# 7
# Conclusion

For all the urgency surrounding climate change and its potentially catastrophic effects, governments have supported clean energy transitions not just for environmental reasons, perhaps not even primarily so. The tendency to link climate actions with economic goals has not fundamentally changed over the past two decades. In China, the Made in China 2025 Initiative has continued to promote the development of export industries for clean energy technologies. Like China, Germany has begun to pass policies to electrify its transportation sector, not just out of environmental concerns but also to maintain competitiveness of the domestic auto industry. In the United States, debates around the possibility of a Green New Deal have explicitly linked climate policy to broad economic development strategies. In Chapter 2, I showed that political support for public investments required to initiate technological change in the energy sector have long depended on the promise of broader economic benefits, in particular through the creation of domestic renewable energy industries. Against the backdrop of such common political goals, why have nations maintained divergent patterns of industrial specialization and distinct constellations of firms? In the cases examined in this book, governments did not employ fundamentally different industrial policy strategies to support domestic industries, nor did they shield the domestic economy from the forces of globalization to differing degrees.

This book argues instead that the key to explaining the persistent and consequential divergence of national patterns of industrial specialization is an understanding of globalization as primarily a process of collaboration. Globalization allowed for two types of experimental action that enable firms to reap benefits from participating in the global economy: the ability of firms to specialize, thanks to new opportunities for collaboration, and their ability to repurpose existing institutions of the domestic economy. Rather than having to maintain in-house the skills required to develop, commercialize, and produce wind turbines and solar panels, collaboration allows firms to focus on distinct and narrow sets of capabilities. Under these conditions, even when governments aim to create comprehensive national industries, firms respond with narrow competitive strategies that build on existing skills and prior experience in other industries. As I have shown in the empirical chapters, specialization also allows firms to appropriate and repurpose existing institutions in the domestic economy as part

of their effort to compete in new industrial sectors, even when these institutions were originally established to support other sectors of the economy. The impact of collaborative advantage is therefore refracted through distinct institutional legacies, yielding distinct national profiles in the global economy. The concept of collaborative advantage at the heart of this argument reverses the conventional wisdom that has portrayed distinct national political economies as threatened by competition in the global economy. By providing new opportunities for collaboration, globalization allows for persistent and consequential divergence of both domestic institutions and national industrial specializations over time.

## Findings

Political economists have often portrayed globalization as a phenomenon of increasing international competition, one with major consequences for the ability of nations to organize distinct domestic political economies. In my third chapter, I developed a theoretical approach to understanding globalization that positions collaboration firmly at the center of firms' engagement with the global economy. I argued that the forces that have prompted concern about heightened competition also put within reach of domestic firms a far greater range of collaborators with diverse skills and capabilities. German equipment producers were able to partner with Chinese wind and solar manufacturers on R&D projects that required production skills not available domestically. Chinese manufacturers were able to work with US start-ups to access core technologies and focus their R&D efforts instead on scaling the production of such technologies, often on German-made production equipment. The distinct strategies of renewable energy firms in different parts of the world became possible precisely because the firms found ways to work together.

Central to this book is *collaborative advantage*, a concept I use to capture the connection between changes in the global economy and the endurance of distinct national industrial specializations. The presence of collaborative advantage in renewable energy sectors allowed renewable energy to find partners for the development and commercialization of new technologies. On the whole, advances in transportation and information technologies made it easier to forge these partnerships, though establishing such connections was certainly more straightforward for some firms than others. China's manufacturers could lure global partners with the promise of a large and rapidly growing domestic economy. American start-ups often lacked international links and relied on far more informal networks to find counterparts for collaboration. Nonetheless, the very existence of other specialized firms in renewable energy sectors allowed wind and solar firms to access capabilities necessary for the development of new

technologies in global supply chains. Collaboration thereby relieved firms in these postglobalization industries of the need to establish the full range of skills to bring their products to market and freed up new opportunities for specialization.

Those opportunities, in turn, empowered new strategies for entering renewable energy industries, including the decision to repurpose existing domestic institutions and public resources. In choosing strategies to enter the rapidly growing renewable energy sectors in the late 1990s and early 2000s, firms picked technical skills that made use of existing industrial capabilities, could not easily be bought or licensed in global networks, and enjoyed robust support from existing institutions in the domestic economy. German firms seized the opportunity to develop designated production equipment and off-the-shelf components, Chinese manufacturers identified a need for skills in scale-up and mass production, and US firms recognized the invention of new technologies as their leading edge. Of course, not all firms in each economy followed these patterns exactly: multinational firms at times established a broader range of capabilities, primarily through acquisitions of smaller firms. Some specialized renewable energy firms broke with national blueprints, including some manufacturers in the United States, start-ups in Germany, and makers of production equipment in China. Nonetheless, the majority of wind and solar firms focused on innovative manufacturing in China, customization in Germany, and the invention of new technologies in the United States.

Firms relied on the appropriation and repurposing of familiar public resources at the domestic level—many of which were originally established for legacy industries well before the emergence of renewable energy as a viable industrial sector. These institutions retained value in wind and solar industries precisely because they no longer had to support the full range of activities required to invent and commercialize new technologies within national borders. This was perhaps most obvious in the case of China. Chinese manufacturers learned to use the resources of the production economy to capture a sizable share of global markets through manufacturing innovation, even though domestic institutions did not support the invention of new technologies to the same degree. German equipment producers, collaborating with Chinese partners, boldly built on a set of legacy institutions that many saw as threatened by the competitive forces of globalization, including vocational training institutions, a financial sector centered around local banks, and research and development (R&D) support for the traditional Mittelstand of small and medium-sized businesses.

The impact of collaborative advantage is best studied at the level of the shop floor, from the perspective of the firm. In Chapters 4–6 I examined the emergence of a global division of labor, tracking how firms responded to state industrial policies and which public resources became most important to them in this process. By placing the firm as the center of inquiry, I found that they relied on

a far broader range of state-provided resources than is commonly associated with industrial policies for renewable energy sectors. Traditional tools of industrial policy—subsidies, R&D funding, and regulation—allowed the state to mobilize interests behind emerging industries and to encourage firms to enter new sectors. Under conditions of collaborative advantage, however, such sectoral intervention did not fully determine firms' technological specializations. Nor, for that matter, did sectoral industrial policies provide sufficient support to allow them to do so. Rather, firms carved out space for experimentation in their responses to state industrial policies, imagining new ways to specialize and collaborate with others—while at the same time repurposing existing institutions and public resources for application in new industries.

In Germany, where federal policies created large domestic markets for wind turbines beginning in the early 1990s and for solar PV modules beginning in the early 2000s, small and medium-sized suppliers from the machine tools, automotive, and equipment manufacturing sectors entered renewable energy industries in large numbers. Government support for renewable energy markets provided incentives for entry, while collaboration with Chinese manufacturers made it possible for these firms to prioritize narrow, competitive specializations in customization. Skills, training, and labor market institutions, local banks, and an infrastructure for collaborative industrial research supported these firms as they applied their capabilities to new industrial sectors. These supportive institutions had not been established for the purpose of encouraging firms to enter renewable energy industries, of course. But they found new life when they enabled firms from Germany's legacy industries to respond to novel opportunities created by federal energy policies, thereby building new constituents in support of legacy institutions.

Central government policies in China encouraged the emulation of advanced R&D capabilities of foreign companies through R&D funding and by fostering technology transfers from foreign-invested firms. Although domestic wind and solar producers participated in central government science and technology programs, they used government support to establish engineering capabilities in manufacturing. Firms found a helping hand in their endeavors from China's infrastructure for mass manufacturing, which subnational governments often maintained in disregard of central government preferences for advanced R&D. The ability to access components and technologies in global supply chains permitted China's firms to repurpose domestic support for R&D and local policies for manufacturing. The end result was the creation of powerful engineering capabilities in scale-up and commercialization, neither of which had been mastered in other parts of the world.

While wind and solar firms in Germany and China established innovative capabilities very closely linked to production activities, renewable energy firms

in the United States focused on the invention of new technologies, often without locating scale-up and commercialization domestically. Regulatory and tax policies supported the creation of domestic markets, yet industrial policy for renewable energy industries primarily took the form of R&D funding for universities and national laboratories for energy research. Also in the United States, specialization allowed firms to take advantage of legacy institutions. Start-ups made use of institutions for the licensing and commercial spin-off of technologies born of federally funded research—institutions created through series of legislative reforms dating back to the 1980s. But these firms were often unable to access skills in scale-up and mass manufacturing in their home country, requiring them to hunt for global partners in order to bring their technologies to market.

Comparative literatures on innovation often share the notion that innovation occurs in distinct national industrial ecosystems. Such research assumes that firms are relying on the institutional arrangements of the domestic economy to establish different types of innovative capabilities, but it is within the domestic economy firm that resources, capabilities, and market opportunities are combined and coordinated. Such coordination takes the form of tight organizational links between R&D and manufacturing in early stages of product development and relies on the resources of the broader economy to create knowledge within the firm.[1] Although existing scholars part ways over which elements of industrial ecosystems stand as most important for innovation outcomes, most still agree that the capabilities required for innovation are established, combined, and coordinated by firms embedded in the domestic industrial base.

Renewable energy industries have not followed these core assumptions in the literature. In both industries, firms collaborated to develop new products with distant partners, leapfrogging, obviating, or reversing the traditional sequence of innovation activities. In doing so, wind and solar firms circumvented the traditional division of labor between industrialized and developing economies and transcended the national economies expected to anchor and support them. Perhaps counterintuitively, globalization allowed firms to craft such distinct and specialized paths for participation in wind and solar industries. In the United States, start-ups maintained capabilities in the *invention* of new technologies, but rarely developed skills in commercialization and mass production.[2] In Germany, wind and solar firms clustered in the development of production equipment and customized components, offering expertise in *customization*.[3] In China, large wind and solar manufacturers focused on *innovative manufacturing*

[1] Hall and Soskice 2001; Nelson 1993; Vernon 1966.
[2] Knight 2011, 176.
[3] Arbeitsgemeinschaft Windenergie-Zulieferindustrie 2012; Germany Trade & Invest 2010, 2011b.

capabilities required for commercialization and scale-up.[4] National diversity in the structures of production and in firms' industrial strengths did not result from the state's ability to successfully protect the domestic economy from the competitive pressures of globalization or sticky institutions constraining firm behavior. The persistent and consequential divergence of national patterns of industrial specialization emerged from aggregate firm decisions to compete through the augmentation of existing industrial strengths, actively renewing and repurposing domestic legacy institutions and public resources in the process.

## Collaborative Advantage in Comparative Perspective

Three structural conditions enabled collaborate advantage in renewable energy. As I laid out in Chapter 3, these sectors benefited from the presence of potential partners for collaboration in global supply chains, from firms' ability to engage in collaboration owing to flat hierarchies in global supply chains and a lack of incumbent firms that could prevent access for newcomers, and from governments that tolerated firms' divergence from stated industrial policy goals.

As I have argued, these structural conditions are more likely to be present in sectors that developed after the reorganization of the global economy in the 1990s—my central reason for selecting renewable energy industries for this study. The near-simultaneous development of wind and solar industries in China, Germany, and the United States allowed for the emergence of global supply chains that were necessary for specialization. Over time, such specialization became self-reinforcing, as vertically integrated firms would have had to compete with highly specialized firms across the full range of activities to invent, commercialize, and produce new wind and solar technologies. The lack of incumbent firms in renewable energy sectors allowed new entrants to take full advantage of new opportunities for collaboration. As I noted in Chapter 3, incumbents in other sectors often responded to globalization by defending legacy production structures, raising barriers to new competitors, and controlling access to global supply chains. Wind and solar sectors instead found ways to experiment. As a result, large discrepancies often existed between industrial policy targets and the responses of firms, but governments tolerated firms' divergence from their goals.

The structural conditions for collaborative advantage are, of course, not unique to wind and solar. A growing body of research suggests, for instance, that Chinese firms have been able to acquire knowledge-intensive manufacturing capabilities in the auto and electronics sectors, forging similar patterns of global collaboration even in cases where incumbent firms seek to protect

[4] See Nahm and Steinfeld 2014, 294–98.

preglobalization arrangements. In the automobile industry, among others, the engineering capabilities of Chinese firms have allowed them to create products particularly suited for China's "middle market" (based on cost and functionality).[5] Although China's automakers are not outcompeting global incumbents for high-end products, the changes to product designs to reduce cost and optimize functionality are not entirely different from the findings presented here, even if their improvements in design and manufacturing process target mid-tier markets. The ability of Chinese automotive suppliers to build such capabilities marks an unintended consequence of the sequencing of China's economic reforms, which first focused on nurturing domestic manufacturing capabilities before allowing foreign direct investment and trade liberalization.[6] At the same time, Western incumbents, established long before the opening of China's economy to foreign firms in the 1980s, prevented Chinese firms from moving into desirable parts of the supply chain.[7] The impact of collaborative advantage in China's auto sector was therefore limited by the presence of incumbent firms and nonhierarchical forms of industrial organization.

In today's automotive sector, incumbent firms appear to be losing—however gradually—their ability to control global supply chains.[8] Technological change, including the growing importance of electronics in engine control and safety equipment, has made auto manufacturers dependent on collaboration with suppliers who offer expertise that automakers historically did not possess (nor did they need to). These changes have only accelerated in the transition to electric vehicles, which introduced new components, including batteries and electric drivetrains. The division of labor in the electric vehicle sector now bears some resemblance to what I have outlined in the renewable energy sectors, as Chinese firms have applied their capabilities in innovative manufacturing to focus on scale-up and mass production. Relying on the same domestic resources that buoyed aspiring wind and solar manufacturers, Chinese firms now control more than two-thirds of the global production capacity for lithium-ion batteries while rapidly reducing the associated costs.[9]

State goals of building comprehensive industries wholly within national borders—particularly in industries deemed critical to national competitiveness—continue to resemble claims about a "clean energy race" that we heard from governments in the mid-2000s. China's share of global production capacity for electric vehicle batteries is similar in scale to China's role in solar PV, but it presents a far different threat to the legacy industries that form

[5] Brandt and Thun 2010.
[6] Brandt and Thun 2010, 1571.
[7] Brandt and Thun 2016, 88–90.
[8] Sabel and Herrigel 2018, 236.
[9] Helveston and Nahm 2019, 794.

the backbone of advanced industrialized economies elsewhere. In an interview with *The Financial Times*, Bruno LeMaire, France's finance minister, has argued that "the auto industry is vital to Europe's industrial base. But if it has to import batteries, which account for about 40 percent of the cost of an electric vehicle, Europe risks losing the value-added part of the production chain and the technological knowhow that stems from it. . . . Mobility is a matter of sovereignty."[10] As China reemphasizes its goals of technological independence in the Fourteenth Five-Year Plan, the European Union has forged ahead with initiatives to establish a domestic battery industry to reduce reliance on China.[11] If the development of wind and solar technologies is any guide, however, such industrial policy goals are likely to clash with the economic reality on the ground.

While the politics surrounding the global division of labor in the auto industry clearly differed from early renewable energy sectors—advanced industrial economies were fighting for the survival of existing vertically integrated industries rather than competing for future ones—governments faced a similar divergence between state goals and industrial outcomes. Germany has thus far failed to attract significant battery manufacturing despite government goals to reduce dependence on Chinese imports, yet German suppliers are again specializing in production equipment and complex components. A 2019 trip to a solar supplier I first visited in 2011 revealed that the firm had since used its experience in the development of complex production equipment to develop test equipment for electric vehicle engines. As demand for new production equipment in the solar industry had flattened over time, the firm had shifted much of its production to the electric vehicle sector, where it was building equipment for new assembly plants around the world.[12] In the United States, which lost much of its battery manufacturing industry, start-ups have nonetheless developed new battery chemistries that promise to surpass current lithium-ion technologies in performance.[13] This suggests that globalization created new opportunities for collaboration in the automotive sector, yet these changes were more easily perceived as an economic loss when compared to the vertically integrated domestic supply chains of the past. It remains to be seen whether governments will allow for firm experimentation in response to state industrial policies, the third structural condition of collaborative advantage.

The electronics industry has a shorter history than the automotive sector and has witnessed a more wholesale shift of global manufacturing capacity to East Asia.[14] Research on electronics and semiconductor firms in China suggests that

[10] Hall and Milne 2019.
[11] Nahm 2020; Tang 2020.
[12] Author interview, managing partner, Solar PV Supplier. October 15, 2019.
[13] Zaleski 2019.
[14] Pisano and Shih 2009, 2012.

engineering capabilities in manufacturing allowed local firms to improve and reengineer existing products.[15] Similar to the dynamic I describe in the wind and solar industries, electronics and semiconductor manufacturers were able to build such capabilities with the help of local governments, which, due to limited resources, favored investments in the improvement of existing technologies over high-risk technology ventures. Research shows that Chinese firms in these sectors mixed established technologies to come up with new solutions, a tactic that might have to do with the existence of global incumbents in the electronics and semiconductor industries that predated Chinese entrants. Collaborative advantage would predict that such innovation should also be grounded in the ability to access technology in global supply chains and build on the continued support of local governments for mass production. Over time, innovation by Chinese firms in these industries may well turn out to be an integral step along the trajectory from lab to market innovation, as Chinese firms build unique strengths in commercialization and mass production to outcompete manufacturing capabilities in other parts of the world.

This book explains the persistent and consequential divergence of national patterns of industrial specializations by examining China together with two advanced industrialized economies. Comparing the contributions of German and American firms allowed me to identify the role of China's renewable energy manufacturers in collaborative processes of innovation, a role that, in turn, permitted German and Chinese firms to enter the wind and solar industries with highly specialized skills. How do Chinese capabilities in innovative manufacturing stack up against those of other developing economies? Collaborative advantage would predict that firms in other economies should also use collaboration to incrementally build on existing industrial legacies. It is possible that China—with its large domestic market, its extensive support for manufacturing, and its ability to bring partners for collaboration within arm's reach of local firms by attracting foreign direct investment—is uniquely equipped to establish engineering capabilities in manufacturing. But can such upgrading through the repurposing of industrial legacies be replicated in other contexts?

One possibility might be that variations in the existing manufacturing activities of domestic firms affect the specialization of producers. Chapter 4 described how wind and solar suppliers carried Germany's industrial legacy of customization and small-batch production into new economic sectors. Differences in local industrial capabilities, public resources, and institutional support should affect upgrading trajectories in developing economies, as well. In Malaysia, the combination of flexible labor policy and state investments in training institutions attracted semiconductor firms that specialized in making rapid changes to

[15] Breznitz and Murphree 2011; Murphree and Breznitz 2020.

production volumes. Semiconductor firms in Penang took advantage of opportunities for collaboration by building on existing strengths in managing such volatility among local producers.[16] The Malaysian state encouraged local firms to develop skills in chip design and early-stage R&D, yet firms built on existing strengths to respond to niche markets instead. For instance, producers of technology-intensive test equipment for flexible production processes utilized local expertise in rapid scale-up and scale-down of production. Although semiconductor manufacturers who specialized in managing volatility were the early collaborators and customers of such equipment producers, their products were eventually sold into global markets.[17]

Another scenario, and one that possibly applies to a larger number of economies, could be that few industrial capabilities exist locally, or that such capabilities remain concentrated in a few sectors shielded from the broader economy. The central argument of this book implies that in such cases, the establishment of innovative manufacturing skills should be significantly more difficult: even at its best, industrial policy can only mobilize firms to incrementally improve on existing strengths. The framework presented in this study correspondingly suggests that firms in this situation are not without recourse, however: they can access manufacturing capabilities through collaboration and still find pathways into global industries. In Vietnam, for instance, the state spent much of its resources on the state-owned sector, which targeted extractive industries, provided little revenue or skill upgrading, and remained shielded from the broader economy. In spite of these state preferences, a growing number of private sector firms in software and services such as e-commerce moved into global supply chains through higher-value activities, without possessing capabilities in physical manufacturing.[18] These firms creatively redeployed resources and policies aimed at the state-owned sector, relied on investment from overseas Vietnamese, and worked with global partners to move into new industries.

India's strength in software and services without accompanying proficiencies in mass production might represent another case of innovation without production. With half of the population employed in agriculture and a small manufacturing sector that historically struggled to compete despite low labor costs, Indian firms built on their strengths in elite education to enter global supply chains. Sixty percent of India's GDP stemmed from firms in services and software.[19] Possibly as a consequence of weak domestic manufacturing capabilities, Suzlon, a global wind turbine manufacturer headquartered in Pune, entered the wind industry not through capabilities in production, but through aggressive

[16] Samel 2013.
[17] Samel 2013, 71.
[18] Chirot, Anh, and Steinfeld 2012; Chirot 2016.
[19] Iyer and Vietor 2014, 8–13.

foreign acquisitions funded by its founder, a local textile magnate. Established in 1995, Suzlon purchased R&D subsidiaries in Germany and the Netherlands as well as European gearbox, generator, and blade manufacturers by 2007.[20] Recent research on India's solar industry—a key target of Modi's attempts to spur the development of a domestic manufacturing sector—confirm the difficulty of establishing mass production capabilities in this context. Although the absence of domestic legacies in India's mass production likely precluded the possibility of upgrading trajectories akin to China's, collaborative advantage nonetheless opened opportunities for the nation to participate in innovation—through collaboration for firms unable to draw on local manufacturing strengths.[21]

## Prospects for Collaboration

Arguments about national diversity in the global economy are not new to scholars of political economy. Globalization—the increasing interdependence and integration of national economies in global markets—has led many to ask whether competitive pressures, emulation, and the diffusion of best practices in the global economy will ultimately lead to the convergence of national production structures, regulatory institutions, and economic policies. In the 1980s, the weakness of the American economy and the strong performance of firms from Japan and Germany—economies organized around very different relationships between the state, society, and business—raised questions about whether such national differences were here to stay, or whether distinct national practices would eventually give way to global convergence.[22]

Scholars have since pointed to a range of factors that could shield national economies from such pressures. Some have suggested that the importance of domestic markets leaves significant room for continued differences in the organization of production.[23] Others have argued that mutually reinforcing institutional arrangements lead to divergent but stable national political economies, each suitable to different types of production activities.[24] Yet differences in domestic politics and institutions have continued to allow even small, developing economies to craft divergent paths toward the establishment of domestic high-tech firms in global economic sectors.[25]

[20] Lewis 2007.
[21] Behuria 2020, 2.
[22] For an overview of the debates about national diversity in the global economy, see Berger 1996.
[23] Wade 1996.
[24] Hall and Soskice 2001.
[25] Breznitz 2007.

Such scholarship on the diversity of national capitalisms has concerned itself with options for the state to protect domestic industrial practices from the pressures of the global economy. Central to this book is an argument that, in effect, turns this older position on its head. The global economy is less a threat than an opportunity for collaboration that allows firms to survive, and in many cases to flourish, by maintaining distinct industrial capabilities. In the case of wind and solar industries, this remained true even as governments sought to locate new activities domestically, effectively encouraging some degree of convergence in domestic industrial activity. Such goals took the most obvious form in China, where central government policy very deliberately encouraged the development of R&D capabilities similar to those of firms in the West. Yet China's wind and solar firms, defying these instructions, chose to improve their proficiencies in scale-up and mass production.

In Germany and the United States, governments also hoped that demand-side subsidies, R&D support, and tax credits for manufacturing in renewable energy industries would lead to the development of industrial capacities along the full trajectory from early-stage R&D to mass production. But in practice, this hope played out differently. In Germany, small and medium-sized suppliers of components and manufacturing equipment found far more success by applying their strengths in customization and small-batch production to wind and solar industries than German manufacturers of solar panels, which competed with China's innovative manufacturing skills head-on. In the United States, beset with a weak supplier base, federal R&D support allowed for the renewal of historical strength in early-stage R&D but did not lead to a broad revival for domestic manufacturing. Distinct national strengths in different industrial activities remained, even in new economic sectors where the absence of global incumbents offered firms myriad options for specialization.

Empowered by collaborative advantage in the wind and solar industries, international economic integration and distinct domestic political economies found themselves in a strong position. They were not locked into a zero-sum game in which states had to actively push back on global competitive pressures to maintain national differences. Entering new industries through collaboration allowed firms to choose industrial specializations that were reinforced by existing economic institutions, most established for other purposes before the dawn of renewable energy sectors. By showing how firms picked competitive strategies in the global economy that built on and were buttressed by existing domestic institutions, I have made the case for a firm-based mechanism for institutional endurance: institutions survived because globalization lent them utility in a diverse array of industrial contexts.

The flip side of this equation, however, may be that different economies are not equally suitable to all types of industrial activities. If the specializations that

firms choose have roots in past practices, and if sectoral intervention can only incrementally change how firms take advantage of opportunities in new industries, then governments cannot easily encourage firms to match the skills of foreign competitors. Tensions between state goals and economic outcomes became apparent in each of the three cases examined here. The gap between the promise of vertically integrated industries and the reality of economic specialization had political consequences.

In the fall of 2012, the bankrupt California solar start-up Solyndra filed a lawsuit against the three large Chinese solar manufacturers. The suit alleged that Trina, Yingli, and Suntech had conspired to drive Solyndra out of business by selling their panels below cost in the US market. The defendants, the suit claimed, "employed a complex scheme, in collaboration with each other and raw material suppliers and certain lenders, to flood the United States solar market with solar panels at below-cost prices." Coordination among trade associations, government, and the Chinese solar manufacturers had prompted the decision to "export more than 95 percent of their production and dump their products in the United States to achieve market domination."[26] The 2011 Solyndra collapse had followed a string of bankruptcies in the US solar sector. Because it had received USD 500 million in loan guarantees from the US federal government—that is, taxpayer money—Solyndra's failure attracted particular attention. Republicans quickly accused the Obama administration of granting loan guarantees for political reasons. An evaluation conducted by the Department of Energy later found that Solyndra had misrepresented the true state of its financial affairs to the government on several occasions. Concerned about the politics of a US jury trial, China's solar manufacturers eventually settled the case for a fraction of the damages cited in initial court filings without admission of guilt.[27]

Regardless of the accuracy of the allegations, the lawsuit captured broad sentiments about globalization, China's role in renewable energy industries, and the prospects for US competitiveness. The suit claimed that Chinese government support was behind the dominant role of Chinese renewable energy manufacturers in global markets, reflecting arguments also made in other trade cases against China at the time. The suit affirmed notions about China as a highly coordinated industrial policy regime, capable of strategically mobilizing its various administrative branches in pursuit of aggressive state goals to dominate emerging industries. Finally, the suit made the case that the cost advantages of Chinese firms were devastating to US innovation—and that such cost advantages had their basis in nothing but generous state subsidies and differences in factor prices.

[26] Winston & Strawn LLP 2012.
[27] Friedman 2015; Publicover 2016.

Around the same time, manufacturers of solar panels in Germany and the United States started to call for trade barriers to prevent import competition from China.[28] The theory of collaborative advantage suggests that such measures are unlikely to lead to the establishment of innovative manufacturing capabilities in the West. Collaborative advantage requires a combination of global collaboration, local ecosystems for mass production, and central government science and technology policy for success to be realized. Trade barriers work against this type of activity and could effectively ban Chinese solar panels and wind turbine components from entering Germany and the United States. Such barriers might even encourage the relocation of some manufacturing activities. Absent similar industrial ecosystems and institutional legacies, renewable energy producers in the West, "supported" by these trade barriers, will probably not be able to replicate the engineering specializations of their Chinese competitors in the short term.[29]

Even worse effects could be felt in the collaborative processes of technology development that currently span geographical and organizational boundaries. If opportunities for global collaboration, as I have argued, enable firms to focus on existing strengths while relying on partners for complementary capabilities, then trade barriers undermine the very basis on which firms participate in wind and solar sectors. The protests of Germany's component suppliers and manufacturers of production equipment, who vehemently opposed European Union plans to enact antidumping measures against China's solar producers, stemmed from their recognition that their contributions to solar technology development relied on collaboration with these Chinese partners.[30] Although US news outlets in 2013 somewhat gleefully reported the bankruptcy of one of China's largest solar manufacturers, Suntech, the troubles besetting the Chinese solar industry had consequences for technology development in the United States, as well.[31] Applied Materials, the US-based manufacturer of production equipment that had invested large sums in thin-film solar research, all but shut its solar PV division after its Chinese partners ran into trouble, ending lines of research originally funded by US government grants.[32]

Today, each trajectory of industrial specialization lives or dies based on a firm's ability to access complementary capabilities in other parts of the world. Tensions between those who successfully find a niche in global industries and those who suffer from competition in global markets are unlikely to dissipate anytime soon. Differences among these specializations are visible, for instance, in job creation

[28] Bullis 2012.
[29] Helveston and Nahm 2019.
[30] Meckling and Hughes 2017; Wessendorf 2013.
[31] Plumer 2013; Bradsher 2013b.
[32] Tibken 2012.

numbers and the relative ease or difficulty that firms face when trying to enter global networks. US start-ups created far fewer domestic jobs than their Chinese partners or German suppliers. Even if renewable energy sectors yielded employment in installation and maintenance, the lack of a sizable domestic solar manufacturing sector in the United States sparked political discontent. Insertion into global firm networks was also easier for highly networked German firms and Chinese manufacturers, whose large domestic market naturally attracted foreign partners, than it was for small US start-ups without such support.

Although new opportunities for collaboration broadened the range of firms capable of engaging a global division of labor, they did not eradicate concerns about national competitiveness, the global distribution of growth and employment, and the economic returns from domestic industrial specializations. While policymakers may not be able to change the fundamental risks and rewards of each of these specializations, there is a role for the state in helping firms participate in global networks. The challenge might not be to preserve distinct national structures of production against the pressures of globalization or to prevent competition through trade barriers and import tariffs, but rather to make certain that sufficient numbers of domestic firms can apply their capabilities to new opportunities in global industries. Governments should be advised to craft policies that allow for the creative repurposing and firm experimentation that I described in my empirical chapters, without shuttering access to global partners in the misguided hope that new activities will spring up domestically.

## Globalization and Climate Change

There is currently little evidence that governments will heed such advice. In China, the controversial "Made in China 2025" policy has dropped from public discourse, but the underlying ambition—technological independence and global dominance in strategic industrial sectors—has continued to guide policymaking in Beijing. China's Fourteenth Five-Year Plan has renewed ambitions to reduce dependence on foreign technologies, called for China to overtake the United States economy by 2035, and laid out goals to become a global leader in innovation for key industrial sectors.[33] In Europe, antiglobalization platforms helped populist parties gain ground in parliaments across the continent. While collaboration with China on energy and climate formed the top of the political agenda during the Obama administration, the 2016 presidential election in the United States gave rise to a neomercantilist mindset in Washington that saw engagement with the global economy as a zero-sum game. Already during

[33] Tang 2020.

the Obama administration, voices across the political spectrum in Washington began making the case for economic decoupling from China, arguing that economic integration had not in fact led China to align with Western political norms and economic practices. The COVID-19 pandemic has significantly accelerated such tendencies, highlighting not only the vulnerability of the world's economic supply chains to external shocks, but also strengthening mercantilist calls for national self-sufficiency in China, the United States, and elsewhere. There is little indication that a Biden administration is planning a drastic course reversal on these issues.[34]

Few industries have more at stake in these battles than those producing clean energy technologies, including the wind turbines and solar panels discussed in this book, but also electric vehicles and lithium-ion batteries that are increasingly needed for electric cars and on-grid storage. As a result of its specialization in innovative manufacturing, China has increased its share of global solar PV production from less than one percent in 2001 to over 60 percent of the world's solar panels today. China now makes more than one-third of global wind turbines, it is the world's largest producer of electric cars, and it commands more than two-thirds of global production capacity for lithium ion batteries.[35] In large part because of China's unprecedented investment in manufacturing in these sectors, the cost of clean energy technologies has fallen sharply. Since 2009, prices for wind turbines and solar panels have decreased by 69 percent and 88 percent, respectively, making these technologies increasingly competitive with conventional sources of energy. This is particularly the case when they are deployed in conjunction with battery storage, where China's massive investments in new manufacturing capacity have also led to rapid cost declines.[36]

As a global problem of unparalleled dimensions, climate change requires a global response, including in the invention, commercialization, and production of technologies that can forge deep decarbonization. In the United States and Europe, policymakers frequently attribute China's rapid rise in clean energy industries to illegal industrial policies, including forced technology transfer, unfair subsidies, and intellectual property theft. Such accusations have led to a series of problematic policy responses, including the ongoing tariff battles with China, both in the United States and in the European Union. Missing from such conversations is an understanding of Chinese manufacturers' critical contributions of knowledge and innovation to the development and commercialization of clean energy technologies that I have outlined in this book.

[34] Farrell and Newman 2020.
[35] Helveston and Nahm 2019.
[36] Lazard 2018.

We already have many of the technologies needed to begin making rapid progress toward reducing carbon emissions, and recent cost reductions of solar and wind—at least in part attributable to Chinese firms—mean that meeting climate goals is becoming ever more affordable. The geography of wind and solar supply chains—some of the first industries to emerge after globalization led to a wholesale reorganization of the global economy in the 1990s—makes collaboration with China fundamental in any effort to avoid the worst consequences of climate change—and, indeed, beneficial to the United States. Meeting the goals of the Paris Agreement will require net-zero emissions by 2050 and substantial reductions before then. Given the limited remaining carbon budget, emissions must have peaked and begun declining by 2030 at the latest. Transportation and power sectors should be decarbonized by 2035 to meet global climate goals.[37] It is unrealistic to expect that any other economy will be able to replicate or surpass China's capabilities in innovative manufacturing and build comprehensive domestic clean energy industries within that dramatically short time frame. This is especially the case in light of the unique institutional framework and industrial legacies that have supported the development of these skills in China over the past thirty years.

As I have shown in this book, collaboration made possible the development of the contemporary renewable energy sectors, including partnerships among American innovators, German equipment manufacturers, and Chinese producers with their skills in rapid scale-up and cost reduction. Trade battles and widespread talk of decoupling have begun to undermine these relationships, even as we need them now more than ever—to bring new technologies to market quickly and efficiently and to deploy them at the scale required to meet our shared climate challenge. If it proves successful, the current pushback against the global division of labor that has undermined the development of clean energy sectors would also thwart human progress on decarbonization, making it highly unlikely that global warming will be contained to levels that allow us to continue life as we currently know it.

Zero-sum approaches to engaging the global economy also obfuscate what countries stand to gain from such relationships beyond the core benefits of collaborative advantage. This is certainly true for US renewable energy industries, which have suffered losses as a result of trade barriers to Chinese technologies first put in place under the Obama administration and then extended under the Trump and Biden administrations. Such trade barriers have not brought manufacturing "back" to the United States. The removal of these barriers and the restoration of open trade relationships is imperative to meeting global climate

[37] IPCC 2018.

goals. And addressing these grand challenges will continue to require advances in science and technology. For the United States, this means building on strengths in invention through investments in R&D. Yet the new technologies that result from such efforts must eventually be commercialized and brought to mass production. Working with German equipment producers and Chinese manufacturers is, for now, the fastest way to bring these technologies from lab to market.

The global division of labor in the industries at the core of this book is not, of course, fixed or inevitable. Collaboration with China means working with and learning from Chinese partners, but in the long run, it can also take the form of new US efforts to improve domestic competitiveness, including in segments of the clean energy supply chains that are currently not well-supported in the US (and German) economies. American competitiveness in these sectors could improve with the help of new resources for domestic firms. These could include, for example, new domestic infrastructure banks to finance manufacturing projects, renewed investments in US vocational training and technical colleges, and stable regulatory frameworks to support domestic markets for clean energy technologies. Resources like these take on even more importance when we note that China, too, continues to engage in technonationalism and to pursue national self-sufficiency in key technology areas.

Yet only long-term investments in clean energy industries will allow the world to change its relationship with China in these industries without jeopardizing global climate goals. Even then, it is unlikely that entire value chains for complex energy technologies would ever lie entirely within national borders. As trade conflicts between China and the United States threaten efforts to strengthen global ties in clean energy industries, we risk losing sight of the climate challenge confronting our world—and risk missing the narrow remaining window we still have to sufficiently reduce global carbon emissions. Collaboration and a global division of labor in these industries is currently the most promising path toward rapid global decarbonization, but it does not preclude investments to shift the balance in these relationships over time. For now, we cannot solve the climate crisis without collaboration with China, and the politics surrounding the COVID-19 pandemic have made such collaboration even more difficult.

Over the past forty years, scholarship on globalization has examined possibilities for the state to protect distinct national practices from the competitive pressures of the international economy. If recent developments are any guide, globalization itself may stand in need of protection in a world where collaboration is both misunderstood and undervalued. Tensions among political promises, economic opportunities, and domestic outcomes are inherent to the globalization process, but today they threaten to undermine international

economic integration even where it has led to widespread benefits. The abrupt end to the world's first economic globalization in the early twentieth century should remind policymakers that progress is reversible. Nowhere would the end of collaboration be more consequential than in the clean energy industries we urgently need to solve our global climate crisis.