Going Green Like China

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Abstract

China has become the world's leading innovator in renewable energy technologies, accounting for 85% of global new patents in 2023 (up from 15% in 2009). This paper examines how China's hybrid system—state-owned electricity enterprises dominating downstream and private firms manufacturing upstream equipment—has facilitated this transformation. National renewable energy targets, enforced through career incentives for SOE managers, create strong and predictable downstream demand that stimulates upstream innovation. Using global supplier–customer pair-level data, we show that revenue growth among Chinese downstream customers is significantly associated with their suppliers' subsequent patenting. This effect is absent for non-Chinese customers but stronger among those politically aligned with the central government. Exploiting the 2022 clearance of feed-in tariff subsidy arrears to electricity firms as a demand shock provides causal evidence. Direct subsidies to suppliers have no significant effect, whereas subsidies to fast-growing downstream customers do. Finally, this arrangement also leads to overinvestment and excess capacity among suppliers.

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1 Introduction

The journal *Science* has named the surge in renewable energy as its 2025 Breakthrough of the Year (Appenzeller, 2025). The year 2025 marks the first time that renewable energy sources have surpassed coal as the world's primary source of electricity. Some renewable energy technologies, such as solar panels, have become more cost-effective than conventional fossil fuel–based energy.[1] Even without any subsidies, households are now incentivized to install rooftop solar panels to reduce energy expenses.

An important fact accompanying this achievement is that China has emerged as the dominant force in the manufacturing and innovation of renewable energy equipment. Chinese companies now supply approximately 80% of the world's solar cells, 70% of its wind turbines, and 70% of its lithium batteries (Thorp, 2025). They also file more than 80% of the new green patents in the renewable energy industry—a remarkable shift from the 2000s, when green technology was led mainly by the European Union and the United States.

Prior to its strategic shift around 2012, China prioritized economic growth at the expense of environmental protection. Since then, China has made steady progress toward building a greener economy—improving air and water quality, increasing electric vehicle adoption, expanding renewable power capacity, and reducing reliance on fossil fuels and coal. As the world's largest electricity consumer and carbon emitter, China's transition toward a low-carbon society, together with the global diffusion of its green technologies, makes a substantial contribution to global efforts to achieve net-zero emissions.[2]

What has driven this shift? How has China, within the span of a decade, transformed itself from a heavily polluted country into a global leader in the adoption, manufacturing,

[1] As New York Times reporter David Gelles recently observed, "Chinese solar panels are literally the cheapest form of energy we have ever had on Earth."

[2] Greening electricity is one of the keys to reaching net zero. Global energy-related CO_2 emissions totalled 36.8 Gt in 2022, with electricity and heat generation alone accounting for 14.65 Gt ($\approx$ 40%), followed by industry (direct fuel combustion, excluding electricity consumed) at 9.15 Gt ($\approx$ 25%) and transportation at 7.98 Gt ($\approx$ 22%) (International Energy Agency, 2023). China accounts for approximately one-third of global electricity consumption (International Energy Agency, 2025*a*). Renewable sources—solar, wind, and hydropower—currently supply roughly 32% of global electricity generation (International Energy Agency, 2025*b*).

and innovation of green technologies? In this paper, we answer this question by examining renewable energy equipment firms in China and other major countries. Our explanation highlights the uniqueness of China's hybrid economic system and supply chain structure, which combines national planning with market competition. This system appears effective in fostering green innovation, although it has inevitably led to overcapacity.

The renewable energy industry generally features a two-tier supply chain structure. The upstream segment consists of renewable energy equipment manufacturers, primarily producing solar panels, wind turbines, and energy storage systems. The downstream segment comprises end users from a number of industries, among which electricity generation companies operating power plants represent the main customers.

A distinctive feature of China's hybrid economic model lies in the composition of its downstream sector. Most electricity generation firms are state-owned enterprises (SOEs), with eleven major companies under direct control of the central government. These SOEs are not only responsible for producing electricity but also for executing national strategic goals in renewable energy development. The key factor is managerial political incentives: managers compete with their peers to advance government targets for green energy expansion in pursuit of promotion.

In contrast, the suppliers in the upstream segment—the renewable energy equipment manufacturers—are predominantly private firms. These companies compete intensely to provide equipment to the state-owned electric power groups, offering increasingly advanced technologies at lower prices. As a result, the upstream renewable equipment market is highly competitive, and it is also the sector that files the new patents advancing renewable energy technology.

China announced its "dual-carbon" goals in 2020, pledging to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060, in alignment with its commitments under the Paris Agreement. To realize these objectives, the central government established a series of phased targets and implementation strategies through its Five-Year Plans, be-

ginning with the 12th Plan period (2011–2015). These plans not only provide strategic guidance on industrial and technological development but also set concrete, quantitative goals—for example, specifying the cumulative gigawatt (GW) capacity of solar and wind power installations to be achieved by the end of each planning period.

The national targets are subsequently allocated among the eleven major state-owned electricity enterprises. Meeting these targets has become a politically binding task. We provide evidence that, during this period, chief executives and chairpersons of state-owned enterprises (SOEs) with higher achievements in renewable energy installation were more likely to be promoted to senior government positions, controlling for financial performance. Given such institutional incentives, SOE leaders have strong motivations to exceed their assigned targets. As a result, the renewable energy installation goals in each of the past three Five-Year Plans have been substantially overfulfilled. For instance, under the 13th Five-Year Plan (2016–2020), the national target for solar power installation was 1,100 GW, whereas actual installations reached approximately 2,500 GW; under the 14th Plan (2021–2025), the target was 6,500 GW, while realized capacity reached around 11,400 GW.

Strong demand from downstream firms can stimulate both production and innovation among their suppliers. Moreover, under national planning, supplier firms perceive the high demand for renewable energy equipment as persistent and credible, which further encourages upstream innovation (e.g., Leahy and Neary, 1997; Kamien, Muller and Zang, 1992). We find empirical evidence supporting this channel in the renewable energy equipment industry.

Specifically, we find that within supplier–customer relationships, a customer's revenue growth—used as a proxy for demand—is positively correlated with the supplier's innovation, measured by the number of new patents filed, in subsequent years, after controlling for the supplier's own revenue growth and pair fixed effects. A one-standard-deviation increase in customers' revenue growth is associated with a 13.5% increase in the number of patents filed by the supplier in the next year. Notably, this effect is significant only for suppliers serving Chinese customers, including both domestic and foreign supplier firms. This finding

is robust to controlling for customer- and supplier-country by year fixed effects and various customer and supplier characteristics.

To more directly link the political incentives of customer-firm managers to upstream innovation, we show that the effect is more pronounced among customers that are electricity power groups directly administered by the central government. Taken together, the findings support the demand channel formalized by Aghion et al. (2025): downstream greenification expands upstream suppliers' revenues and thereby strengthens their incentives to innovate; and the national planning mandates and political incentives embedded in SOEs can thus be thought of as a coordination device that pushes both downstream and upstream sectors toward the high-greenification steady state.

One potential endogeneity concern is that our results may be driven by sorting between high-growth customers and innovative suppliers, rather than by strong customer demand actually stimulating suppliers' patenting activity. Although we include pair fixed effects to address this issue, we further strengthen our identification strategy by exploiting a plausibly exogenous shock to some customers' demand for renewable energy equipment.

The Chinese government has long provided subsidy incentives for the installation of renewable power plants through its feed-in-tariff (FIT) program. However, these subsidies were largely recorded as receivables on the electricity firms' balance sheets until 2022, when the central government issued special-purpose funds to finance their disbursement. As a result, customers that had installed more renewable capacity experienced substantial cash inflows in 2022, which in turn increased their investment and demand for renewable energy equipment in subsequent periods. We define these customers as the treated group and conduct a difference-in-differences analysis. The results indicate that suppliers serving the treated customers filed significantly more patents following the shock. We also confirm that the pre-event trends between treated and control groups are parallel.

It is widely believed that government subsidies have been the main driving force behind the rapid expansion of China's renewable energy industry. We directly examine the effect of

subsidies within our empirical setting. For Chinese firms in our sample, we observe detailed records of government subsidies reported in their annual financial statements. We find that subsidies granted either directly to suppliers or to their customers are not significantly associated with higher patenting activity by suppliers in subsequent years. This result aligns with the literature highlighting information frictions that hinder the effectiveness of industrial policy and central planning (see, e.g., Noman and Stiglitz, 2016; Juhász and Lane, 2024, for surveys).

However, subsidies allocated to fast-growing downstream firms—those experiencing high revenue growth—effectively stimulate innovation among their suppliers. This suggests that the fast-growing customers are producing information on supplier quality. Only subsidies channeled to the best-performing downstream firms appear to generate meaningful innovation spillovers along the supply chain.

Finally, we examine the issue of overcapacity, which has been a central topic in discussions of China's renewable energy industry. The national guidance and political oversight of state-owned electricity enterprises have not only stimulated strong growth but also reduced demand uncertainty for upstream suppliers. While such an arrangement encourages innovation among suppliers, it can also lead to excessive investment and production.

We find consistent evidence of overcapacity. First, higher growth in customers' revenue is associated with increased investment by their suppliers in subsequent years. This effect is observed only among suppliers serving Chinese customers, yet it is significant for both domestic and foreign suppliers. Second, following periods of strong customer growth, suppliers tend to exhibit rising inventory levels, suggesting overproduction. This pattern is consistent with the "bullwhip" effect described by Leng et al. (2025), whereby demand shocks in downstream industries can be amplified upstream as suppliers adjust their production and investment decisions based on expected future demand.

Related literature and discussion A large body of work establishes that output expansion and demand can effectively drive corporate innovation (Leahy and Neary, 1997; Acemoglu and Linn, 2004; Myers and Pauly, 2019; Clemens and Rogers, 2026; Aghion et al., 2024; Lileeva and Trefler, 2010; Bustos, 2011; Slavtchev and Wiederhold, 2016). More recent research highlights the particular role of supply-chain networks in shaping innovation incentives and the diffusion of knowledge (Chu, Tian and Wang, 2019; Liu and Ma, 2021; Palit, Hora and Ghosh, 2022).

In the context of green innovation, our paper is most closely related to the theoretical work of Aghion et al. (2025), who develop a dynamic model of green technological transition along a vertical supply chain. A key mechanism in their framework is the demand channel: downstream greenification expands the market for upstream clean technologies, increasing innovators' revenues and incentives to invest. We provide large-scale empirical evidence supporting this mechanism.

Aghion et al. (2025) further establish that cross-sectoral strategic complementarities can trap economies in low-greenification steady states—even under optimal carbon taxation—making sector-specific industrial policy, particularly targeting downstream sectors, necessary to overcome the coordination failure. Our results suggest that China's hybrid economy resolves precisely this coordination problem: the promotion incentives facing SOE managers in the downstream electricity sector make their demand commitments credible and persistent, enabling upstream private suppliers to invest in greenification without waiting for rivals to act, thereby pushing the industry toward a high-greenification equilibrium.

A growing body of research examines the effectiveness of industrial policies designed to promote the green transition (e.g., Acemoglu et al., 2016, 2012; Aghion, Hemous and Veugelers, 2025) and has identified several key impediments. Juhász and Lane (2024) and Wang, Wurgler and Zhang (2026) emphasize the challenges arising from the political economy of green industrial policy, including policy uncertainty and time inconsistency. Noman and Stiglitz (2016) highlight the role of information frictions in constraining the effectiveness of

policy design and implementation. In the realm of sustainable investment, Hong, Kubik and Shore (2025) document the high return volatility of green assets, while Duchin, Gao and Xu (2025) show that greenwashing further distorts market signals by obscuring firms' true environmental performance.

China's approach to the green transition differs fundamentally from the market-based frameworks prevalent elsewhere. It is driven by top-down national planning and enforced through political controls over SOEs, yet it still relies on competition and innovation from the private sector. The long-term planning horizons embedded in successive Five-Year Plans substantially reduce policy uncertainty that might otherwise deter upstream investment. Moreover, managerial incentives tied to green electricity installation create credible demand signals for private upstream firms, help produce information, and leave little room for greenwashing. While China's distinctive approach may not be directly generalizable to other countries, it offers valuable insights into addressing the challenges in green transition.

The literature on the Chinese economy has long emphasized competition among local government officials as a key driver of economic growth (e.g., Qian and Xu, 1993; Maskin, Qian and Xu, 2000; Li and Zhou, 2005; Song, Storesletten and Zilibotti, 2011; Jia, Kudamatsu and Seim, 2015; Song and Xiong, 2023), with evidence suggesting that such tournament-style incentives can partially substitute for weak formal institutions. Groves et al. (1995) document similar competitive dynamics among SOE managers. We extend this line of research by showing that the central government has harnessed these tournament mechanisms to effectively advance its "dual-carbon" objectives, leveraging political control over personnel appointments in major electricity firms to sustain credible and persistent downstream demand for renewable energy equipment.

2 Background and Stylized Fact

2.1 China's green transition

Strategic turn to sustainability Since initiating economic reforms in the 1980s, China has long prioritized rapid economic growth over environmental protection. As the country's economy expanded and it emerged as the "world's factory," China attracted increasing global attention for its environmental challenges—ranging from severe air pollution and deteriorating water quality to rising carbon emissions. Domestic concerns have also grown, as the Chinese public became increasingly aware of the food safety and health hazards arising from environmental issues.

A major policy shift began to take shape around 2012, when the Chinese government articulated a vision of sustainable development.[3] The leadership began to emphasize that economic expansion should no longer come at the expense of environmental protection. This shift was institutionalized through a revised performance evaluation framework in 2013 for local government officials, which replaced the previous emphasis on GDP growth alone with balanced criteria that also account for environmental protection and energy efficiency.[4]

In September 2020, at the 75th United Nations General Assembly, China formally announced its "dual-carbon" goals—peaking carbon emissions before 2030 and achieving carbon neutrality before 2060. This is in line with its pledge under the Paris Agreement. The strong national push for renewable energy development also reflects China's strategic considerations regarding energy security, as the country continues to depend heavily on imported oil and natural gas to meet domestic energy demand. Together, these policy changes mark China's transition toward a model of green growth guided by both environmental and

[3] In his report to the 18th National Congress of the Communist Party of China on November 8, 2012, then-President Hu Jintao formally elevated the concept of "ecological civilization" to one of the nation's five overarching development objectives, explicitly emphasizing that economic growth should not come at the expense of environmental sustainability. See https://cpc.people.com.cn/n/2012/1118/c64094-19612151.html.

[4] See Organization Department of the Central Committee of the Communist Party of China (2013), "Notice on Improving the Performance Evaluation of Local Party and Government Leadership Teams and Leading Cadres," Document No. 22 [2013], December 6, 2013. Available at https://news.12371.cn/2013/12/09/ARTI1386590057904551.shtml.

strategic imperatives.

National planning As with many of its other national strategic objectives, China relies on its series of Five-Year Plans to implement goals related to environmental protection and renewable energy development. Each plan is first formulated and approved at the national level, after which local governments, sectoral ministries, and major SOEs develop more specific targets, actions, and policies in alignment with national priorities. These plans not only offer broad policy and technological guidance for industrial development but also specify concrete, quantitative targets to be achieved by the end of each planning period. Many of these targets are binding, and most are successfully met by their respective deadlines.

Although China's economy has transitioned away from a centrally planned system, the Five-Year Plans continue to provide a coherent and accountable framework for future development. They also set clear expectations for markets and private sectors, reducing policy uncertainty and guiding long-term investment decisions. In practice, many private enterprises formulate their own strategic plans based on the guidance and targets articulated in the government's Five-Year Plans.

Starting with the 12th Five-Year Plan (2011–2015), goals for the renewable energy industry have been carefully addressed. It also outlines the technological development path and supply-chain strategies. Importantly, quantitative objectives were established for key indicators such as carbon intensity, energy efficiency, and the share of non-fossil fuels in primary energy consumption. The next two five-year plans continued this trend.

Table 1 lists the key targets set in China's recent Five-Year Plans. For instance, the 12th Plan set a goal of reaching a total installed solar PV capacity of 210 GW, which increased to 1,100 GW and 6,500 GW in the 13th (2016–2020) and 14th (2021–2025) Plans, respectively. The table also shows targets for the energy consumption structure: the share of non-fossil energy in total primary energy consumption is targeted to reach 11.4% by 2015, 15% by 2020, and 20% by 2025.

Policy support and initiatives Among the various policies and initiatives that China has implemented to facilitate the green transition, three stand out as particularly critical.

First, the government has provided substantial subsidies to renewable energy producers and manufacturers. The centerpiece is the feed-in tariff (FIT) system, under which the NDRC introduced benchmark on-grid tariffs for wind power in 2009 and solar PV in 2011, setting prices above the coal-fired benchmark to create an implicit per-unit generation subsidy.[5] Benchmark tariffs were gradually reduced and converged to coal-fired prices by 2020, completing a phased subsidy withdrawal. China's approach is analogous to FIT schemes adopted in Europe.[6]

Beyond the FIT, the government also provides tax incentives—qualifying renewable energy equipment manufacturers benefit from a three-year corporate income tax exemption followed by three years at a 50% reduced rate—and channels fiscal grants to renewable energy R&D through the National Key Research and Development Program.

Second, China's state-owned banking system has directed large volumes of credit toward the green transition through designated green loans. These loans are typically extended at preferential interest rates and are subject to green project certification standards and ongoing monitoring over the loan period. The People's Bank of China (PBOC) sets national green credit targets, which are then allocated to the five major state-controlled commercial banks. As shown in the Online Appendix Figure A1, total green loan balances and their share of total bank credit have risen rapidly since 2012. By contrast, market-based instruments such as sustainable funds and green bonds remain relatively small in scale in China, making the state-directed banking channel the primary source of green financing.

Third, China has invested heavily in ultra-high-voltage (UHV) transmission infrastruc-

[5]See NDRC Price [2009] No. 1906 (http://ndrc.gov.cn/xxgk/zcfb/tz/200907/t20090727_965206.*html*) and NDRC Price [2011] No. 1594 (https://www.ndrc.gov.cn/xxgk/zcfb/tz/201108/t20110801_964803.*html*). Tariffs were set on a zonal basis reflecting regional resource endowments.

[6]Germany's Renewable Energy Sources Act (EEG, 2000) provided above-market guaranteed tariffs before transitioning to competitive auctions in 2017; the UK's Renewables Obligation scheme (2003–2017) required electricity suppliers to source minimum renewable shares before being replaced by a Contracts for Difference auction mechanism; and Italy's *Conto Energia* program offered differentiated solar PV tariffs until an annual cost cap of €6.7 billion was reached in 2013.

ture, which is essential for integrating renewable electricity into the national grid. Wind and solar resources are concentrated in economically underdeveloped western regions where local electricity demand is limited, while major consumption centers lie thousands of kilometers to the east. UHV lines—capable of transmitting power at 1,000 kV AC or ±800 kV DC—make long-distance electricity transmission economically viable with minimal energy losses. China began developing UHV technology since 2009 and today operates the world's largest UHV grid; the Online Appendix Figure A2 documents the rapid expansion of this infrastructure over time.

Taken together, these policy initiatives have collectively accelerated China's green transition. Nevertheless, they primarily constitute aggregate, time-series drivers of the transition. This paper's test instead focuses on the cross-sectional dimension: specifically, how supply-chain relationships between renewable energy equipment suppliers and their customers drive upstream innovation.

2.2 Progress and stylized facts

This strategic turning point is clearly reflected in the data. Panel A of Table 2 reports annual measures of water and air quality, all of which show steady and substantial improvement over time. For example, the average lake water quality index increased from 42.3 in 2011 to 74.6 in 2023, while the concentration of PM2.5 in the air declined from 85 to 30 over the same period. Panel B shows that greenhouse gas emissions from electricity generation declined from 0.75 kg/kWh in 2011 to 0.58 kg/kWh in 2023, while the share of electricity generated from renewable sources rose from 2% in 2011 to 15.6% in 2023.

China's progress in decarbonization has been broadly comparable to, if not faster than, that of other major economies, despite starting from a relatively high baseline in the early 2010s. Panel A of Figure 1 shows that the carbon intensity of GDP (measured as kilograms of CO_2 emitted per dollar of output) has declined markedly in China since 2010, substantially narrowing the gap with other countries. Panel B compares the carbon intensity of power

generation across major economies and reveals a similarly pronounced downward trend for China.

Statistics on newly installed electricity generation capacity reveal even more striking progress by China. Figure 2 presents the annual additions of solar and wind power capacity by country. In recent years, China's new installations have exceeded the combined total of all other countries. While this trend partly reflects China's position as the world's largest electricity consumer, the pace of expansion is remarkable. A decade ago, most new renewable capacity was concentrated in the European Union and the United States, but China has since surpassed both regions. This shift marks a significant realignment in global renewable energy investment and manufacturing, underscoring China's growing influence in shaping the trajectory of the global energy transition.

A comparison between Figure 2 and Table 1 shows that the targets set in the Five-Year Plans have not only been fully met but, in most cases, substantially exceeded by the end of each planning period. For example, the realized share of non-fossil in total primary energy consumption reached 12.0% in 2015, 15.8% in 2020, and 19.8% in 2025. Meanwhile, the share of coal in energy consumption declined from 64% in 2015 to 53.2% in 2025, closely tracking the official targets. Some goals were even substantially overfulfilled. For instance, the actual installed capacity of solar power reached 2,500 GW by 2020 and 11,400 GW by 2025, far surpassing the planned targets of 1,100 GW and 6,500 GW, respectively. A similar pattern is observed for wind power, where installations reached 2,800 GW and 5,900 GW in 2020 and 2025, compared with the targets of 2,100 GW and 4,500 GW.

2.3 Hybrid supply-chain structure

The renewable energy industry generally exhibits a two-tier supply chain structure. The upstream segment mainly consists of three industries, solar panels, wind turbines, and energy storage systems, along with their suppliers of basic materials, minerals, and so on; see Panel A of Figure 3.

The downstream segment comprises end users across multiple industries that utilize these technologies. Panel B of Figure 3 presents the industry composition of customer companies. The largest customers are concentrated in the utility, energy, transportation, and electrical equipment sectors. Among them, electricity generation companies operating power plants (classified under utilities) account for a substantial share of total demand.

Customers' political incentive A distinctive feature of China's hybrid model is that the downstream electricity generation sector is dominated by a group of large state-owned enterprises commonly known as the "five major and six minor" power groups.[7] These groups are centrally administered by the State-owned Assets Supervision and Administration Commission (SASAC) of the central government and account for more than half of the nation's total installed capacity.

Over time, SASAC has evolved its regulatory approach on sustainable development from broad normative guidance to a concrete and enforceable element of executive performance assessment for large SOEs. For these power groups, they are not only responsible for electricity generation but also play a central role in carrying out national strategic objectives related to renewable energy development. In 2021, SASAC further institutionalized this focus by incorporating the "Dual-Carbon" goals into the performance evaluation framework.[8] Managers of these state-owned electricity enterprises face career incentives: their performance evaluations and potential promotions are clearly tied to their success in meeting or exceeding targets for green energy expansion.

Such incentive structures not only reinforce strong and predictable demand for renewable energy equipment but also generate valuable information about high-quality and innovative equipment suppliers. This information-production function helps mitigate the informational inefficiencies typically associated with a centrally planned system, thereby improving resource

[7]The five major groups include Huaneng, Datang, Huadian, State Power Investment Corporation (SPIC), and China Energy Investment Corporation; The six minor groups are SDIC Power, China National Nuclear Corporation, China Three Gorges Corporation, CGN Group, CECEP Group, and China Resources Power.

[8]See the official policy documents issued by SASAC in 2008, 2019, and 2021.

allocation within the renewable energy industry. This is similar to the discussion on how political incentive of local government officials can help make informative regional economic policies (e.g., Maskin, Qian and Xu, 2000; Li and Zhou, 2005; Song and Xiong, 2023).

In our sample of Chinese firms, the asset-weighted state ownership share among customer companies is above 80%, ensuring that national planning objectives are effectively transmitted through the supply chain and reflected in industrial production outcomes.

Suppliers In contrast, the suppliers in the upstream segment—the renewable energy equipment manufacturers—are predominantly private firms. The asset-weighted state ownership share of Chinese supplier companies is only around 10%. These companies compete intensely to provide equipment to the state-owned electric power groups, offering increasingly advanced technologies at lower prices. As a result, the upstream renewable equipment market is highly competitive, and it is also the sector that files the new patents advancing renewable energy technology.

Importantly, innovation in the renewable energy industry is primarily driven by the private sector. Figure 4 (Panels A and B) reports the annual number of environment-related patents applied for and granted, respectively. In 2023, Chinese suppliers accounted for more than 85% of patent filings in the renewable energy sector. By contrast, innovation in this field was previously dominated by firms from the European Union and the United States.

In sum, China's hybrid supply chain can be characterized by state-owned customers with strong and predictable demand, combined with a private and highly competitive supplier sector that drives innovation.

3 Data and Sample Construction

3.1 Sample construction

We focus on firms that produce renewable energy equipment, identified using the Bloomberg Industry Classification System (BICS). Specifically, we select all firms classified under the Level 4 sub-industry *Renewable Energy Equipment* within the *Energy* sector, which covers manufacturers of solar, wind, and energy storage equipment.[9] This yields a global universe of 8,040 firms, of which 1,182 are publicly listed.

Patent information is from Orbis Intellectual Property, which covers records from patent offices worldwide. We match 6,030 of the 8,040 identified firms to Orbis using ISINs, LEIs, and firm names, and find 1,261 with at least one patent. We identify environment-related patents using two complementary criteria: CPC codes within the Y02 categories (Hege, Li and Zhang, 2024) and IPC codes listed in the IPC Green Inventory (Bolton, Kacperczyk and Wiedemann, 2023).

Supply chain relationships are obtained from FactSet Revere, which compiles supplier–customer links from firms' financial statement disclosures and public news sources. We focus on pairs in which a renewable energy equipment firm serves as supplier. A total of 647 such firms participate in at least one supply chain relationship during 2009–2023, of which 553 maintain relationships lasting longer than one year. Coverage is inherently limited to publicly listed firms subject to mandatory supply chain disclosure requirements.[10]

Finally, we collect financial data for all firms in our sample for 2009–2023 from Compustat (U.S. firms), Compustat Global (non-U.S. listed firms), and BvD Orbis Global Financials. Control variables for both the customer and supplier sides are defined in Table 3. Firm-level

[9]The sub-industry comprises three Level 5 segments: *Solar Energy Equipment* (polysilicon, photovoltaic cells and modules, thin-film modules), *Wind Energy Equipment* (turbines and components such as bearings, blades, and towers), and *Other Renewable Energy Equipment* (fuel cells, energy storage systems, and related technologies). Leading firms in each segment are listed in Online Appendix Table A1.

[10]In China, listed firms must disclose the revenue share of their top five customers and suppliers, but may report trading partners anonymously. In the United States, the SEC requires disclosure of customers representing at least 10% of total revenue, but does not mandate supplier disclosure.

emissions data (Scope 1/2/3) for customer firms are obtained from Trucost and matched using ISIN.

For Chinese firms listed on domestic stock markets, firm-level subsidy data are obtained from CSMAR based on mandatory disclosures in annual financial statements. We match CSMAR records to our main sample using ISINs and firm names. To our best knowledge, this information is not available for firms listed in other markets.

3.2 Summary Statistics

After restricting the sample to observations with non-missing financial data for both parties, customer total assets above USD 100 million,[11] relationships lasting more than one year, and at least one supplier patent during the relationship, we obtain 7,609 customer–supplier–year observations covering 340 renewable energy equipment firms.

Table 3 reports summary statistics. Suppliers file an average of 205 patents per year (median 45), nearly all environment-related. Customer's 3-year average revenue growth averages 11.7 % per year and supplier revenue growth 18.5%. Figure 3 shows the industry composition of suppliers (Panel A) and customers (Panel B). The largest customer industries are Utilities (24%) and Energy (18%), followed by Electrical Components and Transportation Equipment within the Industrial sector (14% and 13%, respectively). Among supplier firms with available BICS Level 5 segment information, Solar Energy Equipment firms account for 39%, Wind Energy Equipment firms for 23%, Energy Storage Systems firms for 28%, and others.

[11] We do not require disclosure of transaction values, which would sharply reduce sample size. The asset threshold ensures that retained customers are economically meaningful to their suppliers.

4 Empirical Result

4.1 Managerial Incentive of Customers

We provide empirical evidence that renewable energy development has become an increasingly important component in SOE executive promotion, as explicitly stated in SASAC's performance evaluation framework. We focus on the 11 major SASAC-administered power generation groups, which account for the majority of renewable electricity generation in China, and manually track the career movements of their chairpersons and CEOs using annual reports and public sources.

We classify the following career movements as promotions: transfers to government agencies (e.g., the National Energy Administration), promotions from CEO to chairperson within the same group, and appointments as chairperson of a larger SOE group. We then estimate a logit model with year fixed effects to examine whether renewable energy adoption increases the probability of executive promotion, conditional on financial performance:

$$Promotion_{c,t+1\to t+K} = \beta_1 RenewAdp_{c,t} + \gamma\, Controls_{c,t} + Year_t + \epsilon_{s,c,t} \tag{1}$$

$Promotion_{c,t+1\to t+K}$ is a dummy variable that equals one if the SOE's CEO or chairman experiences a promotion in year $t+1$ to $t+K$ and zero otherwise, where $K \in \{1,2,3\}$. $RenewAdp$ is measured as newly installed renewable energy capacity scaled by total assets (Watts per USD). Control variables include the firm size ($\ln(Asset)$), return on equity (ROE), revenue growth ($\Delta Revenue$), and gross margin ($GrossMargin$), all obtained from Tianyancha. The sample period is from 2015 to 2024.

As the central government has placed increasing emphasis on the "Dual-Carbon" objectives and gradually incorporated them into the executive evaluation framework, we expect the effect of $RenewAdp$ on $Promotion$ to strengthen over time. To test this, we augment

the specification with an interaction between $RenewAdp$ and a time trend t:

$$\begin{aligned} Promotion_{c,t+1\to t+K} = \beta_1 RenewAdp_{c,t} + \beta_2 RenewAdp_{c,t} \times t_t \\ + \gamma\, Controls_{c,t} + Year_t + \epsilon_{s,c,t} \end{aligned} \tag{2}$$

Table 4 shows that renewable energy adoption has a significantly positive effect on the likelihood of executive promotion over the subsequent three years. Since $RenewAdp$ (Watts of Renewable Energy installation per USD asset) is quite small, we standardized it and report the coefficient. Results in Column (5) show that a one-standard-deviation increase in $RenewAdp$ raises the probability of promotion by approximately 13.6 percentage points ($1.278 \times 0.121 \times (1-0.121) \approx 0.136$, evaluated at the sample mean promotion rate of 12.1%), indicating that higher renewable energy adoption is associated with substantially greater promotion prospects. The positive coefficient on $RenewAdp \times t$ further indicates that this relationship has strengthened over time, consistent with SASAC's progressive tightening of green performance targets.[12]

As green performance targets have become increasingly central to SOE evaluation, renewable energy adoption has emerged as a key competitive strategy for executives seeking advancement. This career incentive creates strong and persistent demand for renewable energy equipment, making central SOEs important and predictable customers for upstream suppliers.

Our findings are consistent with the broader tournament literature on Chinese local government officials. Li and Zhou (2005) and Maskin, Qian and Xu (2000) show that regional officials with stronger economic performance are significantly more likely to be promoted, creating powerful career incentives that drive local economic activity. We extend this finding to SOE managers, documenting that green energy adoption has become an increasingly important criterion in executive evaluation. Our results also relate to Shleifer and Vishny (1994),

[12] In the conditional logit model with year fixed effects, years with no within-year variation in $Promotion_{t+1}$ are dropped, leading to a smaller number of observations in Columns (1).

who argue that political objectives can distort managerial incentives away from value maximization; in our setting, however, this political incentive is channeled productively toward renewable energy expansion, aligning managerial career concerns with national sustainability goals.

4.2 Demand-pulled Innovation among Suppliers

Under China's "Dual Carbon" national planning framework and the career incentives of SOE managers, demand for renewable energy equipment from electricity firms is viewed as highly strong and predictable. Lower uncertainty about future demand strengthens suppliers' incentives to invest in innovation, giving rise to demand-pulled innovation in supply chains with Chinese customers.

To examine this effect, we estimate the following model:

$$\begin{aligned} Patent_{s,t+1} = \beta_1 \, \Delta Revenue^{C}_{s,c,t-2\to t} + \gamma \, Controls^{S}_{s,t} + \gamma_2 \, Controls^{C}_{c,t} \\ + Pair_{s,c} + Country^{C}_{s,c} \times Year_t + Country^{S}_{s,c} \times Year_t + \epsilon_{s,c,t} \end{aligned} \tag{3}$$

where S refers to the supplier firm, and C the customer firm. The dependent variable is the supplier's innovation intensity, proxied by the number of patents filed by the supplier ($Patent$). We proxy customer demand using the average growth rate of customers' total revenue in the past 3 years ($\Delta Revenue^{C}_{t-2\to t}$).[13] We control for firm characteristics on both the customer and supplier sides, including suppliers' $\Delta Revenue^{S}_{t-2\to t}$ (average growth rate of total revenue in the past 3 years), $R\&D^S$ (R&D expenditure scaled by total revenue), $\ln(Asset^S)$ (natural logarithm of total assets), ROA^S (net income divided by total assets), $CapEx^S$ (capital expenditures scaled by total assets), and $Tangibility^S$ (property, plant, and equipment divided by total assets), as well as customers' $\ln(Asset^C)$, ROA^C, $CapEx^C$, and $Tangibility^C$.

[13] If the supply chain relationship has existed for less than three years, the average growth rate is calculated from the start of the relationship.

Since the dependent variable is a count variable, we use a Poisson regression model with fixed effects, as suggested by Cohn, Liu and Wardlaw (2022). We include supplier–customer pair fixed effects to absorb time-invariant matching between high-growth customers and innovative suppliers, thereby alleviating concerns that our results are driven by endogenous sorting. The fixed effects $Country^{C}_{s,c} \times Year_t$ and $Country^{S}_{s,c} \times Year_t$ help mitigate concerns that the results are driven by country-year level events, such as policies supporting renewable energy innovation in either the customer or supplier country.

Panel A of Table 5 reports results of Equation (3) separately for Chinese customers (Columns (1)–(4)) and non-Chinese customers (Columns (5)–(7)). As anticipated, Columns (1) and (2) show that Chinese customers' revenue growth has a significantly positive effect on their suppliers' subsequent patenting. The magnitude is economically meaningful: a one-standard-deviation increase in customer revenue growth is associated with a 13.5% increase in supplier patents in the following year under the most stringent specification.[14]

Columns (3) and (4) further split the Chinese-customer sample by supplier's country. The positive effect persists for foreign suppliers to Chinese customers (Column (4)): the coefficient is economically meaningful and statistically significant at 10 % level (t-stat = 1.82) given the much smaller sample size. In contrast, $\Delta Revenue^{C}_{t-2\to t}$ is negative and statistically insignificant across all specifications for non-Chinese customers (Columns (5)–(7)). Notably, suppliers' own revenue growth has little effect on innovation across any column.

To formally test whether the coefficient on $\Delta Revenue^{C}_{t-2\to t}$ differs between Chinese and non-Chinese customers, we estimate Equation (4) on the full sample, augmenting the baseline with an interaction between $\Delta Revenue^{C}_{t-2\to t}$ and $isCN^{C}$, a dummy equal to one if the customer is Chinese.

[14] $0.296 \times 0.429 = 0.127, e^{0.127} - 1 = 0.135$

$$
\begin{aligned}
Patent_{s,t+1} = {} & \beta_1 \, \Delta Revenue^{C}_{s,c,t-2\to t} + \beta_2 \, \Delta Revenue^{C}_{s,c,t-2\to t} \times isCN^{C}_{s,c} \\
& + \gamma_1 \, Controls_{s,t} + \gamma_2 \, Controls_{c,t} + Pair_{s,c} \\
& + Country^{C}_{s,c} \times Year_t + Country^{S}_{s,c} \times Year_t + \epsilon_{s,c,t}
\end{aligned}
\tag{4}
$$

Panel B of Table 5 reports these results. The coefficient on $isCN^{C} \times \Delta Revenue^{C}_{t-2\to t}$ is significantly positive across all fixed-effect specifications, confirming a significantly stronger demand-pull effect for Chinese customers.

This result provides direct empirical support for the demand channel at the core of Aghion et al. (2025). Their Proposition 5(i) predicts that downstream greenification increases upstream innovators' revenues and thereby strengthens their incentives to pay the costs of greenification. In China, as SOEs expand their renewable energy capacity, the renewable equipment market generates the revenue signals that induce upstream suppliers to invest in green innovation.

The fact that this effect appears only among Chinese customers highlights the importance of the *credibility* of downstream demand commitments. Career incentives for SOE managers—linked to quantitative installation targets—make demand both sizable and highly predictable, a feature absent among non-Chinese customers operating under purely market-driven incentives.

To test this conjecture, we further exploit heterogeneity among Chinese customer firms. Specifically, the effect should be stronger for the 11 major power generation groups administered by SASAC compared with other Chinese downstream customers. These firms have strong political incentives to fulfill national targets for renewable energy installation. We estimate Equation (5) using the subsample of Chinese customers, augmenting the baseline specification with an interaction term between $\Delta Revenue^{C}_{t-2\to t}$ and SOE_PG^{C}, a dummy variable equal to one if the customer belongs to one of the 11 major power generation groups

described in Section 4.1.

$$\begin{aligned} Patent_{s,t+1} = \beta_1 \, \Delta Revenue^{C}_{s,c,t-2\to t} + \beta_2 \, \Delta Revenue^{C}_{s,c,t-2\to t} \times SOE_PG^{C}_{s,c} \\ + \gamma_1 \, Controls_{s,t} + \gamma_2 \, Controls_{c,t} + Pair_{s,c} + Country^{S}_{s,c} \times Year_t + \epsilon_{s,c,t} \end{aligned} \tag{5}$$

Panel C of Table 5 reports the results. The coefficient on $\Delta Revenue^{C}_{t-2\to t} \times SOE_PG^{C}$ is significantly positive across both specifications in Columns (1)–(2). Moreover, the effect is significant for both Chinese and foreign equipment firms supplying to Chinese customers, as shown in Columns (3)–(4). These results suggest that SOE managers with stronger career incentives in the energy sector generate more credible demand signals, giving rise to a clear demand-driven innovation pattern among their suppliers.

These results are related to the framework of Aghion et al. (2025): non-Chinese firms lack the downstream coordination mechanism necessary to escape the low-greenification equilibrium, explaining why the demand channel remains inactive outside China. By contrast, under China's hybrid system, national planning and the political incentives of SOE managers function as a coordination mechanism that steers the economy toward a high-greenification equilibrium.

Robustness First, we conduct the analysis on a subsample of electricity firms as downstream customers. In this setting, we can more precisely capture the demand for solar- and wind-related equipment by using the amount of newly installed renewable electricity generation capacity.[15] Accordingly, we also restrict the supplier sample to manufacturers of solar and wind power equipment. Consistent with our baseline results, Online Appendix Table A2 shows that the coefficient on installed renewable electricity capacity, $RenewAdp_{t-2\to t}$, is significant for the Chinese subsample in driving supplier innovation, but insignificant for non-Chinese customers.

Second, our findings are robust to using a one-year, rather than three-year, growth rate in

[15]Installed capacity is measured using plant-level data from the Global Energy Monitor (GEM) database; see Section 4.3 for details.

total revenue to calculate $\Delta Revenue_t^C$, which captures more recent demand. The results are reported in Online Appendix Table A3. Our finding remains robust if we change the measure of innovation intensity from the number of patents filed to the number of environment-related patents filed by the supplier ($EnvPatent$), as shown in Online Appendix Table A4. The impact of customer revenue growth on innovation intensity remains significant if we measure it using the number of patents filed by the supplier in a longer horizon (i.e., 3 years), as shown in Online Appendix Table A5.

Falsification Test We conduct a falsification test by replacing each actual customer with a fictitious one that has no supply chain relationship with the supplier. The fictitious customer is drawn from our sample, matched to the same country as the actual customer and to the closest firm size in that year. It is assigned at the start of the relationship and held fixed throughout its duration.

We re-estimate Equations (3) using fictitious customers in place of actual ones; results are reported in Table 6. Since there is no real business relationship between the supplier and the fictitious customer, the supplier's innovation intensity should be unrelated to the fictitious customer's revenue growth. Consistent with this expectation, the coefficient on $\Delta Revenue_{t-2\to t}^C$ is insignificant for Chinese fictitious customers.

Because fictitious and actual customers are matched on country and size, they face similar macroeconomic conditions and renewable energy–related policies. The null result for fictitious customers therefore rules out the possibility that our baseline findings are driven by broad country-level policy support, and confirms that the demand-pull effect operates through the supplier–customer relationship itself.

Real effect We assess whether the demand-pull innovation we document translates into real environmental outcomes. We regress the change in customers' Scope 1 greenhouse gas (GHG) emissions on suppliers' patent counts, and find that higher innovation intensity among Chinese renewable energy equipment suppliers is associated with a statistically significant

reduction in customers' GHG emissions beginning in year $t+2$. The economic magnitudes are sizable: a 1% increase in patents (environment-related patents) filed by Chinese suppliers is associated with a 0.284% (0.340%) reduction in customers' total emissions in year $t+2$ and a 0.166% (0.233%) reduction in year $t+3$. The reduction is also significant for GHG emission intensity. Results are reported in Online Appendix Table A6.

4.3 Quasi-natural Policy Experiment

An alternative explanation for the positive relationship between Chinese customers' revenue growth and their suppliers' innovation is sorting: high-growth customers may systematically form supply-chain relationships with more innovative suppliers. Although the pair fixed effects in our baseline model alleviate this concern, we further strengthen identification by exploiting a plausibly exogenous shock to Chinese customers' demand for renewable energy equipment. This demand shock arises from delays in the disbursement of China's FIT subsidies for renewable energy generation.

As discussed in Section 2.1, FIT subsidies apply to Chinese firms operating solar or wind power plants. Because firm-level FIT subsidy amounts are not publicly disclosed, we estimate each firm's subsidy receivable using plant-level data from Global Energy Monitor (GEM), which provides establishment year, installed capacity, and location for individual power plants. For each plant k in region c commissioned in year t_0, the annual subsidy is:

$$FIT_Subsidy_{k,t} = \left(FIT_rate_{c,t_0} - CoalPrice_t\right) \times OperatingHours_{k,t} \times Capacity_k, \quad (6)$$

where FIT_rate_{c,t_0} is the benchmark tariff at commissioning, $CoalPrice_t$ is the benchmark coal-fired electricity price, and $OperatingHours_{k,t}$ is annual plant utilization.[16] Data on FIT_rate_{c,t_0} by region and resource tier are from NDRC policy documents, and operating

[16]We use the initial FIT rate (FIT_rate_{c,t_0}) throughout the factory's lifecycle. Because each policy adjustment only targets newly commissioned projects, the subsidy rate is determined at the time of factory establishment and remains fixed thereafter.

hours from the National Energy Administration. Then, we map power plants to the firms in our sample using their owners' name, and sum up plant level FIT subsidies to the firm level.

China planned to finance FIT subsidies through a renewable energy surcharge on electricity consumption. However, prior to 2022, surcharge revenues could not fully cover subsidy obligations, resulting in a persistent payment shortfall.[17]

Figure 5 documents this shortfall by plotting the national-level FIT subsidy payable (aggregated from plant-level estimates) alongside actual FIT-related fiscal income and expenditures from CEIC. A persistent gap is evident before 2022; in 2021, for example, actual fiscal expenditures covered only 51% of estimated subsidy obligations.

Starting in 2022, the Ministry of Finance began disbursing accumulated unpaid subsidies through special-purpose central government funds.[18] This results in a sharp increase in actual subsidy payments as shown in Figure 5. This represented a substantial and largely unexpected improvement in cash flows for renewable energy producers.[19]

We exploit this policy-induced cash-flow shock in a difference-in-differences framework. Treated customers are firms eligible to receive FIT subsidy, and are therefore very likely to receive large lump-sum disbursements when the government cleared its arrears. The control group consists of customer firms that did not operate solar or wind power plants before 2020 and were therefore unaffected by the 2022 disbursement. [20] First, we validate whether the shock indeed increases customers' contemporaneous cash flows and subsequently higher investment and demand for renewable energy equipment. Specifically, we conduct the

[17]Extensive documentation of these arrears exists in government reports and firm disclosures. The NPC's "Inspection of the Implementation of the Renewable Energy Law" reports that during 2016–2020, funding had not been secured for more than 90% of newly added renewable energy generation projects; see http://www.npc.gov.cn/npc/c2/c30834/201912/t20191224_303904.html. Separately, Jinko Power disclosed that nearly 95% of its accounts receivable consisted of overdue FIT subsidy payments; see https://stock.10jqka.com.cn/20241104/c663161493.shtml.

[18]See https://sgnec.sgcc.com.cn/home/newsenergydetail?newsId=2207150404300032986.

[19]Longyuan Power disclosed that it received RMB 11.4 billion in the first half of 2022 from the RMB 100 billion tranche of renewable energy subsidy arrears disbursed; see https://news.qq.com/rain/a/20231226A073YQ00.

[20]We do not have direct information on the actual accumulated FIT subsidy arrears for each firm prior to 2022. Therefore, we use the eligibility to receive FIT subsidies as a proxy of the likelihood to receive lump-sum disbursements in 2022. Due to the subsidy degression, only firms that built solar and wind farms before 2020 were eligible to receive the FIT subsidies.

following regressions:

$$OCF^{C}_{c,t} = \beta_1 Treat^{C} \times Post_t + \gamma_1 Controls^{S}_{s,t} + \gamma_2 Controls^{C}_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t} \tag{7}$$

$$CapEx^{C}_{c,t+1} = \beta_1 Treat^{C} \times Post_t + \gamma_1 Controls^{S}_{s,t} + \gamma_2 Controls^{C}_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t} \tag{8}$$

where $Treat^{C}$ is a dummy variable equal to 1 if the firm is eligible to receive FIT subsidies from the Chinese government, $Post$ equals one for 2022 and subsequent years, and control variables include customers' $\ln(Asset^{C})$, ROA^{C}, $CapEx^{C}$, and $Tangibility^{C}$.

The results are reported in Columns (1) to (2) of Table 7. We find that the policy shock significantly increases treated customers' operating cash flow in the current year and their capital expenditure in the subsequent year, confirming that treated customers experience an expansion in demand for equipment following the policy shock.

Next, we examine whether the demand-pull channel transmits upstream to suppliers. Equation (9) estimates the effect of the policy shock on the number of patents filed by suppliers in the subsequent year.

$$Patent_{s,t+1} = \beta_1 Treat^{C} \times Post_t + \gamma_1 Controls_{s,t} + \gamma_2 Controls_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t} \tag{9}$$

As shown in Columns (3) to (5) of Table 7, the coefficients on $Treat^{C} \times Post_t$ are significantly positive across all specifications, indicating that an exogenous increase in customer demand induced by the subsidy disbursement policy leads to higher supplier innovation intensity. The economic magnitude is also sizable: suppliers of treated customers experience a 28.1% ($e^{0.248} - 1$) increase in patent filings in the subsequent year.

To verify the parallel trend assumption, we interact the treatment indicator ($Treat_i$) with a series of year dummies, setting the year prior to the policy implementation as the

base period. Figure 6 reports the point estimates and their corresponding 95% confidence intervals. The statistically insignificant coefficients for all pre-treatment periods support the parallel trend assumption, indicating no systematic differences between treatment and control groups prior to the policy shock.

4.4 Role of government subsidies

Government subsidies have long been believed as a central driver of China's rapid renewable energy expansion (e.g., Helveston and Nahm, 2019; Auffhammer et al., 2021; Dong, Zhou and Li, 2021). Yet systematic firm-level evidence on the effectiveness of these subsidies remains limited. From a theoretical standpoint, economists have long cautioned that industrial policies are prone to inefficiency owing to information asymmetry between governments and firms (Hayek, 1945; Kornai, 1980; Noman and Stiglitz, 2016).

In this subsection, we examine whether and how subsidies drive innovation along the supply chain, providing direct firm-level evidence on the conditions under which government subsidies are most effective. Publicly listed firms in the Chinese A-share stock market are required to disclose government subsidies received in their annual financial statements. We construct the variable *Subsidy* as total government subsidies scaled by revenue for each listed firm. Restricting the sample to supplier–customer pairs in which both firms are listed in China, we estimate the following Poisson model with fixed effects:

$$\begin{aligned} Patent_{s,t+1} = \beta_1 \, \Delta Revenue^{C}_{s,c,t-2\to t} + \beta_2 \, \Delta Revenue^{C}_{s,c,t-2\to t} \times HighSubsidy^{C}_{s,c} \\ + \gamma_1 \, Controls_{s,t} + \gamma_2 \, Controls_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t} \end{aligned} \tag{10}$$

where $HighSubsidy^{C}$ is a dummy variable equal to one if the customer's average *Subsidy* over the past five years is above the median (in Columns (1) to (2)) or quantile (in Columns (3) to (4)) among the customers in the same BICS sector in that year. As some Chinese suppliers are listed overseas and do not report subsidy data (e.g., Flat Group before 2019, JA Solar before 2019, Trina before 2020, Jinko before 2025), we use the average *Subsidy*

within the supplier's BICS Level 5 segment as a proxy for the subsidy level received by each supplier. Control variables are the same as in the baseline specification.

Table 8 reports the regression results across different control variable specifications. The interaction term $\Delta Revenue^C \times HighSubsidy^C$ is significantly positive, whereas the coefficient on $HighSubsidy^C$ alone is not significant. This pattern suggests that subsidies received by downstream customers do not, by themselves, stimulate upstream innovation. Rather, subsidies amplify the demand-pull effect only when directed at fast-growing downstream customers.

This finding is consistent with an information-asymmetry interpretation: the government cannot readily identify which upstream firms will convert subsidies into productive innovation, so direct subsidy provision alone may fail to stimulate upstream innovation. By contrast, when subsidies flow to high-growth downstream customers, those customers—who possess superior information about their suppliers' capabilities—transmit credible demand signals that effectively drive upstream innovation. This finding echoes the argument in Aghion et al. (2025) that subsidizing the downstream sector is more effective than subsidizing the upstream sector.

4.5 Overcapacity

Another widely discussed issue regarding China's renewable energy industry is overcapacity (e.g., Yellen, 2024). When upstream manufacturers base production and investment decisions on anticipated future demand, demand shocks in the downstream industry propagate upstream and can be amplified along the supply chain (Leng et al., 2025). In addition, economies of scale make expanding production capacity an effective way to lower unit costs, thereby conferring a competitive advantage on suppliers. Together, these forces can lead to excessive investment and production in upstream renewable energy equipment manufacturing.

We examine whether the demand-pulled mechanism identified earlier also contributes to

upstream overinvestment and overcapacity using the following model:

$$\begin{aligned} OverCapacity_{s,t\to t+K} = \beta_1\, \Delta Revenue^{C}_{s,c,t-2\to t} + \gamma_1\, Controls^{S}_{s,t} + \gamma_2\, Controls^{C}_{c,t} \\ + Pair_{s,c} + Country^{C}_{s,c} \times Year_t + Country^{S}_{s,c} \times Year_t + \epsilon_{s,c,t} \end{aligned} \tag{11}$$

We measure $OverCapacity$ from two perspectives: (i) $\Delta Inventory$, the annual change in inventory scaled by COGS; and (ii) ΔPPE, investment in property, plant, and equipment (PPE) divided by total asset.

We calculate the average of suppliers' $\Delta Inventory$ over the subsequent one to three years and estimate Equation (11). The results are reported in Table 9. Panel A presents the estimates separately for supplier–customer pairs with Chinese customers (Columns (1) to (3)) and non-Chinese customers (Columns (4) to (6)). For Chinese customers, the coefficient on customer revenue growth $\Delta Revenue^{C}_{t-2\to t}$ is positive and statistically significant across all horizons, indicating that stronger downstream demand is associated with a persistent increase in upstream inventory accumulation. In contrast, the corresponding coefficients for non-Chinese customers are small and statistically insignificant, suggesting no comparable inventory response.

To test whether the difference in supplier inventory is significant between Chinese customers and non-Chinese customers, we run a regression on the global sample and introduce an interaction term $\Delta Revenue^{C}_{s,c,t-2\to t} \times isCN^{C}_{s,c}$:

$$\begin{aligned} OverCapacity_{s,t\to t+K} = \beta_1\, \Delta Revenue^{C}_{s,c,t-2\to t} + \beta_2\, \Delta Revenue^{C}_{s,c,t-2\to t} \times isCN^{C}_{s,c} \\ + \gamma_1\, Controls_{s,t} + \gamma_2\, Controls_{c,t} + Pair_{s,c} \\ + Country^{C}_{s,c} \times Year_t + Country^{S}_{s,c} \times Year_t + \epsilon_{s,c,t} \end{aligned} \tag{12}$$

Panel B of Table 9 reports the results. The interaction term $\Delta Revenue^{C}_{t-2\to t} \times isCN^{C}$ is significantly positive at $k = 1$, confirming that the inventory build-up in response to downstream demand growth is significantly stronger when the customer is Chinese.

Table 10 reports the results using the average of suppliers' ΔPPE over the subsequent one to three years as an alternative measure of overcapacity. Panel A presents the estimates separately for supplier–customer pairs with Chinese customers (Columns (1) to (3)) and non-Chinese customers (Columns (4) to (6)). For Chinese customers, the coefficient on $\Delta Revenue^{C}_{t-2\to t}$ is positive and becomes statistically significant at 5% level starting from year $t+2$, suggesting that stronger downstream demand leads to a sustained increase in upstream fixed asset investment over the following years. For non-Chinese customers, the coefficients are small and insignificant.

Panel B reports results for the full sample by interacting customer revenue growth with the Chinese customer indicator, $\Delta Revenue^{C}_{t-2\to t} \times isCN^{C}$. The interaction term is positive and statistically significant for $k = 2$ and $k = 3$, confirming that the PPE investment response to downstream demand is significantly stronger when the customer is Chinese.

Together, these results show that the demand-pull from Chinese customers not only drives upstream inventory accumulation but also induces sustained fixed capital investment over subsequent years. This evidence suggests that overcapacity is a natural consequence of China's state-driven model for developing its renewable energy industry.

5 Conclusion

China has transformed within a single decade from one of the world's most heavily polluted countries into the dominant global force in the manufacturing and innovation of renewable energy technologies. This paper examines the institutional mechanisms behind this transformation. We argue that China's hybrid economic system—in which state-owned enterprises dominate the downstream electricity segment while private, competitive firms drive upstream equipment manufacturing—generates an unusually effective demand-pull channel for green innovation. National renewable energy targets set in successive Five-Year Plans, enforced through career incentives for SOE managers, create strong, credible, and persistent

downstream demand that stimulates innovation among upstream suppliers.

We first document the managerial incentive mechanism at the heart of this system. Using data on career movements of executives at the major SASAC-administered power generation groups, we show that SOE leaders with stronger renewable energy installation achievements are significantly more likely to be promoted to senior positions, controlling for financial performance. This relationship has strengthened over time as the central government has progressively tightened green performance criteria in its SOE evaluation framework. These tournament-style incentives align managerial career concerns with national sustainability goals, and—critically—make downstream demand commitments credible and predictable to upstream suppliers.

Using global supplier–customer pair data, we then establish the demand-pull mechanism empirically. A one-standard-deviation increase in Chinese customers' 3-year average revenue growth is associated with a 13.5% increase in supplier patent filings in the subsequent year. This effect holds for both domestic and foreign suppliers serving Chinese customers, but is absent for suppliers of non-Chinese customers. To establish causality, we exploit the Chinese government's 2022 clearance of accumulated FIT subsidy arrears as a quasi-natural experiment: suppliers serving treated electricity firms filed approximately 28.1% more patents following the cashflow shock.

We also examine the role of government subsidies in driving supply-chain innovation. Direct subsidies to suppliers, or to average downstream customers, have no significant association with upstream patenting—consistent with the view that governments face information frictions in identifying productive innovators. In contrast, subsidies directed to fast-growing downstream customers effectively stimulate upstream innovation.

Finally, we show that the same institutional forces driving innovation also generate overcapacity. Following periods of strong Chinese customer revenue growth, suppliers accumulate excess inventory and expand fixed capital investment over one-to-three-year horizons. These effects are absent for suppliers of non-Chinese customers. Our findings suggest that over-

capacity in China's renewable energy sector is not a separate policy failure but an inherent byproduct of the same institutional mechanism that drives innovation.

Our findings offer broader insights for the economics of green transition. Standard policy prescriptions—carbon pricing, direct subsidies, sustainable investment mandates—are facing challenges. China's unique approach largely sidesteps these by using the career incentive structure of its SOE sector to generate credible, large-scale downstream demand, effectively delegating the innovation decision to competitive upstream markets while anchoring long-run demand expectations through national planning.

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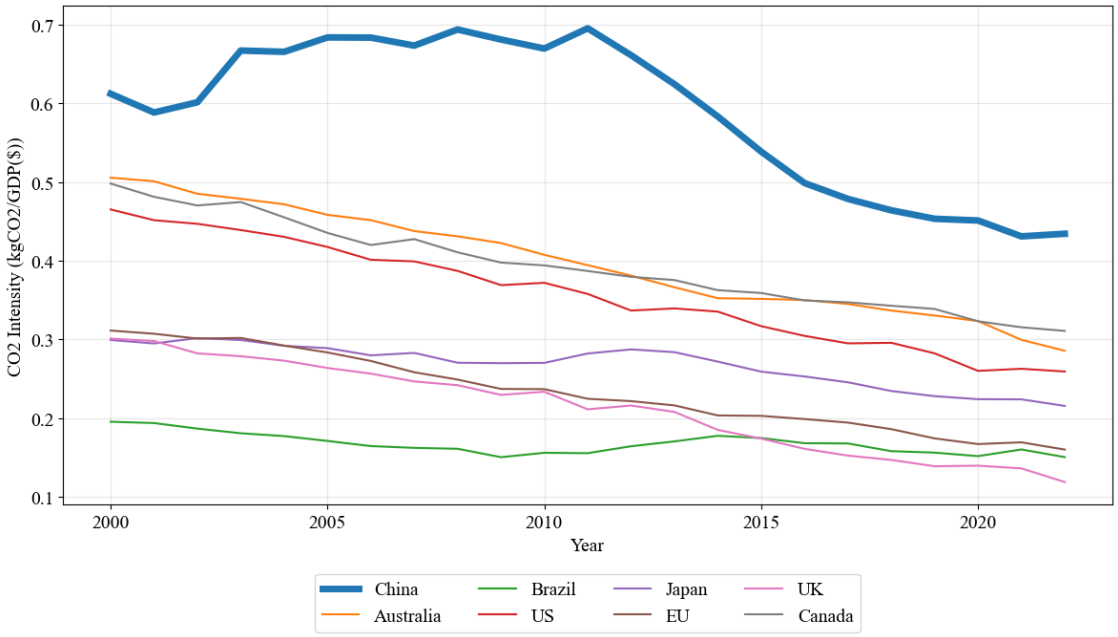
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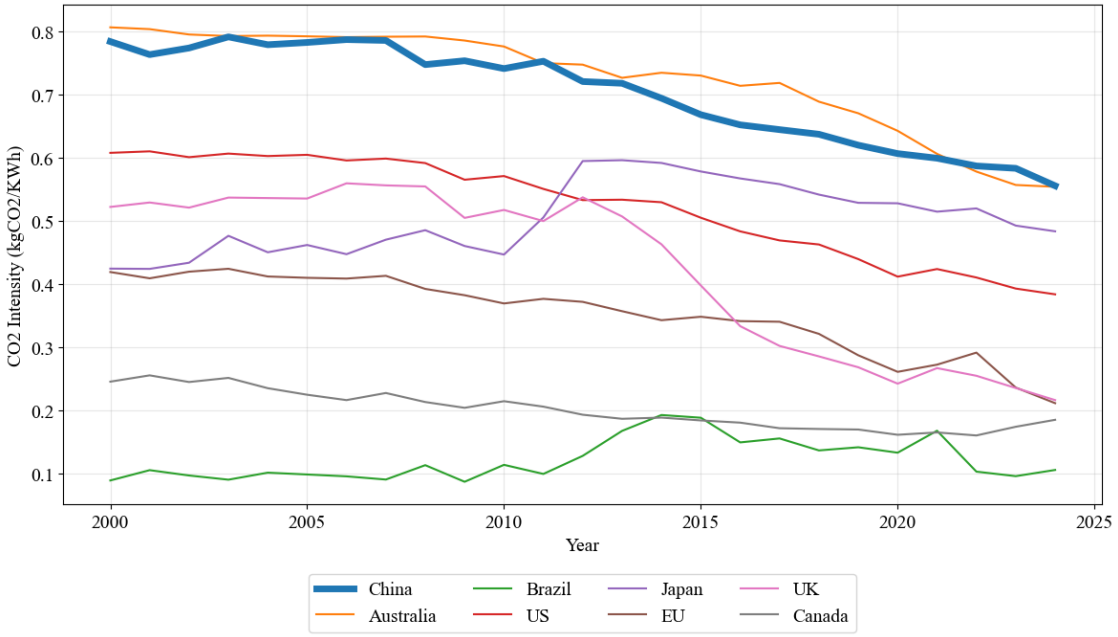
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Figure 1: Carbon Intensity



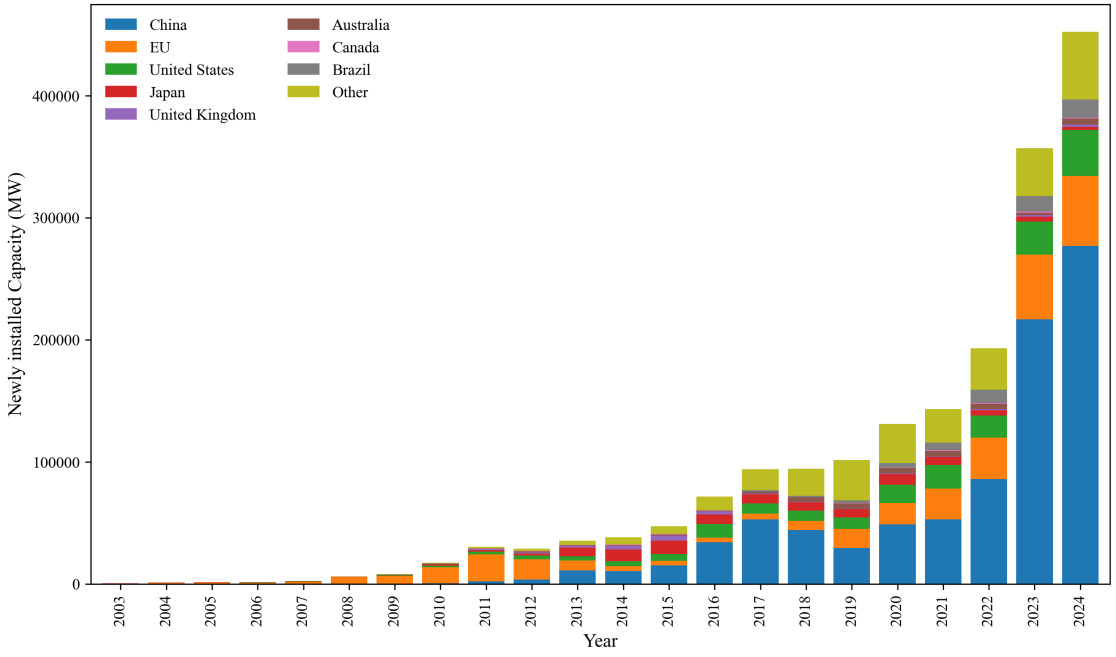
(a) Carbon Intensity of GDP



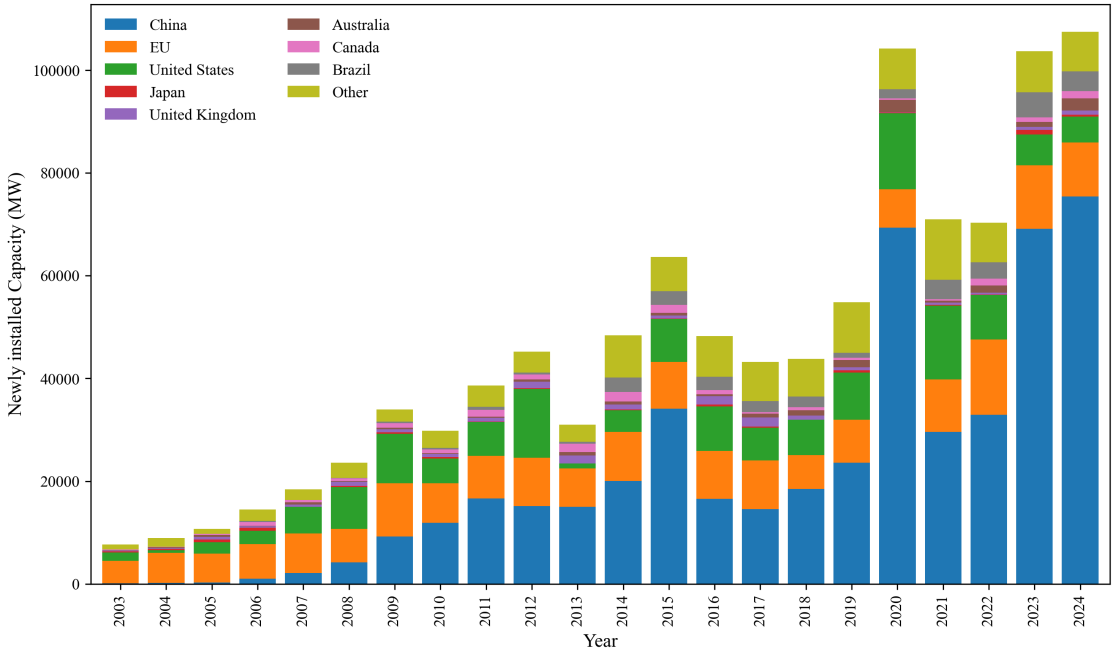
(b) Carbon Intensity of Power Generation

Notes: This figure shows carbon intensity in GDP (Panel A) and power generation (Panel B) for each country from 2000 to 2024. Data is collected from Our World in Data.

Figure 2: Newly Built Renewable Energy Capacity



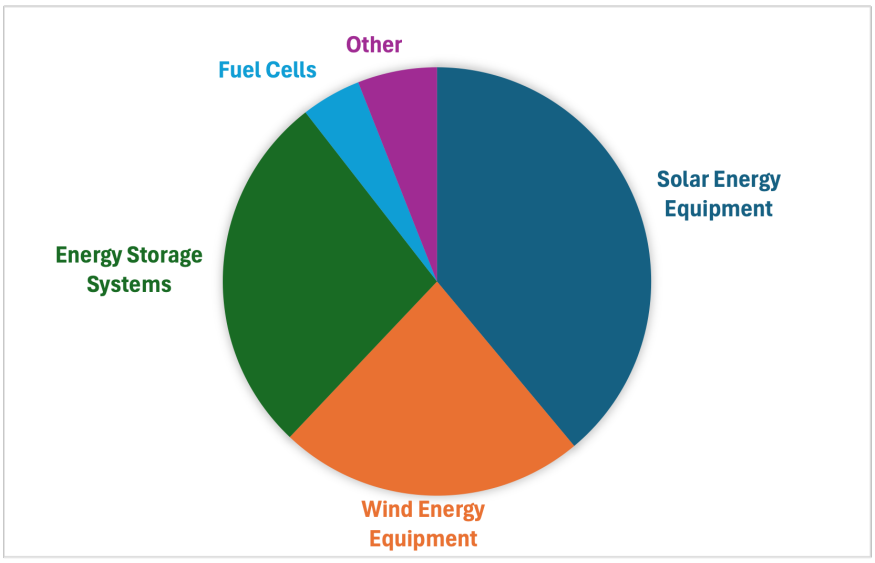
(a) Solar PV



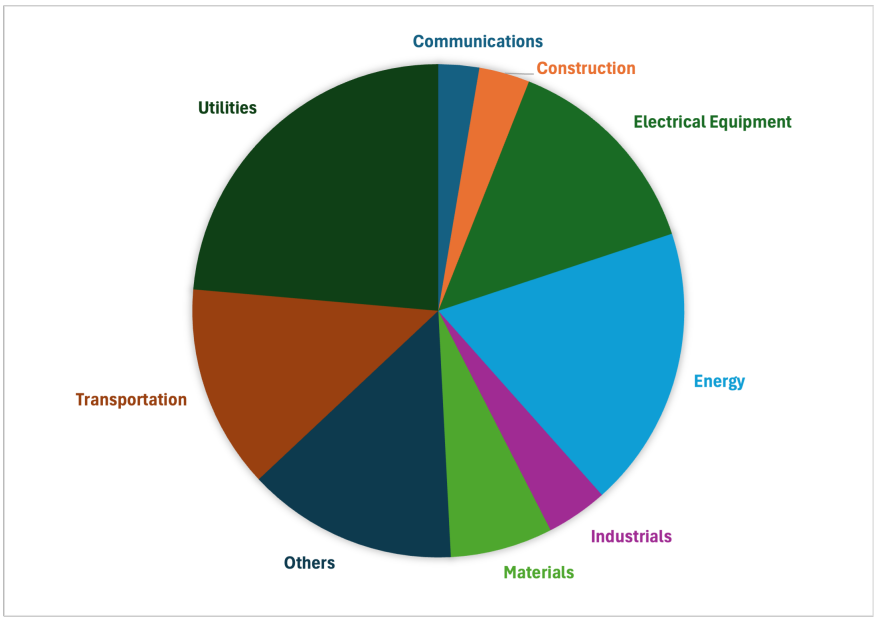
(b) Wind Energy

Notes: This figure shows the newly built renewable energy capacity, including solar PV installation (Panel A) and wind energy installation (Panel B) for each country from 2003 to 2024. Data is collected from IRENA.

Figure 3: Industry Distribution of Suppliers and Customers



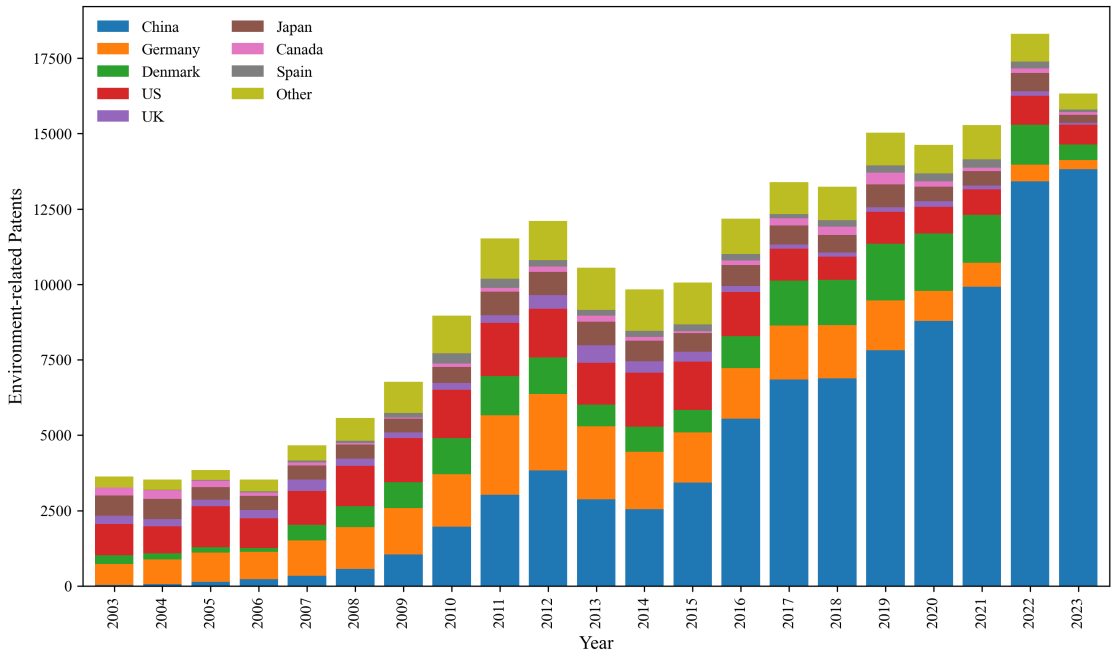
(a) Supplier industry



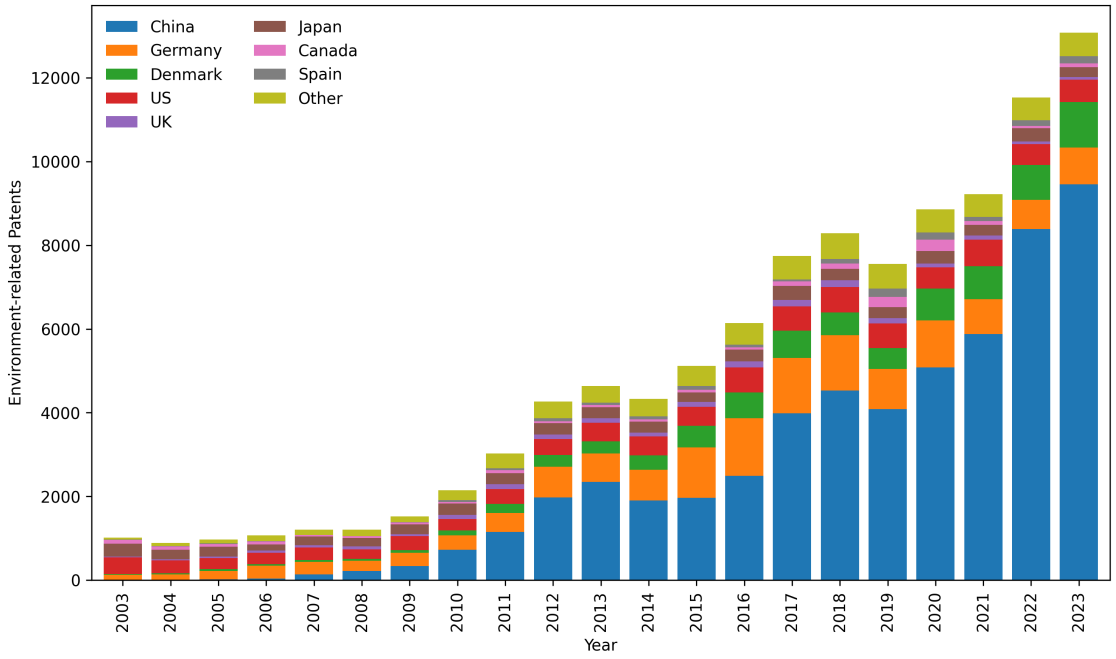
(b) Customer industry

Notes: This figure shows the industry distribution of customer and supplier under the BICS industry classification.

Figure 4: Renewable Energy Equipment Firms' Green Patent



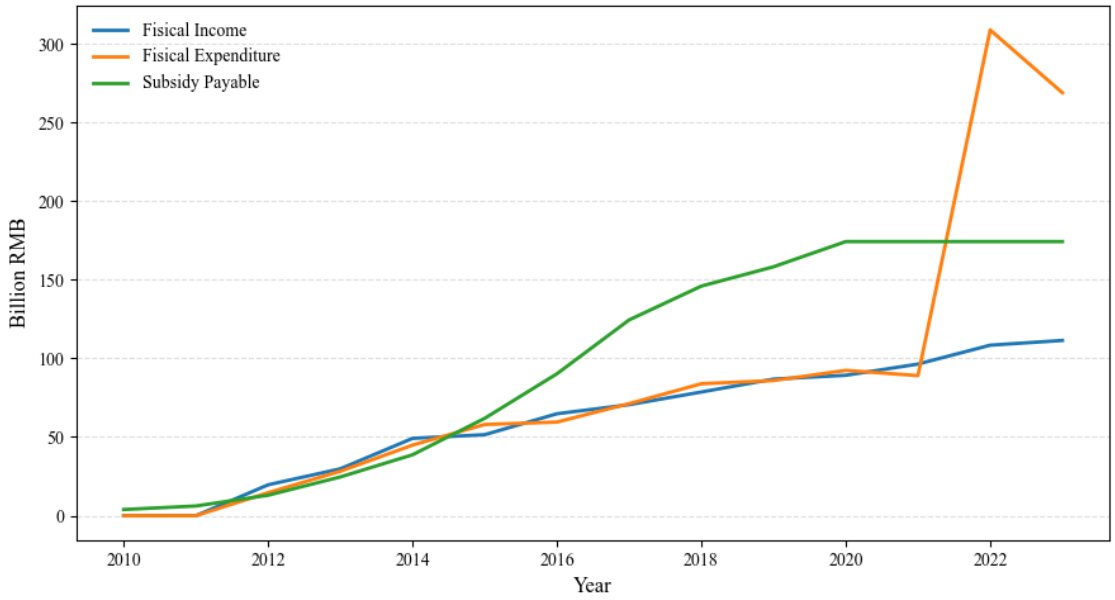
(a) Environment-related Patents Applied



(b) Environment-related Patents Granted

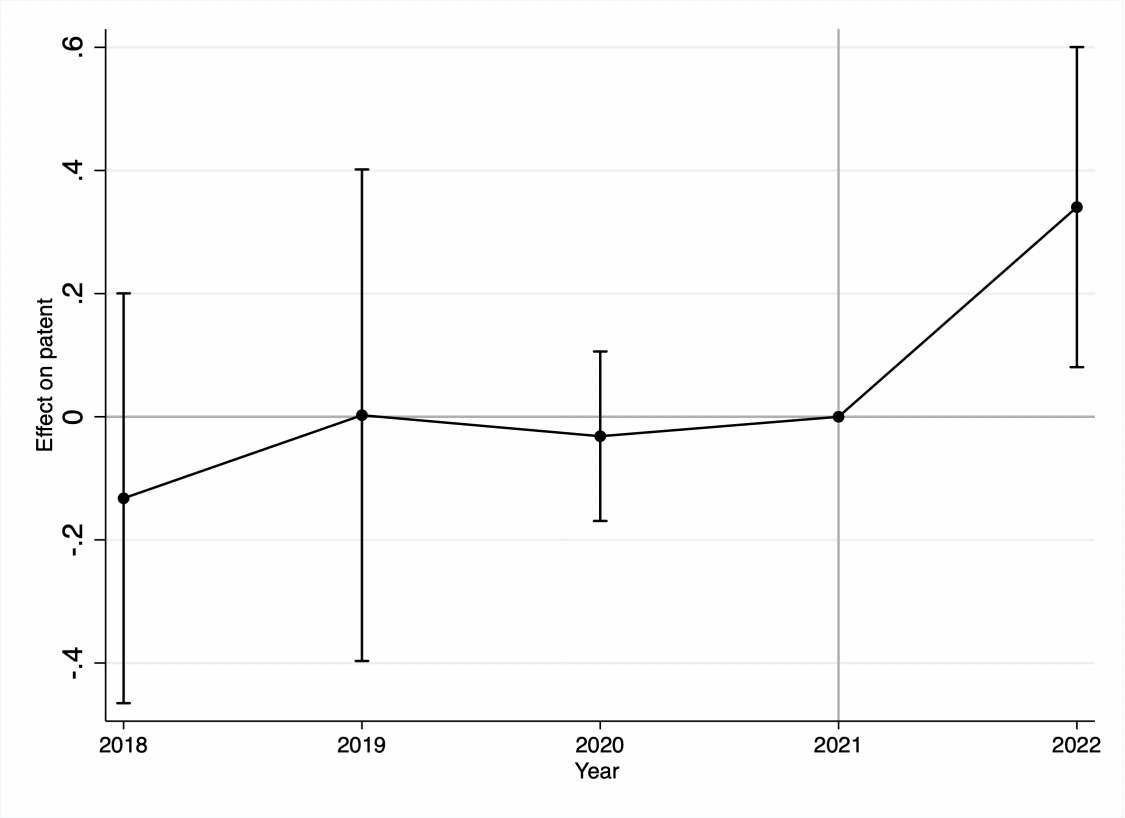
Notes: This figure shows the number of environment-related patents filed (Panel A) and granted (Panel B) by firms in BICS sub-industry *Renewable Energy Equipment* for each country.

Figure 5: China's FIT Subsidy Arrear and Clearance



Notes: This figure demonstrate FIT subsidy arrear and clearance in China by showing the difference between FIT subsidy payable and the actual fiscal expenditure for this type of subsidy.

Figure 6: Placebo Test of Subsidy Shock



Notes: This figure test the parallel trend after 2018 by estimating the Poisson equation :

$$Patent_{i,t+1} = \sum_{\tau=2018, \tau \neq 2021}^{2022} \beta_\tau (Treat_i^C \times Year_\tau) + Pair_{s,c} + \delta_t + \varepsilon_{c,s,t}$$

We plots the estimated coefficients β_τ along with their 95% confidence intervals.

Table 1: China's Five-Year Plan on Energy Transition

This table presents the energy transition target outlined in China's Five-Year Plans and the actual achievements. [21]

	Planning Period					
	2011–2015		2016–2020		2021–2025	
	Target	Actual	Target	Actual	Target	Actual
Total installed capacity (GW)						
Solar PV	210	432	1100	2500	6500	11400*
Wind	1000	1308	2100	2800	4500	5900*
Energy consumption structure (%)						
Non Fossil	11.4	12	15	15.8	20	21.5
Coal	65	64	58	56.8	/	53.2*

[20]Data marked with an asterisk indicate that the actual achievements for the 2021-2025 period are not yet officially available. Data on total installed capacity are as of October 2025, while data on energy consumption shares are as of 2024.

Table 2: Environment Related Indicators in China

This table presents environment related indicators for China from 2011 to 2023. Panel A reports measures of water quality, including the share of lakes with good water quality (Lake) and the proportion of near-shore sea areas with good water quality (Near-shore Sea); air quality indicators, including the share of cities experiencing acid rain (Acid Rain (%)), average SO2 concentration (SO_2 ($\mu g\,m^{-3}$), and average PM2.5 concentration ($PM_{2.5}$ ($\mu g\,m^{-3}$). Panel B reports indicators of renewable energy adoption, including greenhouse gas emissions per unit of electricity generation (Electric Related GHG (kg/kWh)), the share of non-hydropower renewable energy in total electricity generation (Renewable Energy (%)), and the share of new energy vehicles in total new vehicle sales (EV Market Share). Detailed source of these data is shown in Appendix A.1.

Panel A: Environment Protection

	Water Quality		Air Quality		
	Lake	Near-shore Sea	Acid rain (%)	SO_2 ($\mu g\,m^{-3}$)	$PM_{2.5}$ ($\mu g\,m^{-3}$)
2011	42.3	62.8	48.5	41	85
2012	61.3	69.4	41.0	37	83
2013	60.7	66.4	44.4	40	72
2014	61.3	66.8	44.3	35	62
2015	69.4	70.5	40.4	25	50
2016	66.6	73.4	38.8	22	47
2017	62.5	67.8	36.1	18	43
2018	66.6	74.6	37.6	14	39
2019	69.1	76.6	33.3	11	36
2020	76.8	77.4	34.0	10	33
2021	72.9	81.3	30.8	9	31
2022	73.8	81.9	33.8	9	29
2023	74.6	85.0	28.8	9	30

Table 2: Environment Related Indicators in China (Continued)

Panel B: Renewable Energy Adoption

	Electric Related GHG (kg/kWh)	Renewable Energy (%)	EV Market Share
2011	0.75	2.01	
2012	0.72	2.64	
2013	0.72	3.24	
2014	0.69	3.61	
2015	0.67	4.56	1.5
2016	0.65	5.95	1.81
2017	0.64	7.20	2.69
2018	0.64	8.57	4.47
2019	0.62	9.51	4.66
2020	0.61	10.66	5.40
2021	0.60	12.86	13.48
2022	0.59	13.68	25.62
2023	0.58	15.56	31.53

Table 3: Summary Statistics

This table shows summary statistics. We report the *Patent* (patent filed each year), *EnvPatent* (environment-related patent filed each year), for the supplier. We also report the $\Delta Revenue$ (growth rate of total revenue), $R\&D$ (R&D expenditure scaled by total revenue), $\ln(Asset)$ (natural logarithm of total assets), ROA (net income divided by total assets), $CapEx$ (capital expenditures scaled by total assets), and $Tangibility$ (property, plant, and equipment divided by total assets) for both supplier (with superscript S) and customer (with superscript C)

	N	Mean	sd	p1	p25	p50	p75	p99
	Panel A: Statistics for the Global Customer-Supplier Pairs							
$Patent^S$	7609	205.125	329.988	0.000	7.000	45.000	237.000	1182.000
$EnvPatent^S$	7609	201.082	323.949	0.000	6.000	42.000	233.000	1182.000
$\Delta Revenue^C_{t-2\to t}$	7609	0.117	0.296	-0.361	-0.022	0.049	0.167	1.342
$\Delta Revenue^S_{t-2\to t}$	7609	0.185	0.403	-0.420	-0.024	0.102	0.291	1.796
$\ln(Asset)^C$	7609	23.190	2.107	18.772	21.583	23.340	24.768	27.122
$CapEX^C$	7609	0.051	0.046	0.000	0.018	0.041	0.070	0.239
$Tangibility^C$	7609	0.612	0.422	0.000	0.268	0.562	0.899	2.092
ROA_C	7609	0.027	0.059	-0.213	0.003	0.025	0.049	0.220
$\ln(Asset)^S$	7609	21.231	2.156	16.390	19.662	21.458	22.652	26.251
$CapEX^S$	7609	0.044	0.049	0.000	0.008	0.030	0.062	0.227
$Tangibility^S$	7609	0.374	0.260	0.033	0.176	0.305	0.500	1.242
ROA_S	7609	-0.036	0.159	-0.924	-0.027	0.000	0.033	0.157
$R\&D^S$	7609	0.098	0.341	0.000	0.008	0.028	0.063	1.839
	Panel B: Statistics for SOE Energy Group in China							
$Promotion$	107	0.121	0.328	0.000	0.000	0.000	0.000	1.000
$RenewAdp$	107	0.023	0.016	0.001	0.010	0.021	0.033	0.063
$ln(Asset)$	107	25.540	0.628	23.751	25.330	25.553	25.966	26.660
ROE	107	0.064	0.033	-0.001	0.039	0.069	0.081	0.135
$\Delta Revenue$	96	0.083	0.116	-0.165	0.018	0.068	0.126	0.737
$GrossMargin(\%)$	107	0.274	0.105	0.104	0.204	0.253	0.327	0.536

Table 4: Executive Promotion for SOE Managers

This table examines how renewable energy adoption affects the probability of executive promotion among 11 central state owned energy corporation, using logit models with year fixed effects as specified in Equation (1) and Equation (2). The dependent variable, $Promotion_{t \to t+k}$, is a dummy equal to one if either the CEO or the board chair is promoted during this period. $RenewAdp$ is measured as newly installed renewable energy capacity scaled by total assets. t is a time trend variable. Control variables include firm size ($\ln(Asset)$), return on equity (ROE), revenue growth (RG), and gross margin ($GrossMargin$). T-stats in parentheses are calculated using robust standard errors.

	$Promotion_{t+1}$		$Promotion_{t+1 \to t+2}$		$Promotion_{t+1 \to t+3}$	
	(1)	(2)	(3)	(4)	(5)	(6)
$RenewAdp_t$	0.944*	-0.861	0.681**	0.027	1.278***	1.741***
	(1.665)	(-0.898)	(2.277)	(0.061)	(4.516)	(2.590)
$RenewAdp_t \times t_t$		0.403*		0.172*		-0.107
		(1.849)		(1.721)		(-0.770)
Year Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	64	64	96	96	96	96
Pseudo R-square	0.204	0.254	0.200	0.221	0.250	0.254

Table 5: Main Result: Demand-pulled Innovation among Suppliers

This table presents the results of the fixed effect Poisson regression model. Panel A reports the results of Equation (3) for samples with Chinese and non-Chinese customers separately, further distinguishing between Chinese suppliers ($isCN^S = 1$) in Column (3) and non-Chinese suppliers ($isCN^S = 0$) in Column (4). Panel B reports the results of Equation (4) for the full sample. Panel C reports the results of Equation (5) for the Chinese subsample. The dependent variable $Patent$ is the number of patent filed by the supplier. $\Delta Revenue^C_{t-2\to t}$ is the average revenue growth of customer in the past 3 years. $isCN^C$ is a dummy variable distinguishing whether the customer is a Chinese firm and SOE_PG^C is a dummy variable distinguishing whether the customer belongs to a SASAC-administered power generation group. Control variables include firm characteristics from both supplier side firm characteristics ($\Delta Revenue^S_{t-2\to t}$,$R\&D^S$,ln($Asset^S$), ROA^S, $CapEx^S$, and $Tangibility^S$) and customer side (ln($Asset^C$), ROA^C, $CapEx^C$, and $Tangibility^C$). T-stat in parentheses are calculated using standard errors clustered at the customer-supplier pair level.

Panel A

	$Patent_{t+1}$						
	Chinese Customer				Non-Chinese Customer		
	All suppliers		$isCN^S = 1$	$isCN^S = 0$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta Revenue^C_{t-2\to t}$	0.336***	0.429***	0.558***	0.193*	-0.045	-0.047	-0.053
	(2.813)	(3.224)	(3.335)	(1.821)	(-0.909)	(-0.860)	(-1.408)
$\Delta Revenue^S_{t-2\to t}$	0.337*	0.418**	0.380**	0.283	0.008	-0.048	-0.039
	(1.741)	(2.235)	(2.071)	(1.022)	(0.119)	(-0.671)	(-0.526)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes	No	No
$Country^C \times Year$ FE	No	Yes	No	No	No	Yes	Yes
$Country^S \times Year$ FE	No	Yes	No	No	No	No	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	859	798	645	214	6746	6428	5965
Pseudo R-square	0.960	0.964	0.959	0.975	0.955	0.961	0.973

Table 5: Main Result: Demand-pulled Innovation among Suppliers (Continued)

Panel B

	$Patent_{t+1}$		
	(1)	(2)	(3)
$\Delta Revenue^{C}_{t-2\to t}$	-0.045	-0.037	-0.046
	(-0.915)	(-0.687)	(-1.190)
$\Delta Revenue^{C}_{t-2\to t} \times isCN^{C}$	0.274**	0.300**	0.301**
	(2.046)	(2.367)	(2.339)
$\Delta Revenue^{S}_{t-2\to t}$	0.019	-0.003	0.032
	(0.275)	(-0.042)	(0.329)
Pair FE	Yes	Yes	Yes
Year FE	Yes	No	No
$Country^{C} \times Year$ FE	No	Yes	Yes
$Country^{S} \times Year$ FE	No	No	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	7609	7287	6812
Pseudo R-square	0.955	0.960	0.972

Panel C

	$Patent_{t+1}$			
			Chinese Customer	
	All sample		$isCN^{S}=1$	$isCN^{S}=0$
	(1)	(2)	(3)	(4)
$\Delta Revenue^{C}_{t-2\to t}$	0.279**	0.395***	0.509***	0.141
	(2.391)	(2.871)	(2.980)	(1.607)
$\Delta Revenue^{C}_{t-2\to t} \times SOE_PG^{C}$	1.353***	0.831**	1.211**	1.124***
	(3.189)	(2.232)	(2.321)	(2.998)
$\Delta Revenue^{S}_{t-2\to t}$	0.259	0.364*	0.303	0.148
	(1.309)	(1.872)	(1.585)	(0.589)
Pair FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes
$Country^{S} \times Year$ FE	No	Yes	No	No
Supplier Controls	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes
Observations	859	798	645	214
Pseudo R-square	0.961	0.964	0.959	0.975

Table 6: Falsification Test

This table presents the results of the falsification test, we re-estimate Equation (3) by replacing the actual customer in each supplier–customer relationship with a fictitious customer. The fictitious customer is a firm in our sample that is located in the same country as the original customer and has the closest total assets in that year. Control variables include firm characteristics from both supplier side firm characteristics and customer side. T-stat in parentheses are calculated using standard errors clustered at the customer-supplier pair level.

	$Patent_{t+1}$						
	Chinese Customer				Non-Chinese Customer		
	All sample		$isCN^C = 1$	$isCN^C = 0$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta Revenue^C_{t-2\to t}$	0.043	0.090	0.115	-0.048	0.046	0.062	0.033
	(0.313)	(0.714)	(0.742)	(-1.216)	(0.882)	(1.064)	(0.899)
$\Delta Revenue^S_{t-2\to t}$	0.430*	0.590***	0.620***	-0.061	-0.028	-0.035	-0.006
	(1.945)	(2.579)	(2.658)	(-0.720)	(-0.444)	(-0.511)	(-0.077)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes	No	No
$Country^C \times Year$ FE	No	Yes	No	No	No	Yes	Yes
$Country^S \times Year$ FE	No	Yes	No	No	No	No	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	787	726	581	145	6342	6177	5732
Pseudo R-square	0.959	0.963	0.957	0.986	0.955	0.961	0.973

Table 7: Policy Experiment

This table presents results using the 2022 change in subsidy policy as an exogenous demand shock. Columns (1) and (2) report the regression results of Equation (7) and Equation (8), with the OCF^C (operating cash flow scaled by total asset) and $CapEx^C$ (capital expenditure scaled by total asset) as dependent variables respectively. Columns (3) to (5) report the results of the fixed-effect Poisson model in Equation (9). $Treat^C$ is a dummy variable equal to one if the firm is eligible to receive feed-in tariff subsidies from the Chinese government, and *Post* equals one for years beginning from 2022. The sample is restricted to cases in which both the customer and the supplier are Chinese firms, and the supplier has at least one customer eligible for feed-in tariff subsidies. Customer side and supplier side control variables are provided in Table 5. T-stats in parentheses are calculated using standard errors clustered at the customer-supplier pair level.

	OCF_t^C	$CapEx_{t+1}^C$	$Patent_{t+1}$		
	(1)	(2)	(3)	(4)	(5)
$Treat^C \times Post_t$	0.018**	0.046***	0.349***	0.254**	0.248*
	(2.245)	(3.965)	(2.600)	(2.032)	(1.727)
Pair FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Supplier Controls	Yes	Yes	No	Yes	Yes
Customer Controls	Yes	Yes	No	No	Yes
Observations	440	440	440	440	440
Pseudo R^2	0.837	0.761	0.966	0.968	0.969

Table 8: Role of Government Subsidies

This table shows the result the Poisson regression model with fixed effect in Equation (10). The sample is restricted to cases in which both the customer and the supplier are Chinese firms. $HighSubsidy^C$ is a dummy equals to 1 if customer's 5-year average subsidy ratio is above median (Columns (1) to (2)) or in top quantile (Columns (3) to (4)) within $CustomerSector \times Year$. In addition to firm characteristics from supplier side and customer side described in Table 5, we also control for $IndSubsidy^S$ (the supplier industry level subsidy ratio). T-stats in parentheses are calculated using standard errors clustered at the customer-supplier pair level.

	$Patent_{t+1}$			
	Top 50%		Top 20%	
	(1)	(2)	(3)	(4)
$\Delta Revenue^C_{t-2\to t}$	0.102*	0.185***	0.101*	0.192***
	(1.785)	(3.022)	(1.828)	(2.982)
$HighSubsidy^C_t$	-0.006	0.023	-0.097	-0.077
	(-0.056)	(0.219)	(-1.250)	(-0.957)
$HighSubsidy^C_t \times \Delta Revenue^C_{t-2\to t}$	0.174*	0.267**	0.205***	0.355***
	(1.712)	(2.510)	(2.782)	(3.497)
$\Delta Revenue^S_{t-2\to t}$	0.603***	0.541***	0.630***	0.575***
	(2.996)	(2.837)	(2.983)	(2.799)
$Subsidy^S_t$		42.230		32.859
		(1.048)		(0.825)
Pair FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes	Yes
Customer Controls	No	Yes	No	Yes
Observations	461	461	461	461
Pseudo R^2	0.959	0.960	0.958	0.960

Table 9: Overcapacity: Inventory

This table examines whether customer revenue growth is associated with changes in suppliers' overcapacity. Panel A reports the results of Equation (11) for samples with Chinese and non-Chinese customers separately, while Panel B reports the results of Equation (12) for the full sample. Supplier overcapacity is proxied by the change in inventory ($\Delta Inventory$). Customer side and supplier side control variables are provided in Table 5. T-stats in parentheses are calculated using standard errors clustered at the customer–supplier pair level.

Panel A

	Chinese Customer $\Delta Inventory_{t+1\to t+k}$			Non-Chinese Customer $\Delta Inventory_{t+1\to t+k}$		
	$k=1$	$k=2$	$k=3$	$k=1$	$k=2$	$k=3$
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Revenue^{C}_{t-2\to t}$	0.100**	0.066**	0.051***	-0.000	-0.003	0.002
	(2.289)	(2.012)	(2.603)	(-0.007)	(-0.329)	(0.216)
$\Delta Revenue^{S}_{t-2\to t}$	-0.236***	-0.215***	-0.151***	-0.071***	-0.016*	0.010
	(-4.314)	(-5.809)	(-4.603)	(-5.243)	(-1.690)	(1.517)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
$Country^{C} \times Year$ FE	Yes	Yes	Yes	Yes	Yes	Yes
$Country^{S} \times Year$ FE	Yes	Yes	Yes	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	800	779	531	5047	4907	4096
Pseudo R^2	0.624	0.747	0.890	0.752	0.830	0.909

Table 9: Overcapacity: Inventory (Continued)

Panel B

	$\Delta Inventory_{t+1\to t+k}$		
	$k=1$	$k=2$	$k=3$
	(1)	(2)	(3)
$\Delta Revenue^{C}_{t-2\to t}$	0.000	-0.002	0.005
	(0.002)	(-0.156)	(0.483)
$\Delta Revenue^{C}_{t-2\to} \times isCN^{C}$	0.081**	0.032	0.018
	(1.963)	(1.098)	(1.011)
$\Delta Revenue^{S}_{t-2\to t}$	-0.110***	-0.054***	-0.016**
	(-7.009)	(-4.640)	(-2.062)
Pair FE	Yes	Yes	Yes
$Country^{C} \times Year$ FE	Yes	Yes	Yes
$Country^{S} \times Year$ FE	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	5878	5712	4650
Pseudo R^2	0.713	0.802	0.902

Table 10: Overcapacity: PPE

This table examines whether customer revenue growth is associated with changes in suppliers' overcapacity. Panel A reports the results of Equation (11) for samples with Chinese and non-Chinese customers separately, while Panel B reports the results of Equation (12) for the full sample. Supplier overcapacity is proxied by the change in Property, Plant, and Equipment (ΔPPE). Customer side and supplier side control variables are provided in Table 5. T-stats in parentheses are calculated using standard errors clustered at the customer–supplier pair level.

Panel A

	Chinese Customer $\Delta PPE_{t+1\to t+k}$			Non-Chinese Customer $\Delta PPE_{t+1\to t+k}$		
	$k=1$	$k=2$	$k=3$	$k=1$	$k=2$	$k=3$
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Revenue^{C}_{t-2\to t}$	0.036*	0.050***	0.029**	0.000	0.002	-0.002
	(1.665)	(3.098)	(2.277)	(0.025)	(0.191)	(-0.270)
$\Delta Revenue^{S}_{t-2\to t}$	-0.007	-0.016	-0.010	0.010	-0.006	-0.007
	(-0.354)	(-1.197)	(-0.929)	(1.254)	(-1.023)	(-1.506)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
$Country^{C} \times Year$ FE	Yes	Yes	Yes	Yes	Yes	Yes
$Country^{S} \times Year$ FE	Yes	Yes	Yes	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	800	779	531	5047	4907	4096
Pseudo R^2	0.745	0.890	0.942	0.785	0.857	0.900

Table 10: Overcapacity: PPE (Continued)

Panel B

	$\Delta PPE_{t+1\to t+k}$		
	$k=1$	$k=2$	$k=3$
	(1)	(2)	(3)
$\Delta Revenue^{C}_{t-2\to t}$	0.001	0.003	-0.001
	(0.095)	(0.403)	(-0.131)
$\Delta Revenue^{C}_{t-2\to} \times isCN^{C}$	0.024	0.039**	0.032*
	(1.200)	(2.218)	(1.949)
$\Delta Revenue^{S}_{t-2\to t}$	0.007	-0.012**	-0.011**
	(0.958)	(-2.328)	(-2.367)
Pair FE	Yes	Yes	Yes
$Country^{C} \times Year$ FE	Yes	Yes	Yes
$Country^{S} \times Year$ FE	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	5878	5712	4650
Pseudo R^2	0.775	0.858	0.903

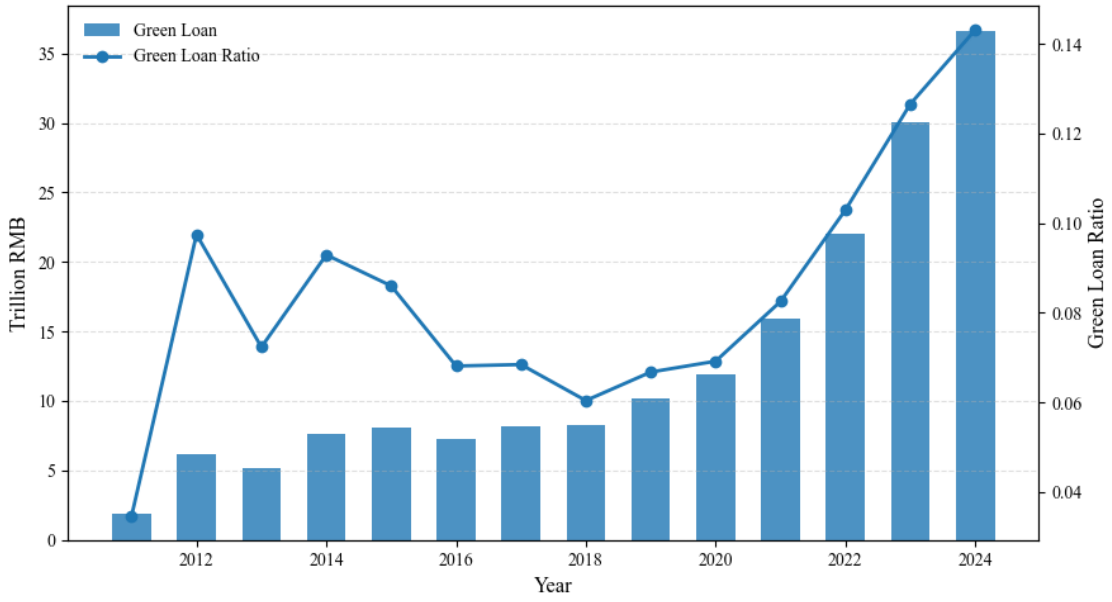
A Appendix

A.1 Environmental Indicators

We construct a comprehensive set of environmental indicators at both the China-specific and global levels to capture trends in environmental quality and the development of clean energy technologies.

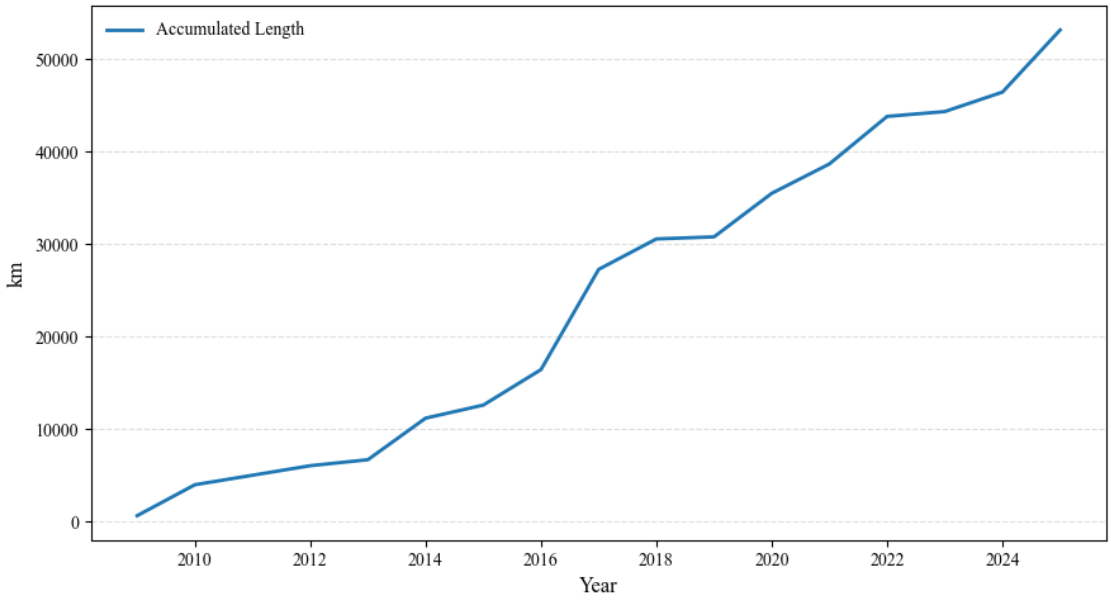
China-specific environmental indicators include (1) measures of water pollution and air pollution (2) trend of renewable energy adoption. Water pollution indicators include the share of lakes with good water quality and the share of coastal waters with good water quality. Air pollution indicators include the proportion of cities experiencing acid rain, the national average concentration of sulfur dioxide (SO_2), and the national average concentration of fine particulate matter ($PM_{2.5}$).These data are obtained from the *Report on the State of the Ecology and Environment* published by the Ministry of Ecology and Environment. To characterize trends in renewable energy adoption, we construct multiple complementary measures. First, we measure renewable electricity generation and compute greenhouse gas (GHG) emissions intensity as GHG emissions per unit of electricity generation, using power-sector GHG emissions scaled by annual electricity output, with data from *Our World in Data*. Finally, we capture electrification in the transportation sector by measuring electric vehicle (EV) adoption as the share of EVs in new vehicle sales, based on data from the *China Association of Automobile Manufacturers*.

Figure A1: Green Loan in China



Notes: This figure shows the outstanding balance of green loan in China its share among the total loans.

Figure A2: Expansion of Ultra-High-Voltage Transmission Infrastructure



Notes: This figure shows the cumulative length of China's ultra-high-voltage (UHV) transmission infrastructure.

Table A1: Leading Firms by Renewable Energy Equipment Segment

This table shows the leading firms in different BICS Level 5 segments under the renewable energy equipment sub-industry.

Segment	**Leading Firms**
Solar Energy Equipment	JinkoSolar; Trina Solar; LONGi Green Energy; Canadian Solar
Wind Energy Equipment	Vestas; Siemens Gamesa; Goldwind; Mingyang Smart Energy
Energy Storage Systems	LG; CATL; Chaowei Power; EVE Energy; Fluence; Exide
Fuel Cell	Lotte Chemical; Plug Power

Table A2: Using Newly Installed Renewable Capacity as a Proxy for Equipment Demand

This table presents the results of the robustness test of the main result by estimating the following regression:

$$Patent_{s,t+1} = \beta_1 RenewAdp^{C}_{s,c,t-2\to t} + \beta_2 RenewAdp^{C}_{s,c,t-2\to t} \times isCN^{C}_{s,c} + \gamma_1 Controls_{s,t} + \gamma_2 Controls_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t}$$

where *RenewAdp* is the newly installed renewable energy capacity in the recent 3 years scaled by total assets. We restrict the sample to pairs where wind and solar energy equipment firms serve as the suppliers.

	$Patent_{t+1}$		
	(1)	(2)	(3)
$RenewAdp^{C}_{t-2\to t}$	1.942**	0.058	0.053
	(2.051)	(0.617)	(0.567)
$RenewAdp^{C}_{t-2\to t} \times CN^{C}$			2.204*
			(1.737)
$\Delta Revenue^{S}_{t-2\to t}$	0.053	0.067	0.048
	(0.308)	(0.861)	(0.653)
Pair FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	505	3816	4323
Pseudo R^2	0.963	0.943	0.944

Table A3: Robustness: Revenue Growth of the Past 1 Year

This table presents the results of the robustness test of the main result, we re-estimate Equation (3) in Panel A and Equation (4) in Panel B by replacing $\Delta Revenue^C$ with the last 1 year revenue growth of the customer.

Panel A

	$Patent_{t+1}$						
	Chinese Customer				Non-Chinese Customer		
	All supplier		$isCN^S = 1$	$isCN^S = 0$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta Revenue_t^C$	0.187**	0.223***	0.247***	0.135	-0.026	-0.034	-0.026
	(2.574)	(2.911)	(2.953)	(1.532)	(-1.304)	(-1.305)	(-1.338)
$\Delta Revenue_t^S$	0.111	0.143	0.137	0.124	0.001	-0.036	-0.011
	(1.270)	(1.615)	(1.571)	(1.129)	(0.034)	(-0.887)	(-0.290)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes	No	No
$Country^C \times Year$ FE	No	Yes	No	No	No	Yes	Yes
$Country^S \times Year$ FE	No	Yes	No	No	No	No	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	859	798	645	214	6797	6464	5990
Pseudo R-square	0.960	0.963	0.957	0.975	0.955	0.961	0.973

Table A3: Robustness: Revenue Growth of the Past 1 Year (Continued)

Panel B

	$Patent_{t+1}$		
	(1)	(2)	(3)
$\Delta Revenue_t^C$	-0.026	-0.030	-0.020
	(-1.283)	(-1.135)	(-1.021)
$\Delta Revenue_t^C \times isCN^C$	0.146**	0.155**	0.163**
	(2.182)	(2.193)	(2.269)
$\Delta Revenue_t^S$	0.001	-0.018	0.015
	(0.026)	(-0.425)	(0.299)
Pair FE	Yes	Yes	Yes
Year FE	Yes	No	No
$Country^C \times Year$ FE	No	Yes	Yes
$Country^S \times Year$ FE	No	No	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	7660	7323	6837
Pseudo R-square	0.955	0.960	0.971

Table A4: Robustness: Environment-related Patents

This table presents the results of the robustness test of the main result, we re-estimate Equation (3) in Panel A and Equation (4) in Panel B by replacing $Patent_{t+1}$ with $EnvPatent_{t+1}$.

Panel A

	$EnvPatent_{t+1}$						
	Chinese Customer				Non-Chinese Customer		
	All sample		$isCN^C = 1$	$isCN^C = 0$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta Revenue^C_{t-2\to t}$	0.327***	0.413***	0.537***	0.189*	-0.042	-0.047	-0.054
	(2.712)	(3.092)	(3.154)	(1.742)	(-0.876)	(-0.878)	(-1.427)
$\Delta Revenue^S_{t-2\to t}$	0.356*	0.447**	0.412**	0.278	-0.007	-0.058	-0.037
	(1.792)	(2.341)	(2.183)	(0.952)	(-0.107)	(-0.792)	(-0.488)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes	No	No
$Country^C \times Year$ FE	No	Yes	No	No	No	Yes	Yes
$Country^S \times Year$ FE	No	Yes	No	No	No	No	Yes
Supplier Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	859	798	645	214	6741	6423	5962
Pseudo R-square	0.960	0.964	0.958	0.975	0.955	0.961	0.973

Table A4: Robustness: Environment-related Patents (Continued)

Panel B

	$EnvPatent_{t+1}$		
	(1)	(2)	(3)
$\Delta Revenue^{C}_{t-2\to t}$	-0.042	-0.038	-0.047
	(-0.877)	(-0.716)	(-1.223)
$\Delta Revenue^{C}_{t-2\to t} \times isCN^{C}$	0.267**	0.300**	0.298**
	(1.995)	(2.324)	(2.297)
$\Delta Revenue^{S}_{t-2\to t}$	0.008	-0.008	0.039
	(0.113)	(-0.107)	(0.396)
Pair FE	Yes	Yes	Yes
Year FE	Yes	No	No
$Country^{C} \times Year$ FE	No	Yes	Yes
$Country^{S} \times Year$ FE	No	No	Yes
Supplier Controls	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes
Observations	7604	7282	6809
Pseudo R-square	0.955	0.960	0.971

Table A5: Robustness: Patents in a Longer Period

This table presents show the effect of $\Delta Revenue^{C}$ on $Patent$ in a longer period. We replace the dependent variable with the patent filed by the firm in the subsequent 2 3 years.

	Chinese Customer		Non-Chinese Customer	
	$Patent_{t+1\to t+2}$	$Patent_{t+1\to t+3}$	$Patent_{t+1\to t+2}$	$Patent_{t+1\to t+3}$
	(1)	(2)	(3)	(4)
$\Delta Revenue^{C}_{t-2\to t}$	0.255**	0.200**	-0.057	-0.058*
	(2.436)	(2.453)	(-1.643)	(-1.923)
$\Delta Revenue^{S}_{t-2\to t}$	0.165	0.092	-0.102	-0.113*
	(0.925)	(0.660)	(-1.434)	(-1.656)
Pair FE	Yes	Yes	Yes	Yes
$Country^{C} \times Year$ FE	Yes	Yes	Yes	Yes
$Country^{S} \times Year$ FE	Yes	Yes	Yes	Yes
Supplier Controls	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes
Observations	798	798	5965	5965
Pseudo R^2	0.976	0.984	0.982	0.986

Table A6: Real Impact on Emission Change

This table examines whether the innovation intensity of renewable energy equipment firms reduces the emissions of their customers by estimating the fixed-effects regression model separately for Chinese and non-Chinese renewable energy equipment firms:

$$\Delta Emission_{c,t+k} = \beta_1 \ln(Patent)_{s,t} + \gamma\, Controls_{c,t} + Pair_{s,c} + Year_t + \epsilon_{s,c,t}$$

Emission reduction is measured by the change in customers' total Scope 1 GHG emissions over the subsequent three years, including both absolute emissions (in Panel A and Panel B) and emissions intensity (in Panel C and Panel D). Innovation intensity is proxied by the number of patents filed by the supplier ($\ln(Patent)$) (in Panel A and Panel C) and the number of environment-related patents filed by the supplier ($\ln(EnvPatent)$) (in Panel B and Panel D). Control variables include the customer's $\Delta Revenue^C$,$\ln(Asset^C)$, ROA^C, $CapEx^C$, and $Tangibility^C$. T-stats in parentheses are calculated using standard errors clustered at the customer–supplier pair level.

Panel A: Patent and Reduction in Total Emissions

	Change of Total Scope 1 GHG Emission					
	Chinese Equipment			Non-Chinese Equipment		
	$t+1-t$	$t+2-t$	$t+3-t$	$t+1-t$	$t+2-t$	$t+3-t$
	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(Patent)$	-0.158	-0.284**	-0.166**	-0.008	-0.036	-0.038
	(-1.204)	(-2.097)	(-2.119)	(-0.360)	(-1.237)	(-1.540)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	589	589	589	3772	3772	3770
R-square	0.371	0.558	0.666	0.291	0.498	0.631

Panel B: Environment-related Patent and Reduction in Total Emissions

	Change of Total Scope 1 GHG Emission					
	Chinese Equipment			Non-Chinese Equipment		
	$t+1-t$	$t+2-t$	$t+3-t$	$t+1-t$	$t+2-t$	$t+3-t$
	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(EnvPatent)$	-0.059	-0.340*	-0.233*	-0.035	-0.099**	-0.063*
	(-0.601)	(-1.926)	(-1.965)	(-1.087)	(-2.213)	(-1.873)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	468	468	468	2593	2593	2591
R-square	0.361	0.514	0.636	0.296	0.513	0.619

Table A6: Real Impact on Emission Change

Panel C: Patent and Reduction in Emission Intensity

	Change of Scope 1 GHG Emission Intensity					
	Chinese Equipment			Non-Chinese Equipment		
	$t+1-t$	$t+2-t$	$t+3-t$	$t+1-t$	$t+2-t$	$t+3-t$
	(1)	(2)	(3)	(4)	(5)	(6)
ln(*Patent*)	-0.130	-0.241*	-0.120*	0.013	-0.009	-0.015
	(-1.123)	(-1.907)	(-1.705)	(0.743)	(-0.415)	(-0.718)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	589	589	589	3772	3772	3770
R-square	0.371	0.537	0.655	0.377	0.501	0.631

Panel D: Environment-related Patent and Reduction in Emission Intensity

	Change of Scope 1 GHG Emission Intensity					
	Chinese Equipment			Non-Chinese Equipment		
	$t+1-t$	$t+2-t$	$t+3-t$	$t+1-t$	$t+2-t$	$t+3-t$
	(1)	(2)	(3)	(4)	(5)	(6)
ln(*EnvPatent*)	-0.087	-0.372**	-0.252**	-0.004	-0.052	-0.028
	(-1.025)	(-2.134)	(-2.105)	(-0.163)	(-1.535)	(-0.983)
Pair FE	Yes	Yes	Yes	Yes	Yes	Yes
$Country^C \times Year$ FE	Yes	Yes	Yes	Yes	Yes	Yes
Customer Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	468	468	468	2593	2593	2591
R-square	0.398	0.507	0.636	0.381	0.527	0.644