reporting on the impacts of domestic policies. Already, these methodological tools are seeing deployment in academic research, for instance on the global spillover effects of the European Green Deal (Zhong *et al.*, 2024).

Finally, spillover effects have also been described in political science, international studies and the study of government, where theories of political integration, particularly in the context of European integration, have invoked functional spillovers that occur when progress or policy advancements in one area or sector influence or create pressures for related changes in another (Haas, 1958; Lindberg, 1963; Sandholtz and Sweet, 1998). In this conceptual framework, spillovers result from the inability to isolate sectors or functions, with changes in one triggering demand for alignment in others. Another, often intentional, form of spillover in the political realm occurs in instances of policy transfer and diffusion, which has likewise seen a burgeoning literature (Dolowitz and Marsh, 2000; Shipan and Volden, 2008; Marsh and Sharman, 2009). Four mechanisms of policy diffusion – learning, competition, emulation and coercion – are commonly cited as explanations for how policymaking processes and policy outcomes in one polity can influence those in other polities, contributing to this spillover effect (Blatter, Portmann, and Rausis, 2022).

Taken together, the foregoing literature review evidences the breadth and heterogeneity of research on spillover effects, with definitions encompassing a wide variety of effects across multiple dimensions. Effects range from concrete physical flows and changes in observable behavior to more abstract notions, such as socioeconomic or political spillovers. Dimensions in which these effects manifest themselves extend from spatial or geographic spillovers to temporal spillovers. All definitions have in common that they raise methodological challenges, from the need for data across these dimensions to the complexities involved in establishing a causal relationship between developments or actions in one context, such as a policy intervention, and the asserted spillover effects. A shared baseline across all definitions, thus, could be the intent to describe situations where developments or actions in one context generate effects in another context. Using this broad understanding, the next section explores how spillover effects have been discussed in the context of climate action, and proposes a taxonomy of climate-related spillover effects.

3.2 Towards a Taxonomy of Climate-Related Spillover Effects

Like much of the research presented in the previous section, one of the earliest attempts to describe spillover effects in the context of climate action focused on their geographical dimension. In an assessment of the Kyoto Protocol, Grubb *et al.* (2002) highlight three types of international spillover effects: substitution due to price effects, diffusion of technological innovations, and policy and political spillovers. In their analysis, substitution effects occur when climate policies result in carbon leakage, shifting emissions from consumption and production to areas with less stringent climate policies; technology spillovers describe the spread of innovations developed in response to climate policy constraints and incentives, with advances in one country helping others reduce their emissions; and policy spillovers, finally, reflect how regulatory practices in developed countries influence policy decisions in developing nations, as these align their regulations with global standards.

More than two decades after Grubb *et al.* (2002) identified these spillover effects, albeit without acknowledging that earlier contribution, the WTO, the OECD, the International Monetary Fund (IMF), the United Nations Conference on Trade and Development (UNCTAD), and the World Bank presented a joint report that contains extensive discussion of these same spillover effects and recommendations for their improved management (WTO *et al.*, 2024). In addition to emissions leakage, green technology dissemination and climate policy diffusion, this report also declares the reduction of global emissions and thus climate impacts a positive spillover and the adverse effects of subsidies for climate-related technologies on foreign producers a negative spillover. As such, this report provides an important and highly visible addition to the literature on spillover effects, reflecting growing concern among the membership of the authoring organizations about the impacts of growing climate policy ambition and unilateral deployment of industrial policies with trade impacts. In its selection of spillover effects to analyze, however, it limits itself to international spillovers that are already well understood, and reveals a disciplinary bias in the surveyed literature. Political sensitivities and capacity constraints may have prevented adoption of a broader scope, but as the following paragraphs show, many further climate-related spillover effects and relevant case studies have been identified in research across different disciplines. To some extent, therefore, this report marks a missed opportunity to provide a more authoritative and inclusive framework for future study of spillover effects.

Indeed, as already discussed in Section 2, much of the existing research has focused on the foregoing three spillover effects. Examples of the abundant literature on the occurrence and extent of emissions leakage was already referenced in Section 2. Similarly, knowledge and innovation spillovers – of which only specific examples were cited above – have seen fertile discussion in economic scholarship, which treats it as the most important market failure aside from the unpriced externality of GHG emissions (Jaffe, Newell, and Stavins, 2005). Here, research has affirmed that innovation in low-carbon technologies is costly and creates benefits to society over time and space that are not priced into their delivery (Gillingham and Stock, 2018); this inability to capture private returns that reflect the full value of innovation, in turn, prevents optimal investment in research, development and deployment of low-carbon technologies (Margolis and Kammen, 1999; Gallagher, Holdren, and Sagar, 2006). Policy interventions that incentivize the supply of or demand for low-carbon technologies can accelerate the technology learning curve to a point where learning by doing and economies of scale effects – reflected in deepening supply chains, growing competition, and managerial, regulatory and engineering optimization – bring down their cost, as has been shown for solar energy (Kavlak, McNerney, and Trancik, 2018; Matsuo, 2019; Nemet, 2019), wind energy (Söderholm and Klaassen, 2007; Aflaki, Basher, and Masini, 2021) and battery storage (Stephan, Anadon, and Hoffmann, 2021; Ziegler, Song, and Trancik, 2021; Noll, Steffen, and Schmidt, 2023). Several studies have also highlighted the importance of innovation and trade in renewable energy technologies, notably through inducement effects generated by foreign demand (Verdolini and Galeotti, 2011; Herman and Xiang, 2022).

Policy spillover effects have likewise seen growing interest in academic scholarship, albeit under different labels, such as policy diffusion and transfer. One body of research, for instance, has examined the conditions and prospects for international diffusion of carbon pricing and other climate policies (Dolphin and Pollitt, 2021; Linsenmeier, Mohommad, and Schwerhoff, 2022b, 2023). In the context of discussions on emissions leakage, the more recent emergence of concrete proposals for border carbon adjustments and adoption of the European CBAM has also stimulated research building on earlier studies about the strategic value and game theory of unilateral restrictions (Helm, Hepburn, and Ruta, 2012; Böhringer, Carbone, and Rutherford, 2016) to assess the policy spillover effects on trade partners through accelerated carbon pricing roadmaps (Clausing *et al.*, 2024; Mehling, Dolphin, and Ritz, 2024). In the international realm, another strand of work has explored opportunities for a strategy that combines restrictive measures, such as border carbon adjustments, with coordinated support for technological innovation to manage negative and leverage positive externalities (Di Maria and Smulders, 2005; Maria and van der Werf, 2008).

While these international spillover effects are likely the most important ones in the context of climate action, other work has identified additional manifestations of climate-related spillover effects. With his notion of a "Green Paradox", for instance, Sinn (2012) posited the existence of a temporal spillover, where anticipation of future climate policy adoption accelerates current emissions as producers exploit resources before policy constraints limit their ability to do so (van der Ploeg and Withagen, 2015). Sectoral or regional spillovers, such as a "waterbed effect" observed in the EU ETS and relocation effects observed at the state level in the U.S., illustrate how flawed policy design or insufficient coordination across policies can result in emission merely shifting across contexts, negating overall benefits in a manner similar to emissions leakage (Eichner and Pethig, 2019; Fankhauser, Hepburn, and Park, 2010; Goulder and Stavins, 2011; Rosendahl, 2019). Similarly, growing penetration of renewable energy sources in electricity generation can have spillover effects across interconnected electricity markets, affecting the value of these resources (Stiewe *et al.*, 2024). As experience with policy interventions, data availability and research designs have improved over time, the study of behavioral spillover effects – such as effects determining the political acceptability of climate policies (Steinhorst and Matthies, 2016), or the rebound effect observed as a result of improved energy efficiency (Berkhout, Muskens, and W. Velthuijsen, 2000; Gillingham, Rapson, and Wagner, 2016) – has likewise proliferated.

Again, it would be impossible to capture the full breadth and diversity of relevant research on climate-related spillover effects in this discussion paper, but the foregoing literature review has sought to offer a first mapping of this burgeoning and heterogeneous field. What becomes clear from the mapping exercise, however, is that spillover effects can be positive or negative for climate action, either enhancing decarbonization efforts – for instance through technology or policy diffusion – or undermining these through carbon leakage, accelerated resource exploitation, or the foregoing waterbed effect. What is more, some spillover effects are intended, resulting from deliberate policy design, while others emerge unexpectedly due to complex system interactions (Fuenfschilling and Binz, 2018). And finally, as in other issue areas, climate-related spillover effects can manifest themselves in various contexts, across time horizons, geographies, sectors, markets, technologies, companies, or behaviors. The table below (Table 1) attempts to summarize these varieties of spillover effects across different contexts, with examples and an indication of whether the spillover effect in question tends to benefit or harm progress on decarbonization.

Context	Example	Description	Climate Impact
Time Horizons	Green Paradox	Increase emissions in the near term due to anticipated regulation	Harmful
Geographies	Emissions Leakage	Emission shifts across geographies due to policy interventions	Harmful
	Policy Diffusion	Adoption of mitigation policies across geographies	Beneficial
	Technology Diffusion	Adoption of clean technologies across geographies	Beneficial
Markets	Price Effects across Interconnected Energy Markets	Changes in value of renewable energy resources due to growing penetration across markets	Harmful
Sectors	Waterbed Effect	Emission shifts across sectors due to policy interventions	Harmful
Companies	Knowledge Spillovers	Innovation and learning by doing benefits shared across firms	Beneficial
Functions	Functional Spillovers	Political integration	Beneficial
Knowledge	Technology Spillovers	Innovation effects transmitting across different technologies	Beneficial
Behaviors	Peer Effect	Changes in social norms or motivation	Beneficial
	Rebound Effect	Efficiency gains stimulate higher energy use	Harmful

Table 1: Types of climate-related spillover effects described in the literature, across contexts and with tentative climate impact

3.3 Political Economy Dimensions of Climate-Related Spillover Effects

When examining these spillover effects and the types of policies that tend to cause them, a pattern with distinct political economy implications emerges. Policies that impose a private cost on emissions, such as carbon pricing or performance and technology standards, tend to create negative spillovers, including emissions leakage and distortions such as the waterbed effect, where gains in one area are offset by losses in another (WTO *et al.*, 2024). Some positive spillovers can also emerge from these types of carbon constraints, for instance innovation effects (Porter and van der Linde, 1995), but they tend to be less pronounced (Taylor, 2012; Calel, 2020). In contrast, policies that socialize the cost of decarbonization, such as subsidies for clean energy or public investment in research and development, tend to generate positive spillovers (WTO *et al.*, 2024). These policies can accelerate the spread of low-carbon technologies, create new markets, and build constituencies of support for more ambitious climate action, although they also risk distorting markets, creating a fiscal burden, and generating distributional impacts (Borenstein and Davis, 2016; Clausing and Wolfram, 2023).

From a political economy perspective, the former category of constraining policies often faces political resistance because these generate immediate and concentrated costs while benefits are diffuse and only accrue in the future (van der Linden, Maibach, and Leiserowitz, 2015; Furceri, Ganslmeier, and Ostry, 2023). Emitters will prefer to let others bear the costs of mitigation – a public good – while still enjoying its attendant benefits (Olson, 1965; Nordhaus, 2015). What is more, the costs cut across constituencies, from consumers and producers to labor and capital as well as political left and right coalitions (Newell and Mulvaney, 2013; Juhász and Lane, 2024), empowering opponents who are able to more easily mobilize against and veto climate policies (Bayulgen and Ladewig, 2017; Meng and Rode, 2019; Mildenberger, 2020). By contrast, the latter category of support policies generally enjoys a more favorable political economy, as the benefits are more immediate and concentrated, allowing policy makers to target them at key stakeholders, while the costs are spread across the broader economy (Cullenward and Victor, 2020; Meckling and Karplus, 2023). Distributional conflict between winners and losers explains political behavior of disruptive and incumbent actors (Aklin and Mildenberger, 2020), but public surveys and opinion polls confirm that this observation extends into the broader population (Rhodes, Axsen, and Jaccard, 2017; Fairbrother, 2022).

Despite a generally more favorable political economy, however, it bears noting that policies which socialize the cost of decarbonization suffer from other constraints that limit their ability to sustain the necessary economic transformation on their own. When implemented in the form of public subsidies, they commit considerable resources and entail a burden on public budgets, making them harder to sustain in a context of high stocks of public debt, large structural budget deficits, and rising interest rates. Where technology support policies are financed through redistribution of cost across consumers, such as electricity ratepayers, they add to cost inflation. Both approaches risk being regressive (Borenstein and Davis, 2016; Böhringer, García-Muros, and González-Eguino, 2022), and come with other risks, such as channeling resources into less efficient or unproven technologies, crowding out private investment, and nurturing rent-seeking behavior and reliance on governmental support rather than genuine market competitiveness (Lincicome and Zhu, 2021). Constraining policies that increase the cost of emissions remain essential to more rapidly crowd out incumbent technologies, ensure greater cost effectiveness, and overcome fiscal constraints (Jakob and Overland, 2024).

From this dynamic follows the possibility of a virtuous policy sequence, in which more popular support policies targeting specific technologies help lower political resistance against broader and more efficient policy options such as carbon pricing. By creating the infrastructure, technologies, and political coalitions necessary for decarbonization, interventions that socialize abatement costs can initiate a virtuous policy cycle through a threefold dynamic: by driving down the costs of mitigation technologies, they reducing the economic burden of decarbonization and make greater policy ambition more palatable (Wagner *et al.*, 2015; Schmidt and Sewerin, 2017; Blanchard, Gollier, and Tirole, 2023); they build supportive constituencies in the form of new industries and workers that benefit from climate policies and are more likely to support further action (Meckling, Sterner, and Wagner, 2017; Pahle *et al.*, 2018); and they ultimately pave the way for policies that impose private costs on emissions as previous economic and political barriers diminish, a pattern of policy sequencing that has been affirmed by empirical research (Linsenmeier, Mohommad, and Schwerhoff, 2022a).

Spillover effects allow this virtuous dynamic to extend beyond jurisdictional boundaries, supporting a sequence in which domestic policies drive down the cost of mitigation globally by accelerating the technology learning curve can also improve the prospects of subsequent diffusion of climate policies that otherwise face greater political economy constraints, such as carbon pricing. Through appropriate policy design, for instance by including incentives for adoption of carbon pricing systems in trade partner countries (Clausing *et al.*, 2024; Mehling, Dolphin, and Ritz, 2024), this process of diffusion can be further accelerated through a targeted policy spillover effect. Over time, this could create opportunities for a shift from excessive reliance on distortive and fiscally burdensome policies to a more cost effective and equitable policy paradigm, such as that proposed by Parry *et al.* (2021) for an international carbon price floor with differentiated tiers of carbon pricing aligned with levels of development or income.

4. CASE STUDY: INDUSTRIAL POLICY IN THE EUROPEAN UNION AND THE UNITED STATES

While other actors, such as China, have arguably had a greater aggregate impact on the prospects of global decarbonization through the sheer scale of industrial policies it has deployed, recent climate policy trajectories in the United States and the European Union offer a compelling case study for the role of spillover effects in policy design and implementation. Historically, the U.S. has often been at the forefront of pioneering climate policy ideas, many of which Europe has subsequently adopted and elaborated through consistent implementation. An impressive demonstration of policy learning and diffusion, this dynamic has resulted in a series of ironic reversals that have earned the EU the distinction of being a global leader on climate action, steadily increasing the ambition of its climate policies through internal and external frictions (Kulovesi and Oberthür, 2020; Dupont *et al.*, 2024), while the U.S., by contrast, has become perceived as an at best unreliable – and at worst undesirable – partner in global climate cooperation (Kemp, 2017). In the latest iteration of this transatlantic spillover dynamic, the U.S. has embraced industrial policies as a necessary condition for political support and durability of its decarbonization efforts, which – by virtue of its economic and political might – has precipitated a global paradigm shift in the policy instruments chosen to drive climate progress alongside economic and strategic priorities. The following subsections trace this trajectory.

4.1 A Study in Irony: Evolving Policy Paradigms Across The Atlantic

One of the earliest instances of this transatlantic exchange is the acceleration of renewable energy deployment through feed-in tariffs, which guarantee renewable energy producers a fixed payment for the electricity they generate and thereby incentivize investment by ensuring a stable revenue stream above market rates over a set period (Mendonça, 2007). The concept originated from a provision in the U.S. Public Utility Regulatory Policies Act (PURPA) of 1978, which required utilities to purchase power from small producers, including renewable energy sources (95th Congress, 1978). Due to its design, which limited remuneration to the avoided cost of utilities, PURPA was unable to drive meaningful uptake of renewable energy. European states drew inspiration from this model, however (Nemet, 2019), and in the 1990s Germany implemented a feed-in tariff system (StrEG, 1990), which it subsequently strengthened and expanded (EEG, 2000). By guaranteeing grid integration and offtake of renewable energy at attractive rates, this policy decision catalyzed a substantial expansion of solar power in Germany (Lauber and Mez, 2004; Hake *et al.*, 2015), rapidly turning that country into the largest solar market in the world (Nahm, 2021). As already described in Section 2 above, the positive spillover effects were profound, creating an induced demand pull that drove technological advancements and significant cost reductions in renewable energy technology (Huang *et al.*, 2016; Buchholz, Dippl, and Eichenseer, 2019), and that enabled deployment of solar photovoltaic generation around the world at levels that far exceeded its deployment within Germany (Gerarden, 2023). What is more, the perceived success of the German policy experience prompted the diffusion of feed-in tariff policies across Europe and even a growing number of developing countries (Huenteler, 2014), while in the U.S. it only saw deployment in a limited number of subnational jurisdictions (Davies, 2012).

Similarly, carbon pricing was initially advocated by the U.S., but ultimately found its true proponent in the EU. During the Clinton administration, a proposal for a comprehensive British Thermal Unit (BTU) tax was introduced in Congress (Erlandson, 1994); it would have applied an energy tax with a border adjustment mechanism to address competitiveness concerns, a feature that was censored at the time by the EU as an unfair measure in violation of international trade rules (Jackson, 1993; Pitschas, 1995). Likewise, during the third session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto in 1997, the U.S. delegation sought support for a flexible market mechanism in the Kyoto Protocol to achieve emission reduction targets at least cost (Oberthür and Ott, 1999), while Europe was initially hesitant about such market-based instruments, favoring fiscal or regulatory approaches instead (Hardy, 2006; van Asselt, 2010). Ironically, while political gridlock in the U.S. prevented passage of the BTU tax and also led to its eventual withdrawal from the Kyoto Protocol (Rosenzweig, 2016), the EU has not only embraced carbon pricing, but is continuously expanding this policy option.

Launched in 2005, the EU Emissions Trading System (EU ETS) began as the largest carbon market in the world and has remained a central pillar of European climate policy (Delbeke, 2006; Meadows, Slingenberg, and Zapfel, 2015). Since its adoption, and as part of the "Fit for 55" package of legislative measures, the EU has approved the expansion of the EU ETS to additional sectors, introduced a second emissions trading system (ETS2) for transportation and heating fuels, and begun implementing a CBAM that will impose a carbon price on certain imported goods to prevent emissions leakage (Schlacke *et al.*, 2022; Mehling and Ritz, 2023). At this point, the EU has clearly assumed a global leadership position on carbon pricing, engaging in active outreach and technical assistance initiatives through bilateral and multilateral channels (Biedenkopf and Torney, 2015; Biedenkopf, 2016; Wettestad, Gulbrandsen, and Andresen, 2021). Initial European opposition to a border carbon adjustment proposed by the U.S. has likewise since given way to the highly visible passage of the first major iteration of this controversial policy approach in the form of the CBAM.

This same pattern of transatlantic policy spillover has continued with the advancement of a "Green New Deal", a notion that first emerged in U.S. politics during the discussion of policy responses to the economic and financial crisis, resulting in passage of the American Recovery and Reinvestment Act (ARRA) of 2009 (111th Congress, 2009), and emerged again a decade later in a resolution adopted by the House of Representatives (Ocasio-Cortez, 2019). These initiatives aimed to stimulate the economy through significant investments in clean energy and infrastructure while addressing climate change and social equity. In 2019, the EU followed with its own "European Green Deal", a far-reaching strategy aimed at making Europe a sustainable and climate neutral continent by 2050 (European Commission, 2019). While the U.S. Green New Deal resolution, like earlier initiatives, never advanced to implementation, the European Green Deal has catalyzed a transformation of such sweeping scale that it, too, is raising questions about the spillover effects it might engender. Aside from positive spillover effects already mentioned earlier, which stand to accelerate the diffusion of clean technology and more ambitious climate policies, the European Green Deal could also contribute to environmental impacts in third countries that "far exceed the ecological benefits" of the European Green Deal itself, including displaced emissions from land use that have been estimated to be almost 250% larger than the domestic emission reductions achieved by the EU agricultural and forestry targets (Zhong *et al.*, 2024).

4.2 Spillovers Beget Spillovers: The Industrial Policy Turn

Most recently, the U.S. has seen a shift towards industrial policy with the passage of landmark legislation, notably the Inflation Reduction Act (IRA) of 2022 (117th Congress, 2022b), the Infrastructure Investment and Jobs Act (IIJA) of 2021 (117th Congress, 2021), and the CHIPS and Science Act (117th Congress, 2022a). These acts represent substantial government intervention through grants, loans, tax credits, and other incentives to accelerate decarbonization, strengthen domestic manufacturing, and enhance technological competitiveness. In response, the EU, itself no stranger to industrial policy, has introduced a Green Deal Industrial Plan (European Commission, 2023), leading to passage of the Net Zero Industry Act (European Union, 2024b) and the Critical Raw Materials Act (European Union, 2024a). Much uncertainty has surrounded the precise extent of government support for decarbonization under current industrial policies on both sides of the Atlantic, but there is little question that these represent historical investments in the low-carbon transition (Bistline, Mehrotra, and Wolfram, 2023; Kleimann *et al.*, 2023; Aldy, 2024).

Once again, the reversal of roles reveals a profound irony. For decades, the U.S. championed free-market capitalism, positioning itself as a counterpoint against the centrally planned economies of the former Soviet Union and other communist or socialist states. This "Washington Consensus" is currently undergoing a process of historical recalibration, however: fundamental parameters of globalization and free trade are facing scrutiny, along with calls for a reversal of a longstanding trend towards trade liberalization. Despite its evidenced benefits for productivity (Alcalá and Ciccone, 2004) and economic growth (Frankel and Romer, 1999), declining global inequality (Milanovic, 2022), and environmental sustainability (Antweiler, Copeland, and Taylor, 2001), free trade has met with growing disenchantment precipitated by the unequal distribution of benefits and a perception that it has contributed to job displacement, a weakened industrial base, and loss of cultural identity in affected regions (Roberts and Lamp, 2021).

From the perspective of spillover effects, these policy shifts have multifaceted implications with unclear net outcomes. U.S. investments in clean energy and technology through the IRA and related acts are expected to drive innovation, reduce costs, and stimulate advancements in emerging technologies, with fundamental global implications (Fournier *et al.*, 2024). Research suggests that the IRA could not only help significantly reduce the distance between forecast emissions levels and the U.S. Nationally Determined Contribution (Bistline *et al.*, 2023; Jenkins *et al.*, 2023) while already evidencing signs of a resurgence in U.S. manufacturing (Bermel *et al.*, 2023), but it is also expected to lower the costs of clean technologies, benefiting other countries through knowledge diffusion and technology transfer, and over time unlocking greater deployment of clean technologies outside the U.S. than within its borders. One study has estimated that, on a cumulative basis, the incentives included in the IRA for certain emerging climate technologies could reduce 2.4-2.9 tons of emissions outside the U.S. for every ton reduced within the U.S. (Kate Larsen *et al.*, 2023), whereas another study expects incremental global cost reductions from capacity and learning rate effects induced by the IRA to reach up to 25% by 2030 (BCG, 2022).

There are, however, also concerns about potential negative impacts of the reliance on industrial policies for the scale and pace of decarbonization. Aside from the drawbacks typically associated with public support policies, such as their fiscal burden, inframarginal effect, and risk of locking in dead-end technologies (see Section 3.3 above), incentives in the IRA also contain provisions that favor domestic production, such as local content requirements and tax credits tied to manufacturing within the U.S. These, in turn, have prompted tensions to flare up with trading partners, who view such provisions as unfair or protectionist (Gründler *et al.*, 2023), and are in some cases already pursuing judicial remedies (WTO, 2024). Similarly, the rapid expansion of distortive subsidies has been criticized for altering trade and investment flows, detracting from the value of tariff bindings and other market access commitments, and undercutting public support for open trade, thereby harming growth and living standards (IMF *et al.*, 2022). More generally, a profound shift in the orientation of the U.S. economy towards strategic rivals such as China has resulted in a changing emphasis from market openness to greater autonomy, as it reassesses the risks associated with economic interdependence and strives for more resilient supply chains and reduced dependence on foreign suppliers (Sullivan and Harris, 2020). Consequently, it has embraced concepts such as "friendshoring" and "de-risking" (Yellen, 2023), and expanded the use of trade remedies against foreign producers of low-carbon technologies to protect domestic industries while diversifying supply chains (Bown, 2023). Overall, the combination of unprecedented public investment, restricted trade flows and a trend towards geographic isolation through localization incentives has been described as one that could substantially "raise aggregate costs of collective ambition" (Noll, Steffen, and Schmidt, 2024).

Although the EU has, by comparison, pursued a more open industrial policy that focuses on import diversification rather than prioritizing domestic manufacturing, it has also chosen to deploy measures that will erect barriers to international flows of low-carbon technologies, such as indicative benchmarks for domestic manufacturing in the NZIA and its own trade remedies against certain technology imports. A case in point is the CBAM, which is an instrument to address a negative spillover – emissions leakage – yet can itself yield both positive and negative spillover effects. With its adoption, the EU may already be contributing to a profound acceleration in the diffusion of carbon pricing across major trade partners (Delbeke and Vis, 2023; Clausing *et al.*, 2024). Like other spillover effects, this policy diffusion effect could ultimately result in an extension of carbon pricing to a volume of emissions that is orders of magnitude greater than the embedded emissions directly covered by the CBAM itself (Mehling, Dolphin, and Ritz, 2024). Still, as it imposes an additional cost on the international trade in goods, the CBAM has been met with extensive criticism for interfering with trade flows and disadvantaging foreign products (Øverland and Sabyrbekov, 2022). Developing countries, in particular, have expressed concerns about the potential economic impacts and fairness of the CBAM they stand to endure (Eicke *et al.*, 2021; Perdana and Vielle, 2022; Magacho, Espagne, and Godin, 2023). Such tensions risk escalating into trade disputes, and could also undermine global cooperation on climate change. Indeed, during the 28th Session of the Conference of the Parties to the UNFCCC in December 2023, a coalition of major emitters – Brazil, South Africa, India and China (BASIC) – requested that "unilateral and coercive" trade measures such as the CBAM be included in the summit agenda, noting that they jeopardize trust and "violate the objectives and principles of the Convention and its Paris Agreement, and seriously undermine multilateral cooperation" (Brazil, 2023).

Political and legal risks are not the only headwinds facing CBAM implementation; Significant technical complexities and capacity constraints could likewise compromise its ability to address the negative spillover effect of emissions leakage (Böhringer *et al.*, 2022; Siskos and Saush, 2023), and have already resulted in compliance shortfalls during the first reporting cycle (European Commission, 2024; Hancock, 2024). Regulatory loopholes and the risk of circumvention through resource shuffling and transshipment or strategic policy responses, such as export subsidies to restore the competitive advantage of affected producers, could further undermine the effectiveness of the CBAM (Zachmann and McWilliams, 2020). While jurisdictions implementing border carbon adjustments can try to identify and counteract such circumvention practices, the empirical record of economic and financial sanctions as well as trade remedies suggests that evasion remains a persistent challenge (Forganni and Reed, 2019; Demarais, 2022). Research on the first operational border carbon adjustment, the Californian inclusion of imported electricity in its subnational emissions trading system, suggests widespread deployment of avoidance practices, essentially negating the environmental benefits from including electricity imports (Bushnell, Chen, and Zaragoza-Watkins, 2014; Caron, Rausch, and Winchester, 2015; Pauer, 2018).

4.3 Escaping the Spillover Spiral: Risks of the Industrial Policy Paradigm

By erecting new barriers to trade and accelerating fragmentation of the global economy, the rise of industrial policies in both the U.S. and the EU highlights the delicate balance between pursuing domestic climate objectives and managing international spillover effects. Faced with a highly polarized domestic demographic, susceptibility for populist messaging, and persistent legislative gridlock, the U.S. has had to forego flexible market incentives such as carbon pricing and instead opted for sweeping government intervention in the form of public investments that far outpace earlier fiscal incentives and other support, along with judicially vulnerable reliance on administrative rulemaking (Dotson and Maghamfar, 2023). Conversely, Europe, traditionally more receptive for statist market interventions, has still held on to its advocacy of carbon pricing, even cautioning against the intensity of the U.S. foray into industrial policy; still, under the pressure of rising concerns about the competitiveness of its domestic industries, it has also begun to shift its policy paradigm towards greater autonomy in what has been described a "geopolitical turn" (McNamara, 2023). Not for the first – and probably not for the last – time, climate action has given rise to escalating tensions across the Atlantic, prompting a U.S. legislator to accuse the European Union (EU) of going "rogue" (Cramer, 2022) and a European head of state to warn of "choices that will fragment the West" because they "create such differences between the U.S. and Europe" (Abutaleb, Noack, and Olorunnipa, 2022).

Altogether, the increased reliance on trade-related climate measures reflects a broader trend. In an effort to map the use of these trade-related climate measures, UNCTAD has identified 680 such measures in the Nationally Determined Contributions (NDCs) submitted to date (UNCTAD, 2023a), and more than 2366 climate-related non-tariff measures (NTMs) affecting 26.4% or US$ 6.5 trillion of world trade (UNCTAD, 2023b). While these policies often seek to address valid concerns, such as supply chain vulnerabilities, and can generate their own positive spillover effects, they also carry the risk of hindering the free flow of goods, services, capital and knowledge that have been essential for past spillover benefits such as the diffusion of technological innovation (Coe and Helpman, 1995; Herman and Xiang, 2022). Noll *et al.* (2024) trace how the trade restrictions included in the IRA can create barriers to innovation and thus learning effects, leading to cost increases and stymied adoption of low-carbon technologies as domestic producers are forced to reorganize supply chains and move production facilities, but also slowing learning processes as these producers are isolated from knowledge held by foreign producers. In their analysis, depending on technology maturity, price increases due to tariffs and restricted learning can nearly double the cost of critical decarbonization options for the implementing countries.

Increasing fragmentation of the global economy could thus seriously impede the development and diffusion of clean technologies at scale, many of which rely on complex global supply chains that are currently dominated by China (Helveston and Nahm, 2019; Goldthau and Hughes, 2020). With their domestic manufacturing targets and commitment to repatriation of supply chains, the U.S. and the EU not only risk significant welfare losses (Cerdeiro *et al.*, 2024), but also stand to increase the cost and reduce the pace of their own and of the global energy transition (Davidson *et al.*, 2022; Helveston, He, and Davidson, 2022; Lewis, 2024). Going forward, rising concerns about the resilience of domestic industries in the face of international competition, as articulated, for instance, in a recent landmark report on the future of European competitiveness (Draghi, 2024), are likely to prompt continued deployment and potentially expansion of such trade restrictions. While this warrants careful monitoring of how industrial policy on both sides of the Atlantic affects positive spillover effects, it also highlights the challenges that any effort at managing such spillover implications will face: positive local effects of industrial policies, such as employment and economic growth, cannot simply be sacrificed without undermining support for increased climate policy ambition; nor can valid concerns about distributional effects and strategic vulnerabilities from unrestricted globalization simply be ignored. Far from simple, "maximising positive spillovers … and minimising negative ones" (OECD, 2024b) will require delicate balancing of competing objectives and navigating difficult tradeoffs.

5. MANAGING SPILLOVER EFFECTS THROUGH POLICY DESIGN AND COOPERATION

As shown by the preceding analysis, spillover effects play a pivotal role in determining the effectiveness of climate action, often surpassing the magnitude of direct impacts. Developments in one context have been shown to have momentous implications in another, including positive and negative, as well as intended and unintended spillover effects. At the same time, the foregoing sections have also documented a paradigmatic shift in the policy approaches currently deployed for decarbonization, with increased reliance on instruments of industrial policy that risk impeding international trade and the flow of goods, services, capital and knowledge across borders. While this industrial policy turn can be rationalized with economic and strategic concerns as well as the need to secure political support for ambitious decarbonization mandates, it has implications for the role and management of spillover effects. Some spillover effects, such as emissions leakage, may become less pronounced as a result of the emerging barriers to trade, yet other beneficial spillover effects, such as the development and diffusion of low-carbon technology, could be inhibited by rising costs and restricted learning effects. In the current context of unparalleled climate urgency, governments cannot afford policy choices that risk costly or unexpected consequences at home or abroad (OECD/EC-JRC, 2021). Understanding, measuring and managing spillover effects is therefore essential to harness their benefits while mitigating adverse outcomes (Schmidt-Traub, Huff, and Bernlöhr, 2019).

In all this, enhanced cooperation and coordination to better align policies, prevent excessive barriers to trade flows, and ensure that collective efforts contribute effectively to global decarbonization goals will be essential. Scenarios involving greater cooperation have been shown to "not only expand the reach of global spillovers but also balance policy costs and herald positive signalling effects for industry players, manufacturers, as well as consumers" (Noll, Steffen, and Schmidt, 2023). Indeed, collaborative dynamics have been credited as a critical factor in enabling the scaling up and deployment of low-carbon technologies across the world (Nahm, 2021), and more recent policy simulations have underscored the benefits of coordination in innovation policy, potentially increasing global returns by over 60% (Martin and Verhoeven, 2023). What is ultimately needed, therefore, is a strategic approach to elicit positive spillovers and limit negative ones through refined policy design and enhanced international cooperation. Some elements of such a possible approach are outlined in the following subsections.

5.1 Reflecting Spillover Effects in Policy Planning and Evaluation

First, there is an urgent need to refine research methods to more systematically understand and measures spillover effects. Accounting for spillover effects is rendered challenging because data are limited, causal linkages are hard to establish, and political interests and priorities are diverse and, in many cases, competing (OECD/EC-JRC, 2021). Measurement of international spillover effects is not commonly undertaken by national statistical offices, and national and international databases are often inconsistent, so that spillovers are not systematically reflected in national and international statistics (Schmidt-Traub, Huff, and Bernlöhr, 2019). To better integrate spillover considerations into data collection and policy planning and evaluation, more holistic methodologies and metrics could help policymakers better evaluate positive and negative spillovers, providing a more comprehensive understanding of the costs and benefits associated with climate action.

Different methods for improved assessment of spillover effects have been proposed, including top-down Multi-Regional Input-Output (MRIO) that combine internationally harmonized input-output tables and trade statistics for sectors or groups of products and services; bottom-up Life Cycle Assessment (LCA) to assess the environmental impact of individual products and their production processes across geographic and temporal scales; Material-Flow Analyses (MFA) tracking specific material flows along supply chains and across countries; and hybrid approaches that seek to combine advantages of the different methods in an effort to overcome individual constraints (Schmidt-Traub, Huff, and Bernlöhr, 2019). Other approaches recommended to this end have included experimental and non-experimental research designs (Angelucci and Di Maro, 2016), input-output tables and a lifecycle perspective to better track transboundary impacts along international value chains, as well as consumption-based accounting to help understand and evaluate the transboundary effects of consumption patterns (OECD/EC-JRC, 2021). Initiatives such as the Climate Club and the IFCMA can help develop and promote the emergence and broad adoption of more streamlined practices and data sharing, as they are already doing with ongoing initiatives on more accurate quantification of the carbon intensity of goods (OECD, 2024c) and enhanced transparency about national climate measures (Nachtigall *et al.*, 2024).

5.2 Instrument Choice in the Presence of Spillover Effects

Second, domestic policy design should actively incentivize positive spillovers. Existing literature demonstrates that innovation spillovers from domestic climate policies can offset emissions leakage, effectively amplifying global decarbonization efforts (Gerlagh and Kuik, 2014). In some cases, policies can even result in negative leakage, where foreign emissions reductions exceed domestic abatement (Baylis, Fullerton, and Karney, 2014). However, maximizing these benefits requires some degree of openness to international trade and collaboration, as beneficial spillovers are significantly greater when borders are open (Coe and Helpman, 1995). Indeed, a more open industrial policy strategy can "achieve faster and potentially more significant cost reductions through spillovers of domestic deployments to other regions, thereby enhancing global learning" (Noll, Steffen, and Schmidt, 2024).

Policy makers should therefore avoid excessive deployment of barriers, such as local content requirements (Stone, Messent, and Flaig, 2015), restrictive localization targets, or static tariffs applied across entire product groups, opting instead for more flexible approaches that incentivize technology diffusion while balancing domestic interests, such as tariff rate quotas or tradable import rate quotas (Rom, 1973). Similarly, minor changes to policy design can help leverage beneficial policy spillovers, as has been observed with the CBAM Regulation, whose Article 9 is likely responsible for encouraging a dramatic acceleration in carbon pricing developments across major EU trade partners (Mehling, Dolphin, and Ritz, 2024). Recognition of this spillover effect may have prompted the inclusion of a relevant provision on recognition of foreign "policies which impose explicit costs" in the Clean Competition Act when it was reintroduced in the U.S. Senate in December 2023 (Whitehouse, 2023).

5.3 Cooperative Management of Spillover Effects

Third, the rise of unilateral industrial policies and subsidies calls for enhanced international cooperation to prevent retaliatory actions and potential subsidy wars. In the absence of active coordination, trade remedies such as anti-dumping measures, countervailing duties, and trade disputes provide costly and contentious *de facto* resolution of such conflicts (Voituriez and Wang, 2015). Collaborative efforts can focus on joint research and development initiatives, recognizing that cooperation on innovation can influence spillover effects positively (El-Sayed and Rubio, 2014). Fora like the G7 Climate Club and the IFCMA offer opportunities to discuss spillover effects and harmonize domestic policy interventions. Informal stakeholder and expert groups can elaborate recommendations for principles and best practices around the design and implementation of trade-related climate measures (TESS, 2023). Policy recommendations from the joint report by WTO *et al.* (2024) thus include improved international coordination to align carbon pricing systems and develop transparent emissions metrics and standards to reduce transaction costs, promote fair competition and minimize potential trade tensions that may arise from disparate national policies, as well as enhance cooperation on technology development from the initial stages of research and development to deployment at scale. Additional steps toward enhanced coordination could include development of international patent pools to facilitate technology transfer while protecting intellectual property rights, and leveraging mechanisms such as Article 6 of the Paris Agreement to incentivize positive spillovers by allowing developed countries to earn credit for providing technologies that help developing nations decarbonize.

Still, there is a delicate balance to maintain in all this, because an exclusive focus on technology cooperation may invite freeriding, while mechanisms such as border carbon adjustments can encourage broader participation but may delay innovation efforts (Helm and Schmidt, 2015). As policy makers and the broader public recognize the role of spillover effects in leveraging the comparative advantage of different geographies, they might be discouraged from supporting low-carbon technologies out of concern that social and economic benefits will accrue to foreign rather than local beneficiaries. To improve alignment of incentives and prevent freeriding effects, countries can explore bilateral and plurilateral cooperation through club architectures that align the interests and incentives of participating countries by offering benefits to which only members have access, and simultaneously imposing penalties for non-compliant members and non-members (Nordhaus, 2015; building on Buchanan, 1965). Such clubs, organized around specific sectors or technologies (Hermwille *et al.*, 2022), could, for instance, help spread the cost of buying down the technology learning and experience curve (Malhotra and Schmidt, 2020) or secure diversified supply chains of critical components and materials. To gain traction in the current geopolitical context, such cooperation will have to be mutually beneficial and advance the national interest of all parties involved (Deese, 2024). Importantly, however, it must also observe ensure conditions for a just transition in developing countries, enabling them to move up the low-carbon technology value chain through local production (Bradlow and Kentikelenis, 2024). Historically, the greatest successes in industrial upgrading have been achieved through establishment of local innovation centers based on transfers of knowledge and training (Lema and Lema, 2012). Transfers of both finance and low-carbon technology from developed countries – which account for 80% of all relevant innovations and 70% of all exports – to developing countries will therefore remain essential, and can help shift the global industrial policy trajectory from a "green race" to a "green division of labor" (Lachapelle, MacNeil, and Paterson, 2017; Rosenow and Mealy, 2024).

6. CONCLUSIONS

As this Discussion Paper has argued, spillover effects can impede or advance climate action. They have enabled some of the greatest successes in climate change mitigation, yet also threaten to undermine accelerating decarbonization efforts. Because they are difficult to define and quantify, they are routinely neglected in the theoretical framing of climate policy instrument choice. Some spillover effects have been extensively studied, while others remain opaque, with scarcely understood causal mechanisms and interactions. Given their scale, which routinely exceeds that of direct effects, epistemic challenges do not justify complacency. In a welcome development, several international bodies have recently begun to elevate spillover effects in their work, but reveal the lack of an overarching conceptual framework in their approach and are politically constrained in the solutions they can propose. This Discussion Paper has therefore suggested a typology of spillover effects, and correlated these with two climate policy approaches that differ substantially in their political economy: interventions that impose a private cost on emissions, and interventions that socialize the cost of climate change mitigation.

Drawing on recent policy developments on both sides of the Atlantic, this Discussion Paper also has shown how spillover effects have influenced past instrument choices, and how those choices are likely to result in new and unintended spillover effects. As Europe, the United States and other major economies chart industrial policy trajectories that threaten to fragment international flows of goods, services, capital, and ideas, they risk exacerbating harmful and impeding beneficial spillover effects, increasing the cost and time horizon of decarbonization. In the current geopolitical context, managing spillover effects to allow spillover benefits while limiting spillover harm will therefore require international cooperation, but such cooperation will also have to strike a careful balance between collective interests and national self-interest to be politically viable. Ideally, by fostering an environment that encourages positive spillovers and mitigates negative ones, nations can collectively enhance the effectiveness of their decarbonization strategies, thereby not only advancing global climate goals but also addressing the geopolitical and economic challenges inherent in the transition to a low-carbon future through a virtuous sequence of climate policy diffusion and implementation.

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