3

Collaborative Advantage and National Patterns of Innovation

In the last chapter I showed that governments in China, Germany, and the United States supported the development of renewable energy technologies—and domestic markets for their use and deployment—not solely for environmental reasons, but also to encourage the growth of domestic industries. The economic motivations behind renewable energy policies were particularly pronounced in the three economies at the core of this book, by far the world's largest investors in wind and solar energy in the early 2000s. Yet the aspiration to combine climate and economic objectives was not unique to the countries examined here. Governments from Brazil to Turkey made clean energy policies contingent on local industrial development, using local content regulations, tariffs, and government procurement programs to ensure that energy policies yielded local economic results.[1] Policies that pursued the dual objective of achieving emissions reductions while creating new sources of growth were easier to implement politically, and public expenses for such programs could be more readily justified.[2] The prospect of growing export markets for renewable energy technologies—part of the broader global shift away from fossil energy sources—further prompted governments to prepare their domestic economies to seize the day, taking advantage of potential opportunities.

Earlier I also dispelled the myth that a clean energy race emerged from such competing government goals. Despite a common political logic that led policymakers to pursue similar aspirations in their support for renewable energy technologies, firms entered wind and solar industries with different industrial specializations. In contrast to the competitive dynamic that pervaded political rhetoric, firms in China, Germany, and the United States tackled different and ultimately complementary types of technical challenges as they sought to bring new energy technologies to market. Manufacturers of wind turbines and solar PV modules certainly competed with one another, as did suppliers for components and production equipment. But they also collaborated: within the global networks that enabled the commercialization of renewable energy

[1] Kuntze and Moerenhout 2013, 30–31; Lewis 2014, 14; Meyer 2015, 1957.
[2] Breetz, Mildenberger, and Stokes 2018, 500; Meckling et al. 2015, 1170; Nahm 2017a, 711–13.

technologies, no one national industry approximated the kind of self-sufficiency that policymakers aspired to.

In this chapter I expand on the explanation for these outcomes. Why did Germany, China, and the United States arrive at distinct national profiles in global wind and solar industries? In accounting for the responses of firms to the policies of the state, I pay particular attention to firms' choices about how to participate in the global economy and their repurposing and adaptation of domestic institutions in that process. I describe two constituent elements of collaborative advantage that explain the persistence of distinct national industrial profiles in the global economy. First, because of new opportunities for collaboration, firms can participate in a global division of labor that allows them to specialize. Rather than having to maintain in-house all the skills required to develop, commercialize, and manufacture wind turbines and solar panels, specialization allows firms to focus on distinct and narrow sets of capabilities. Second, as a result of new possibilities for specialization, firms can repurpose existing institutions for application in new industries. Such institutional repurposing drives the persistence of legacy institutions within the domestic economy and propels their iterative reorientation toward new, global industrial sectors.

As a first step in this explanation, I examine two alternate conceptions of globalization, contrasting those that primarily focus on the role of competition with those that emphasize the role of comparative advantage. I then offer my own view of globalization—based on the concept of collaborative advantage—and show why this explanation, centered on the role of collaboration, is particularly suitable to explain patterns of industrial development and institutional endurance in emerging industries. I show how the impact of collaborative advantage was refracted through experimentation and repurposing of industrial legacies and divergent economic institutions in China, Germany, and the United States, leading to distinct national profiles in global renewable energy industries. The final section in the chapter sets the boundaries of the argument and outlines three structural conditions for collaborative advantage: the rise of global supply chains, nonhierarchical patterns of industrial organization, and opportunities for experimentation in response to state industrial policies.

Two Perspectives on Globalization

Over the past three decades, explaining the consequences of globalization has become a central area of inquiry for scholars of political economy. Broadly defined as a process of greater international economic integration driven by technological advances in transportation and the transmission of information, research in this field has examined the impact of increasing cross-border trade in products,

international capital flows, and technological diffusion on matters of domestic politics ranging from development and economic policymaking to welfare policy and inequality.[3] Perhaps not surprisingly, such scholarship on increasing economic interdependence—irrespective of its substantive focus—has offered vastly different perspectives on the fundamental nature of globalization itself.

One avenue of research has understood globalization primarily as a process of reaping gains from international trade based on comparative advantage. Grounded in the notion that factor endowments shape nations' relative opportunity costs for specializing in the production of some goods over others, research in this tradition has focused on the circumstances that allow and prevent nations from realizing the benefits of greater economic integration.[4] In its most elemental approach, this view of globalization as the realization of comparative advantage assumes that nations trade in finished products, finding their niche in the global economy based on preexisting factor endowments. Relative factor intensities for final products determine the connections between national economies in the global economy. In this view, globalization is primarily an opportunity to benefit from trade.

This view of the global economy has been challenged on its assumption that products continue to have clear national identities. Products now contain multiple components and production stages—each with different factor intensities—that originate in multiple locations around the world.[5] The final assembly location of a product offers little analytical explanation of how globalization connects different production locations, who is likely to benefit, or how exposure to the global economy shapes domestic interests.

Subsequent literatures on global value chains have offered a more nuanced perspective, examining globalization from the vantage point of global production systems. In this view, globalization is primarily a process of progressive outsourcing, in which firms in advanced industrialized economies have shifted low-value manufacturing and design activities to lower-cost locations in developing economies.[6] As the state features only peripherally in research on global value chains, globalization is primarily conceived of as a phenomenon structured and organized through the activities of firms, in particular by lead firms in advanced economies that control global chains hierarchically.[7] This is not to say that states no longer matter: all global value chains connect at some point to the domestic contexts within which firms operate on the ground. The benefits

[3] Baldwin 2016, 5–6. Hall and Soskice 2001, 55. Kaplinsky 2013, chapter 6; Swank 2002, chapter 2; Zysman and Newman 2006, 5–6.

[4] Samuelson 1938, 265.

[5] Frieden and Rogowski 1996, 36–41.

[6] Gereffi 1994, 43.

[7] For a discussion of different modes of governance in global chains, see Gereffi 2018, 1–39; Gereffi, Humphrey, and Sturgeon 2005, 83–84.

of globalization materialize within links among firms, and those firms that can respond flexibly to changing circumstances on the ground shape the structure of the international economic system. Nonetheless, the domestic environment holds secondary importance, even if globalization has important consequences for domestic growth and economic development.

A second view of globalization, one centered on increasing competition, has approached international economic integration from a domestic perspective. Without necessarily refuting potential gains from trade, research in this tradition has pinpointed the constraints imposed on states by the international economy.[8] Globalization limits the resources available to national governments, for example, as taxes cannot be raised without affecting the competitive position of domestic firms. These constraints, in turn, are likely to lower taxes on mobile capital, causing immobile labor to shoulder a higher fiscal burden over time.[9] Capital mobility similarly shapes the possibilities for industrial policy, as investors become unwilling to fund domestic firms if returns are higher elsewhere.[10] An open international economy also places labor, environmental, and other regulations under scrutiny that might affect the competitive position of domestic firms.[11]

A central question emerging from this body of research is the degree to which competitive pressures from the global economy have led nations to liberalize previously distinct institutions and economic practices. Thirty years after these debates first took shape, it has become clear that globalization has not leveled variation across national political economies. States have neither fully converged in the institutions that govern their economies nor come together in the patterns of industrial capabilities possessed by domestic firms.[12] Far from a race to the bottom, in some cases international trade itself has caused a diffusion of stricter labor and environmental standards to developing economies that previously lacked such regulations.[13]

A large body of literature has examined the degree to which domestic institutions have slowed the impact of this competition. Focusing on advanced industrialized economies, Hall and Soskice, among others, have suggested that mutually reinforcing institutional arrangements lent stability to distinct varieties of domestic capitalisms in spite of global pressures to liberalize.[14]

[8] At the core, this perspective argues that technological changes that underpin globalization and the fragmentation of global production have undermined state attempts to bolster national competitiveness by denationalizing comparative advantage. See Baldwin 2016, 222–79.

[9] Rodrik 1998, 87.

[10] Berger 2000, 54–55.

[11] Locke 2013, 10.

[12] See, for instance, Breznitz 2007, 3.

[13] Distelhorst and Locke 2018; Vogel 1995, 5–8.

[14] Hall and Soskice 2001, 38–44. For an empirical critique of this argument, see Taylor 2004.

Complementary institutions preserved distinct political economies, each suitable for different types of production and innovation activities. In "coordinated market economies," such as Germany, the institutions that govern labor markets, financing, and employee participation in corporate governance created an environment best suited to industries that are based on slow-paced incremental innovation. In "liberal market economies" such as the United States, where domestic institutions foster labor market flexibility, well-developed equity markets, and short-term profit expectations, firms based their strategies on radical innovation. Where changes in the international economy have created pressures for reform, distinct national political economies have nonetheless persisted through a process of economic liberalization—a result of sticky institutions that are difficult to change against the opposition from vested interests and self-reinforcing complementarities of domestic economic arrangements.[15]

Yet even if responses to the pressures emanating from the international economy did not level differences among national political economies and the industrial capabilities of domestic firms, historical institutionalists nonetheless pit global economic forces against legacy institutions and the political coalitions that support them.[16] In Europe, for instance, economic competition and the growing reach of global finance has in some places triggered reform. In other economies, such as Germany, competitive pressures have led to a new institutional dualism: an industrial core of legacy sectors invested in existing institutions that suit the nation's competitive strategies, and a rapid shift of remaining economic activity into spheres with fewer institutional constraints, such as services.[17] Globalization, from this perspective, forges long-term and consequential changes in the politics and possibilities of organizing domestic economies within the international system.

Rethinking Globalization

These theories of globalization as either competition or comparative advantage offer little guidance for understanding the industries at the core of this book. Consider the case of two manufacturers of wind turbine generators, one from Germany and one from China. In the spring of 2011, in an industrial park in East Germany, I asked the plant manager of the German manufacturer about competition from China. In the decade before our first meeting, China had become the largest manufacturer of wind turbines in the world, and Chinese firms were now

[15] Thelen 2014, 14.
[16] Höpner and Krempel 2004; Hsueh, 2012; Streeck 2009; Streeck and Mertens 2010.
[17] Thelen 2014, 24.

producing nearly all the major components required to make a turbine domestically, including the generators that constituted a core technology of the German manufacturer. To my surprise, the German plant manager did not appear particularly troubled by China's growing wind industry, even as his German firm could not compete with Chinese suppliers on price. The plant in Germany, he said, had always been too small to mass-produce turbine components, and trying to do so would have proven too expensive. The firm had begun to specialize instead in prototyping and early-stage production of novel generator technologies, including for offshore wind turbines. It then licensed these technologies to China when customization—the core skill of the German producer—was no longer needed.

During our conversation, I learned that a Chinese generator firm had recently bought such a license when the demand for a particular model exceeded the production capacity of the German plant. For all their experience in customization, the German team had long dismissed as unworkable the use of the most cost-effective cooling technology in the generator design they licensed to the Chinese supplier. As I confirmed in China during a conversation with the licensee a few months later, the Chinese firm subsequently changed the production architecture of the original model to accommodate the cheaper fan as it scaled up the model for mass production. The changes prompted a group of German engineers to travel to China, and, eventually, to pay for this proprietary information through reverse licensing. The German firm also began sourcing fans from China.[18]

The traditional views of globalization outlined earlier do not adequately capture the relationship between these two manufacturers, one in a mid-sized German city with a similarly mid-sized production facility, the other in a sprawling Chinese metropolis with the capacity to manufacture more than 1,000 generators annually. The two firms were certainly not locked into the kind of cutthroat competition that some have come to expect from China's integration into the global economy. Both firms held distinct roles and expertise in a division of labor that allowed the German manufacturer to build on core skills in customization and investment in new, cutting-edge generator technologies, while the Chinese firm concentrated on the design changes required to lower cost and bring products to mass production. During my conversation with the German plant manager, I came to understand that the firm possessed neither the ambition nor the access—to financing, infrastructure, training institutions, and broader technological skills—that would be needed to compete with the Chinese supplier on scale. Still, their business model required that someone bring their

[18] Interviews: plant manager, German generator manufacturer, May 17, 2011; executive, Chinese generator manufacturer, August 26, 2011.

products to mass production after demand exceeded capacity at the plant. Licensing enabled the continued focus on customization in Germany.

Yet the two firms were not locked into a licensing relationship invoked in descriptions of globalization as progressive outsourcing, either.[19] The German firm did not have a monopoly on value-added design activities, nor did it enjoy full control over the supply chain. Instead, knowledge traveled both ways, including from China to Germany. The German firm sent engineers to China to observe the performance of their product under conditions of mass production. Their newly acquired knowledge helped these German engineers design new generator models. Simultaneously, the Chinese firm benefited from new technologies developed in Germany. The connection between the two suppliers was neither arm's-length nor unidirectional.

Collaborative Advantage

To explain this phenomenon, I propose a third view of globalization based on the understanding that international economic integration has opened new ways for firms to collaborate. I employ the concept *collaborative advantage* to capture the connection between changes in the global economy and the endurance of distinct national industrial specializations. "Collaborative advantage" is shorthand for two types of experimental action that enable firms to reap benefits from participating in the global economy: because of new opportunities for collaboration, firms can engage in a division of labor that allows them to specialize; and firms can choose competitive strategies for participating in global networks that allow them to repurpose domestic institutions and public resources.

Economically, collaborative advantage describes the importance of specialization in the global economy. Thanks to advances in transportation, the digital transmission of information, and more general acceleration of human mobility, globalization has made it easier for firms to find partners in the development and commercialization of new technologies. The existence of other specialized firms has made it possible to access key skills and capacities necessary for the development of new technologies through collaboration in global supply chains, whether such collaboration occurs through licensing, joint development agreements, or relationships with global suppliers. These new possibilities for collaboration in the global economy have relieved firms of the need to establish in-house the full range of production and innovation skills required to invent and commercialize new technologies.

[19] Petersen and Welch 2002, 160–61.

Historically, national borders defined clear boundaries for industries and collaboration between firms. Over time, innovation in transportation technologies, including the invention of steam engines and modern railways, put new markets within reach; the products generated by such national systems of production increasingly found global customers. A third wave of economic integration subsequently moved many of the activities that now make up the global economy beyond the territorial reach of states. It dispersed individual stages of innovation and production beyond national borders, it began shifting know-how to developing nations that had previously been confined to the periphery of the global economy, and it allowed firms in advanced and developing economies to focus on a set of core capabilities.[20] These changes coincided with the emergence of global supply chain networks as central vehicles for international economic integration, binding individual firms and national economies to the global economy and sparking the collaboration that is central to this argument.[21]

The forces that prompted much concern about exposure to heightened competition also made accessible a far greater range of collaborators with diverse sets of skills and capabilities. As I detail in my empirical chapters, German makers of production equipment were able to rely on Chinese wind and solar manufacturers not just as potential customers but also as partners, with research and development teams devoted to mass manufacturing—expertise that was not available to the German producers domestically. Chinese manufacturers, in turn, found themselves freed up to prioritize research and development related to commercialization of new technologies, in part because they could access such technologies through global networks, including American start-ups and German suppliers of production equipment. In the United States, where start-up firms excelled at creating new technologies but possessed few resources for—and little prior experience with—commercialization and production, global networks offered novel opportunities to bring products to market through collaboration. Quite simply, the distinct and highly specialized competitive strategies of the two generator suppliers proved viable because these firms had found a way to work together.

Politically, collaborative advantage opens up new options for participation in the global economy, including those that repurpose existing domestic institutions and public resources. Faced with multiple opportunities for participating in innovation in global networks, specialization allows firms to build on existing industrial capabilities. Although such skills undergo significant transformation and augmentation in their application to new industries, they shape how firms take advantage of new prospects in emerging industrial sectors.

[20] For a summary of the evolution of globalization over time, see Baldwin 2016, 5–10.
[21] Henderson et al. 2002, 445.

Globalization allows firms to match existing strengths and competencies with competitive niches in global industries. It enables them to choose among different specializations that present trade-offs between skills and resources that firms already have or need to establish. Even when governments intervene to encourage the development of particular skills and industrial sectors—for instance, by emphasizing the importance of manufacturing jobs in renewable energy sectors—firms can pursue alternative trajectories for participation in ways that would be impossible if the full range of innovative abilities had to be established within an individual firm or even within a single domestic economy.

In choosing a strategy to join the global supply chains that now make up the global economy, firms are able to pick sets of technical skills that are well-supported in the domestic economy. Specialization enables experimentation with familiar public resources at the domestic level, many of which were originally established for legacy, not emerging, sectors. Such institutions include the domestic financial sector, the labor market and vocational training institutions, and government programs to support research and development. While industrial legacies and the presence of different types of institutions constrain what types of activities are supported in different economies, institutions are not determinative: globalization allows firms to repurpose elements of existing industrial legacies for new industrial contexts, presenting resources for experimentation and adaptation that can support firms in taking advantage of new prospects without fully prescribing their path. Specialization creates opportunities for creativity and experimentation because it has opened up new possibilities for participation in new industries. By forging an opening for collaboration in global networks, globalization allows firms to sustain and adapt existing skills and domestic economic institutions as they seek competitive niches in emerging sectors. As I showcase in the wind and solar sectors, existing domestic institutions retain their value precisely because they no longer have to support the full range of activities required to invent and commercialize new technologies within national borders.

Political economy literatures have commonly described institutions as the main agents of path dependence. According to such research, institutions often obstruct the realization of private sector interests and are threatened by the competitive pressures of the global economy.[22] The argument advanced in this book reverses this causal logic. Collaborative advantage allows firms to choose industrial competencies that draw on existing economic institutions at the domestic level, because specialization enables firms to craft new paths for participation in global industries. Even when national industrial policies explicitly tried to establish far broader sets of domestic capabilities, collaborative advantage still

[22] Pierson 1994, 2000; Steinfeld 2010; Streeck and Thelen 2005.

enabled wind and solar firms to revive domestic industrial specializations. To put it simply, new options for specialization reinforce existing local institutions.

Such a global division of labor is also self-reinforcing. The incremental development of industrial specializations creates more demand for collaboration: as a result of rapid economic and technological change, even the most capable firms struggle to supply all the skills required to remain competitive in the development of new technologies.[23] Not everything can be accomplished internally. The presence of specialized firms focused entirely on mastering individual steps along the trajectory from lab to market makes it harder for others to compete as generalists, and it thus creates incentives for firms to specialize and focus on core skills. Where firms and nations once prided themselves on being self-sufficient, or islands unto themselves, globalization has challenged that outlook. It has hampered firms' ability to maintain comprehensive competitiveness, but it has also offered an array of bold new opportunities to rely on external actors as needed.

Wu Gang, the founder of Goldwind, one of China's largest wind turbine manufacturers, explained things this way: There "was little reason to start from zero. Technology could be licensed, but manufacturing was not as simple. Early attempts were a terrible failure. Whole blades dropped off and the main shafts broke. It was really very dangerous."[24] Like many renewable energy firms in China, Goldwind had little ambition to reproduce capabilities that could be accessed through collaboration, particularly not if such duplicate skills entailed head-on competition with firms in the United States and Europe. So Goldwind chose to focus its R&D efforts on commercialization and scale-up to mass production. Such skills were scarce in global networks and dovetailed with existing public support for mass production in China.

Because collaborative advantage freed up options for industrial specialization, renewable energy firms in Germany stepped forward to build on existing strengths in customization and automation. For the same reason, Chinese firms broke into global supply chains with skills in commercialization that responded to China's domestic manufacturing strength but also added new competencies in innovation to improve scale-up and mass production. The concept of collaborative advantage reverses the logic that has portrayed distinct national political economies as fundamentally threatened by the competitive pressures resulting from the reorganization of the global economy over the past thirty years. By providing new opportunities for collaboration, globalization causes persistent and consequential divergence of such institutions and national industrial specializations over time.

[23] Sabel and Herrigel 2018, 231–32.
[24] Osnos 2009, 55.

Persistent Divergence of Domestic Institutions

Analyzing domestic institutions to explain cross-national differences is a common practice within research on comparative capitalisms. Here I build on a long history of social science research that has explained the slow pace of institutional change at least partly as a result of institutional interdependence. The institutions considered in this book build on those arrangements that institutional literatures have long held responsible for preserving distinct national capitalisms.[25] My framework departs from such analyses by showing that these institutions continue to be relevant in new, highly globalized industries because they provide utility to firms, not because institutional complementarities lock them into place. In its focus on new and emerging industrial sectors, the concept of collaborative advantage offers a different view of globalization's impact on the distribution of firm capabilities across global supply chains, and its relationship to distinct domestic political economies. The political manifestation of collaborative advantage is that firms are able to choose much more freely which domestic institutions to rely on and support. Scholarship on comparative capitalisms has often described labor market institutions, institutions for social protection, and state-industrial relations as locked into reinforcing complementarities. I show, however, that even if firms choose to work with and repurpose resources at the domestic level, the ability to engage in global collaboration allows them to engage with domestic institutions far more selectively than in the past.

While this argument shares with other literatures an emphasis on the importance of legacies—the outcomes I describe cannot be fully explained through causes that are contemporaneous with that outcome—I offer a different mechanism that links the antecedent and the current phenomenon.[26] Firms from legacy industries and extant economic institutions find pathways into new sectors not because of path dependence resulting from slow-to-change institutions, but because globalization has lent existing institutions new utility in different industrial contexts. Collaborative advantage allows firms to maintain a set of skills that are in keeping with traditional industrial strengths of their countries of origin, but it is the collaboration between them that makes each individual specialization functionally viable and economically successful. In applying themselves to new economic sectors through specialization, firms can repurpose domestic resources, institutions, and networks familiar to them from past industrial activities.[27]

[25] For an overview, see Hall and Soskice 2001, 1–68.

[26] For a comprehensive discussion of the use of legacy-based explanations, see Wittenberg 2015, 367–70.

[27] This view differs both from neoliberal and institutionalist accounts and builds heavily on Herrigel's notion that industrial change is essentially a firm-driven, creative process of adapting to changing circumstances while experimenting with existing resources. See Herrigel, 2010.

The impact of collaborative advantage on the competitive strategies of firms is shaped by economic institutions that differ across national economies: different sets of domestic institutions are of course not equally suitable for all types of industrial specializations. The presence of distinct sets of domestic institutions therefore offers both constraints and new opportunities for the types of production activities that are supported domestically. But because they can specialize and collaborate, firms are no longer fully constrained by domestic institutions; they do not have to let those institutions define their strategies for entering new industries. Instead, collaborative advantage lends utility to domestic institutions in new industrial contexts and presents a set of resources that do not have to be used together, at the same time, or even for the purposes for which they were initially intended. Institutions structuring domestic labor markets, training and education, financing, and research and development might have originated as part of interlocking domestic arrangements where institutional complementarities reinforce one another, but now they can function instrumentally, used by firms to enter new industries without necessarily adhering to their original purpose.

As I showed in the previous chapter, modern renewable energy industries emerged virtually simultaneously in China, Germany, and the United States. By the end of the 2000s, governments in all three economies had converged on the goal of developing comprehensive wind and solar industries that could invent, commercialize, and manufacture strategic energy technologies domestically. They also employed similar policy tools to achieve these objectives. Benefiting from the presence of collaborative advantage in wind and solar industries, firms responded with narrow industrial specializations that built on existing skills by repurposing existing institutions within the domestic economy. In the United States, start-ups maintained capabilities in the *invention* of new technologies but rarely developed skills in commercialization and mass production.[28] In Germany, wind and solar firms clustered around the development of production equipment and customized components, offering what I call capabilities in *customization*.[29] In China, large wind and solar manufacturers prioritized the R&D required for commercializing and scaling-up of novel technologies, which I refer to as *innovative manufacturing* in this book.[30] Only in the context of institutions that existed before the rise of wind and solar industries can one understand the effect of industrial policies on the development of distinct renewable energy sectors in China, Germany, and the United States.[31]

[28] Knight 2011, 176.

[29] Arbeitsgemeinschaft Windenergie-Zulieferindustrie 2012; Germany Trade & Invest 2010, 2011b.

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

[31] On institutions and the political economy of energy transitions more broadly, see Hochstetler, 2020.

The persistent and consequential divergence of national patterns of industrial specialization resulted from aggregate firm decisions to compete by augmenting existing industrial strengths, actively renewing and repurposing different legacy institutions and public resources in each country. In Chapters 4–6, I showcase three types of institutions that became central to the R&D activities of firms but are not usually considered part of the state's repertoire for industrial policy intervention regarding energy or innovation (see Table 3.1): the role of legacy institutions in supporting innovation and production outside renewable energy policy, the role of ownership patterns and financial systems in driving technological specialization, and the role of skills and training institutions in shaping firm practices in wind and solar sectors. The main takeaway is not that these institutions differed across the three economies examined here, but that they maintained relevance as firms learned to repurpose them for application in novel industries, the result of new opportunities to specialize.

First, the case chapters highlight the role of legacy institutions in supporting innovation and production outside the realm of renewable energy policy. These institutions, founded to bolster domestic firms in the existing industrial core, included government programs to promote inter-firm collaboration, public test centers for private sector research, legislation to help firms access technologies developed in research institutes (through licensing and other legal arrangements for technology commercialization), and subsidies for manufacturing. Collectively, such legacy institutions offered an impressive array of resources for different firm strategies, including innovation centered on manufacturing activities and more traditional R&D in laboratory settings.

Firms in all three economies used legacy institutions to support their R&D activities, but they applied them in new industrial sectors and reoriented them to

Table 3.1 Institutional Resources for Specialization

	Germany	**China**	**United States**
Innovation, Production	Collaborative research institutions for small and medium-sized enterprises	Institutions for mass production	Technology transfer from university to private sector
Financial institutions	House banks & credit unions, small loans, patient capital	Development banks, large manufacturing loans	Venture capital, early-stage funding
Skills, training, employment	Vocational training for production workers, long job tenures	Manufacturing engineering schools, migrant labor	University training, short job tenures

operate beyond the parameters of whatever problem they had initially intended to address. In an environment of collaborative advantage, China's institutions for mass manufacturing became the basis for R&D initiatives to support commercialization and cost reduction—they did not constrain or limit domestic firms to more traditional low-value manufacturing activities. In Germany, institutions to support R&D in small and medium-sized family businesses fueled far-reaching transformations of products and competitive strategies as they entered the wind and solar sectors. US government support for technology spin-offs from universities and research institutes, originally set up to support domestic commercialization and the production of federally funded technologies, spurred a proliferation of start-ups that increasingly looked to global partners to bring their technologies to market.

Second, the empirical chapters underline the role of ownership patterns and financial systems in driving patterns of technological specialization. Financial systems differ in their expectations about rates of return, the time frame within which investments must generate a profit, and the willingness to invest in novel technologies and practices. Ownership patterns reinforce such differences, as family-owned firms, for instance, tend to have longer planning horizons than publicly traded firms with short-term shareholder responsibilities. Financial institutions set clear limits on what types of activities can be funded domestically.

In renewable energy sectors, large-scale manufacturing investments and long-term research and development programs lay beyond the scope of US venture capital funds and clashed with the financial incentives of publicly listed companies. Federal research funding became a central revenue source, instead, for firms trying to commercialize early-stage technologies. In Germany, family-owned businesses with access to capital from local house banks found ways to revive traditional strengths in automation: such endeavors entailed long development horizons and uncertain future payoffs that local banks were nonetheless willing to fund. Firms in Germany used the financial institutions of the preglobalization economy to fund their entry into postglobalization renewable energy sectors. In China, manufacturing firms repurposed large loans from state-owned banks for the expansion of manufacturing capacity to set up research and development facilities dedicated to the rapid scale-up and mass production of new energy technologies.

Finally, the empirical chapters to follow examine the role of skills and training institutions in shaping firm practices in wind and solar sectors. The development of new technologies, together with the type of technological problems that industries chose to tackle, related directly to the types of proficiencies supplied by education systems and on-the-job training. While some training was organized internally, firms relied extensively on external institutions to meet training

needs.[32] The original intent behind the creation of such training institutions, however, offered only limited information about what kinds of industrial specialization could be supported in an environment of collaborative advantage. For example, since manufacturing was not simply the execution of product design but also a site of critical research and development, vocational training for manufacturing assumed a new and weightier significance in a global system of cooperation.

The analysis of such domestic institutions to explain cross-national differences is not unique to my work, of course. I am fortunate to build on a long history of social science research that has, at least partially, explained the slow pace of institutional change as a result of institutional interdependence. In particular, the comparative capitalism literature has described labor market institutions, institutions for social protection, and state-industrial relations as locked into reinforcing complementarities. But by attending to new and emerging industrial sectors, my theory offers a different view of globalization's impact—one that pays special attention to the distribution of firm capabilities across global supply chains, as well as to the relationship between firms and legacy institutions unfolding across distinct domestic political economies. While the institutions considered in this book build on those older arrangements that have long been viewed as responsible for the preservation of distinct national capitalisms, my framework departs from traditional analyses by showing how these institutions continue to find relevance in new industries, precisely *because* globalization has allowed firms to repurpose them in support of narrow industrial specializations.[33] Thanks to new opportunities for specialization in global supply chains, firms learned to choose for themselves which domestic institutions to rely on and support. Even if they opted to repurpose resources that were once part of a larger domestic whole, this ability to collaborate globally allowed firms to engage with domestic institutions far more selectively than in the past. Simply put, firms could now pick and choose.

Structural Conditions for Collaborative Advantage

If we think about globalization as primarily a collaborative phenomenon, we begin to see in a new way how firms respond to domestic industrial legacies and institutions, and we also begin to rethink or challenge existing views about the relationship between advanced industrial and developing economies. Consider the difference between the development of new technologies under conditions of

[32] Berger 2000, 182.
[33] For an overview, see Hall and Soskice 2001, 1–68.

collaborative advantage and the vertically integrated company of the Fordist era, when even the rubber plantations for auto tires formed part of the same firm.[34] Creating new technologies requires invention and imagination, of course, but it has also always required improving product designs and production processes along the entire trajectory from lab to market, including in commercialization and manufacturing. The fragmentation of global production, the concomitant rise of global chains, and new opportunities for cooperation have distributed such capabilities across numerous firms in different economies. These firms are not necessarily located near one another, nor do local strengths in a particular activity necessarily draw related industrial activities into the local economy.

As firms in China and other middle-income economies have attracted mass manufacturing, firms in advanced economies have in many cases lost the infrastructure on which skills related to commercialization can be established.[35] When different types of innovation are geographically and organizationally separated, R&D staff dedicated to inventing new technologies often lack the experience to anticipate what the production process will need. These teams rely instead on engineering capabilities residing in the manufacturer or supplier. What such firms have in common, however, is their increasing specialization in narrow sets of activities: they exhibit capabilities in different varieties of innovation on the trajectory from lab to market.

Three factors distinguish an environment of collaborative advantage from the conventional characterization of innovation and manufacturing activities as sequential in timing, distinct, and hierarchical in skill requirements.[36] First, under conditions of collaborative advantage, innovation and manufacturing activities are not sequentially organized. In contrast to product innovation in modular production networks, for instance, in which products are handed off to manufacturers only once they are fully standardized, collaborative innovation requires sustained interaction between different firms specializing in different steps of the innovation process.[37] As my empirical chapters outline in detail, even licensing agreements, typically conceived as transactional interactions between innovative firms in advanced economies and manufacturers in developing economies, often require in-depth interactions between engineers working in quite different fields.

[34] Galey 1979, 262.

[35] Pisano and Shih, in a variation on this argument, propose that the decline of manufacturing in the United States prevents firms from realizing their innovative potential in areas where manufacturing skills are essential to product innovation. Restoring competitiveness for US firms, in their view, requires a revitalization of the American manufacturing sector. Pisano and Shih 2012.

[36] This view has been particularly prominent in discussions of industrial upgrading, which describe a stepwise of progression of late developing economies into ever more complex activities through the strategic imitation of advanced industrial economies. Amsden 2001; Johnson 1982; Kim 1997; Wade 1990.

[37] Sturgeon 2002; Whittaker et al. 2020, 21–88.

Second, when complex products and firm-level specialization in different types of production and R&D activities require collaboration to bring a product to market, innovation and production activities no longer remain separate. Innovative ideas travel in multiple directions, from manufacturers to firms that invent new technologies, and from firms in middle-income economies to firms in advanced industrialized economies.[38] Within global networks, different specializations are interdependent to succeed economically, but these networks also require that teams learn from one another to remain viable in the long term.

Third, under conditions of collaborative advantage, no single link in the chain of production can be identified as the lead position. Consequently, economies and the firms within them cannot be easily grouped into global technological leaders versus those attempting to catch up. Fundamentally, a theory of collaborative advantage calls into question the notion that industrial activities are structured along a single hierarchy of complexity and value from manufacturing to advanced innovation. While firms in advanced economies are still more likely to possess expertise in basic research and early-stage R&D, the importance of innovation in manufacturing challenges those who would portray production merely as the execution of product design. Thanks to the dependence of highly specialized firms on external partners with complementary skills, engineering capabilities can no longer be organized or ranked hierarchically.[39]

Three structural conditions enable collaborative advantage, including in the renewable energy sectors at the core of this book (Table 3.2). In addition to the presence of potential partners for collaboration in *global supply chains*, firms' ability to benefit from collaborative advantage relies on a form of *industrial organization* based on flat hierarchies and a lack of incumbent firms, as well *flexible government policies* that tolerate these firms' divergence from industrial policy goals. The following paragraphs examine these conditions in detail.

At the most fundamental level, collaborative advantage was made possible by changes in the organization of the global economy that predated the emergence of wind and solar industries. The decline of vertical integration, the fragmentation of production, and the rise of firms organized in *global supply chains* created partners for collaboration. In the postwar decades, the core competitive advantage of vertically integrated firms in advanced economies consisted in the ability to establish the full range of engineering capabilities required for technological innovation within the four walls of the firm, thereby making collaboration redundant. Large enterprises made the capital, human, and financial investments required to establish this broad range of engineering capabilities in ways that smaller firms

[38] Helveston and Nahm 2019, 295; Nahm and Steinfeld 2014, 289; Sabel and Herrigel 2018, 231–33.

[39] Binz and Truffer 2017, 1286.

Table 3.2 Structural Conditions for Collaborative Advantage

Structural Condition	Opportunities for Firms	Impact on Renewable Energy Sectors
Global supply chains	New partners for collaboration Ability to specialize	Near simultaneous development of wind and solar industry in China, Germany, and the United States
Nonhierarchical industrial organization	Lack of incumbents and legacy production structures Ability to readily enter global networks	Low/no tariffs, open economy Globalization did not prompt structural adjustment
Flexible government policies	Ability to diverge from official goals	Use of existing institutions and skills Distinct national profiles

could not. By housing manufacturing and R&D capabilities under one roof, such enterprises coordinated and established critical linkages between innovation and production capabilities in the early stages of product development, effectively transitioning new products from lab to mass production.[40] Only after products proved reliable, manufacturing processes achieved standardization, and price premiums from technological advantage were depleted, did production activities shift to developing economies—those with fewer technical capabilities, lower degrees of vertical integration, and less sophisticated market demand.[41]

When President Obama announced in 2009 that the world's nations were in a race for the biggest share of the clean energy economy, these traditional arrangements were under significant pressure—and had been so for some time. Beginning in the 1990s, the rise of the internet suddenly allowed complex design blueprints to be electronically transmitted to faraway production locations, permitting firms to break the connection that had long required R&D and manufacturing to occur in close proximity during the early stages of product development. In subsequent years, new digital technologies made it increasingly possible to standardize interfaces between different components. This improvement allowed firms to introduce modular product architectures where manufacturing was no longer the only outsourced activity: now the design and

[40] Where scholars of East Asian economic development saw a need for the state to encourage the creation of such business in late-developing economies, Chandler, in a study on the origins of large business in the United States, argued that the dominance of conglomerates in the US economy was a result of their competitive success. See Chandler 1977, chapters 3 and 9.

[41] Antràs 2003; Grossman and Helpman 1991; Krugman 1979; Vernon 1966.

fabrication of entire components could be entrusted to third-party suppliers without concerns about how these parts would eventually fit together.[42]

These new options for the organization of production and innovation challenged the primacy of large firms and opened new avenues for collaboration.[43] At a time when the capital investments required for the construction of new manufacturing facilities increased rapidly, firms in advanced economies began to concentrate on research and development; and many moved production activities abroad. They spread their investment risk to suppliers and third-party manufacturers located in developing countries with low production costs.[44] As new digital technologies encouraged firms in advanced economies to reorganize their production strategies, financial markets rewarded such restructuring.[45] For firms in developing economies, meanwhile, global supply chains lowered barriers to entry, permitting them to enter these supply chains for high-technology products through the manufacture of foreign product designs, or through hosting foreign-invested manufacturing facilities. By the time renewable energy sectors began mass manufacturing wind turbines and solar panels in the late 1990s and early 2000s, the global system of production had shifted to global networks of firms, creating opportunities for collaboration that had not existed previously.

Collaborative advantage also required a form of *industrial organization* that allowed firms to freely enter such global networks. Literatures on global value chains have examined how technological complexity and the replaceability of suppliers shape hierarchy in global networks.[46] I argue, however, that the degree to which industries benefited from collaborative advantage depended on their existing footprint and the role of incumbent firms. Research on economic globalization has paid much attention to the role of competition and hierarchy in structuring the international economic order in legacy industries. Incumbent firms in such sectors often responded to economic globalization by defending existing production arrangements against global competition, raising barriers to entry for new competitors, and using their economic and political clout to govern global supply chains in their own best interest.[47] Lead firms subsequently controlled supply chains, becoming powerful organizations that orchestrated the

[42] Although the possibility of separating manufacturing and innovation (through offshoring and outsourcing) and the option to develop modular production architectures are separate developments, they are mutually influencing and driven by the same underlying technological developments. See Camuffo 2004; Langlois 2002.

[43] This paragraph draws heavily on Berger 2005a, chapter 4.

[44] Berger 2005b, 73; Ezell and Atkinson 2011b, 22.

[45] Davis 2009, chapters 1–4.

[46] Scholars of global value chains have identified multiple governance forms with varying degrees of hierarchy and control by lead firms. See Gereffi, Humphrey, and Sturgeon 2005, 86–87.

[47] Opportunities for collaboration are in general greater in sectors where incumbents are not organizing to resist the emergence of global chains. For a discussion of political strategies employed by firms confronting economic change, see Uriu 1996, 12–15.

complex task of coordinating activities among a growing number of firms across national boundaries. The presence of brick-and-mortar manufacturing plants, R&D facilities, and existing supplier relationships of lead firms thus determined when and how new firms were allowed to enter. Investments in existing production arrangements structured whether and how firms were able to exploit the benefits of collaboration.

Collaboration was more readily accessible for firms in new industrial sectors. Wind and solar sectors, like other emerging industries, did not respond to the forces of globalization through economic restructuring and adjustment. From the beginning, renewable energy sectors developed within a new global economic order: they lacked incumbent firms and production arrangements that predated economic globalization. Wind and solar industries, in particular, emerged beyond the influence that incumbent firms with existing assets held over the global division of labor in legacy sectors. Firms could insert themselves into global networks as collaboration lowered barriers to entry and invited the development of narrow, specialized skills. Collaborative advantage is not limited to emerging industrial sectors, of course, but perhaps it achieves its greatest visibility and use here—in industries not weighted down by the legacies of a world before globalization.[48]

In renewable energy industries, the relationships through which firms engaged collaborative advantage took a variety of legal and organizational forms. In some cases, firms with complementary engineering capabilities signed research agreements that anchored the nonhierarchical, mutually beneficial collaboration firmly in a legal contract. In other cases, collaboration took place in supplier relationships between firms with complementary skills. Even contract manufacturing and licensing agreements—supply chain relationships that are seen as far more hierarchical—allowed for collaboration, multidirectional learning, and the participation of multiple firms in joint processes of product development.[49] Frequently, a single technological development required many such relationships at once.

The physical requirements of wind and solar production chains informed the organizational structure of these relationships. In the solar industry, the need for a limited number of production steps, a small number of suppliers, and components that could be moved in standard shipping containers catalyzed the emergence of transnational supply chains. Here, regional clusters of firms specialized in individual stages of the production process. In the wind industry,

[48] I return to this question in the final chapter of this book, where I examine the application of collaborative advantage to global automotive and electronics industries. While the presence of existing, preglobalization incumbents has limited the ability of new firms to enter global supply chains, patterns of specialization and repurposing have nonetheless begun to emerge in these sectors.

[49] For an overview, see Gereffi, Humphrey, and Sturgeon 2005.

where components were difficult to ship and assembly typically took place in close proximity to the final installation location, suppliers often established secondary manufacturing plants around the world. The development of such globalized clusters—in which firms from diverse global backgrounds convened in a number of settings—nonetheless relied on collaboration, primarily between firms' core research and development operations in their home economies. These varied relationships brought together knowledge and skills from diverse firms and far-flung geographical locations. Despite advances in digital technologies, such expertise could not be fully codified in production equipment or design blueprints. Even if production machines and product designs now traveled more easily to faraway destinations, using, adapting, and improving technologies—let alone inventing new ones and producing them at scale—continued to require tacit skills and close interaction. This knowledge spread across a wide number of firms, and it was coordinated in global networks organized around such collaboration—networks that saw no need to defend or prop up preglobalization production arrangements made by incumbent firms.

A third requirement for collaborative advantage was *space for experimentation* as firms responded to state industrial policy through specialization and repurposing. The presence of collaborative advantage and its attendant opportunities for specialization offered firms new options for making use of industrial policies, many of which did not closely align with state goals. Compare contemporary wind and solar industries to the global auto sector of the 1960s and 1970s. For the late industrializers in Korea and Japan, auto manufacturing was primarily an exercise in emulation and reverse engineering, orchestrated by domestic conglomerates and encouraged by favorable industrial policies. Japanese and Korean auto firms had to compete with European and North American automakers who possessed broad technological skills and rich clusters of domestic suppliers. As East Asian developmental states funneled resources into select industrial sectors and made access to such resources dependent on meeting predetermined development goals, firms found themselves with few options but to establish the same range of technological capabilities as the large industrial clusters in the West. Japanese and Korean car manufacturers in the postwar decades therefore had little choice but to develop the full range of skills required to invent, commercialize, and manufacture new vehicles in the domestic economy: those were the skills that their competitors in Europe and North America possessed. Industrial policies that encouraged domestic firms to compete by integrating vertically and by emulating the technological capabilities of foreign competitors formed the centerpiece of industrialization in Japan and Korea.[50]

[50] Johnson 1982, chapters 7 and 8; Kim 1997, chapter 5.

As I showed in Chapter 2, government objectives changed little between the heyday of the East Asian developmental states and the early 2000s, when renewable energy sectors became the target of strategic state intervention. Research on state capacity among the East Asian late developers long emphasized the importance of state autonomy for meeting policy goals, particularly in areas with strong distributional consequences, such as industrial policy, that are prone to capture by outside interests. Building on Weber, scholars have pointed to organizational features of the bureaucracy as predictors of state capacity and effective industrial policy implementation. Hierarchically ranked offices, clearly defined administrative tasks, and meritocratic recruitment stood among the Weberian bureaucratic features that became central to explanations of good government among those East Asian developmental states that extensively employed industrial policy to advance in the global economy.[51]

Governments in China, Germany, and the United States hoped to gain relatively autonomous domestic wind and solar industries in return for large public investments in renewable energy. In one sense, these hopes were not realized: firms responded with specialization and collaboration, not a turn to greater autonomy. Yet at least implicitly, these governments tolerated the creative use of resources they saw unfolding, as firms experimented with strategies to enter global renewable energy sectors. States continued to support wind and solar sectors through industrial policies, even if firms did not meet expectations about traditional trajectories of industrial upgrading. This flexibility of state industrial policies, which is necessary for collaborative advantage to function, contrasts sharply with that of the East Asian developmental states, which rewarded firms only when meeting government-defined upgrading goals and withdrew support from those that failed to comply with official targets. The use of disciplinary mechanisms to encourage firms to meet predetermined upgrading goals, which Alice Amsden identified as an important factor in creating competitive firms in South Korea, likely would have prevented firms from participating in collaboration outside the scope of government plans.[52]

Collaborative advantage thus presented a new set of constraints on the ability of industrial policies to direct domestic industries into particular competitive strategies as the ability to forge autonomous domestic industries came under threat. State industrial policies could encourage firms to enter new industries—and indeed provided critical incentives for doing so—but states enjoyed far less leverage over firms' choices of technological specialization and competitive strategies than before economic globalization. Although governments pursued the goal of creating renewable energy sectors within national boundaries,

[51] See, for instance Amsden 2001, 145–47; Evans 1995, 12–14; Wade 1990, 26–27.
[52] Amsden 2001, 8–12.

industrial policies were unable to achieve these outcomes in the contemporary international economy. Governments in China and Germany failed to replicate the specialization they admired in those American start-ups busily inventing new technologies. Yet the particular institutional resources available to those start-ups prevented the Americans from emulating the R&D capabilities in commercialization common among Chinese manufacturers, as well as the automation skills that German equipment suppliers had mastered.

Political economists have long debated the role of the state in driving domestic industrial outcomes. On the one hand, scholars have pointed to East Asian developmental states to argue that strategic industrial policy interventions can create thriving, innovative firms, even in locations with very little history of industrial activity. Neoclassical economists have instead pointed to market forces and factor accumulation to explain the rise of East Asian firms. The framework I offer here suggests that industrial policy played a more nuanced role in driving industrial outcomes in the three economies under investigation. Under conditions of collaborative advantage, governments were limited in their ability to initiate radical industrial transformation through sectoral intervention; for even in emerging industries, industrial activities took the form of incremental variations on existing strengths, driven by firm experimentation.

I will revisit the role of experimentation in the final chapter of this book, where I show that the discrepancy between government goals and policy outcomes eventually led to a global backlash against collaboration. The trade disputes that have erupted between the European Union, the United States, and Chinese manufacturers of solar panels over the past decade exemplify the expectation that large parts of solar supply chains should locate domestically. They cast light on a growing concern among policymakers about the economic returns on investments in industrial policy.[53] The initial ability of firms to take advantage of collaboration in response to national industrial policies, however, was predicated on their ability to experiment and engage in recursive learning with global partners without government interference.

Empirical Strategy

Before turning to the empirical cases, I need to mention the process of data collection for this project. Sources for the remaining chapters of this book primarily consist of archival documents, public financial filings, and a novel dataset of more than 250 interviews conducted between 2008 and 2019. In China, local government yearbooks provided an important information source on

[53] For a summary of trade disputes in renewable energy sectors, see Lewis 2014, 22.

government institutions and served to cross-check interview data. For the vast majority of claims made in this book, I cite documentary sources in addition to interviews. I conducted interviews with executives of wind turbine and solar PV manufacturers operating in China, Germany, and the United States, as well as their suppliers. I held additional interviews with representatives from wind and solar industry associations, both at the national and subnational level, in each of these locations.

In China, I met with civil servants at national and provincial-level developmental agencies, executives in local developmental zones that hosted renewable energy firms, chambers of commerce representing foreign wind and solar firms operating in China, and academics at government research institutes working on renewable energy technologies and wind and solar industry development. A final group of interviews was conducted with state-owned banks, venture capital funds, and private investment firms with stakes in China's renewable energy industries. In Germany, I interviewed government representatives in federal and state (*Länder*) ministries, officials working in funding agencies dispensing federal research funds, and government officials in charge of regional economic development initiatives. A second group of interview subjects included representatives of lending institutions, including local credit unions and economic development banks. Community colleges and other training institutions are included in this category. In the United States, I supplemented industry research with interviews at public utility commissions, regional development organizations, national laboratories, and nongovernmental organizations in support of renewable energy development. Through participation in a broader research collective at MIT, I obtained access to an additional database of 264 interviews with small US manufacturers across a broad range of industrial sectors. I used these to test the application of my argument and the broader empirical patterns beyond the sectors I examine here in detail.[54]

For both wind and solar sectors, I compiled a list of companies from industry publications and official records. I sent interview requests to the fifteen largest wind and solar manufacturers in each location, as well as to suppliers of key components and production equipment. In the United States, I worked off a list of start-ups. With few exceptions, company executives agreed to be interviewed on the condition of confidentiality. In some cases, I was able to conduct multiple interviews within the same firm, meeting with CEOs and heads of technical departments. When companies had close ties with suppliers and other firms in the process of bringing new products to market, I supplemented my list and scheduled additional interviews with their partners to better understand each firm's individual contributions to product development and innovation. For a

[54] See Berger 2013b; Locke and Wellhausen 2014.

number of companies operating globally, I conducted separate interviews in each of these locations. While these subsequent interview subjects were selected according to their relationship with companies I had already visited, I submitted my initial interview requests for manufacturers and suppliers at random, based on lists compiled from industry publications (Table 3.3).

To keep company interviews consistent while also allowing respondents to address the unique characteristics of their firm's manufacturing and product development process, I employed a semistructured interview technique. The core of each interview consisted of a series of questions about the product development process for two products the firm had commercialized within the past five years. After asking interviewees to walk me through the process by which the firms had brought each idea from the R&D stage to large-scale manufacturing, I followed up with specific questions about workforce skills and technical capabilities, partnerships with suppliers and other firms, sources of capital and financing, and, finally, their reasons for choosing particular production locations. A large number of initial interviews were conducted between 2010 and 2012, covering developments in the wind and solar sectors up until that point. I have since made return trips to China and Germany at least once a year, most recently in January 2020; and I have kept in touch with interview subjects to identify potential changes in firm strategies and specialization. Unless drastic changes occurred in firms' strategies and industrial capabilities over time, I cite the first visit to a firm in the text. All interview subjects were promised complete confidentiality if needed, so I have removed identifying characteristics in the footnotes.

Table 3.3 Author Interviews in China, Germany, and the United States

	# of Interviews	**# of Firms Interviewed**
Wind turbine manufacturers	31	24
Wind turbine component suppliers	25	20
Solar PV manufacturers	37	30
Solar PV component suppliers	39	22
Industry associations	23	n/a
Government interviews	64	n/a
Banks, venture capitals, investment firms	37	n/a
Total	256	96