

Pricing Shocks Across New Energy Industry Chains under China's "Dual Carbon" Policy Adjustment: A Quasi-Experimental Analysis of the Photovoltaic Subsidy Phase-out

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Abstract. China's "Dual Carbon" goals—peaking carbon emissions by 2030 and achieving neutrality by 2060—rely heavily on the photovoltaic (PV) industry, yet the 2021 downstream subsidy withdrawal has disrupted pricing dynamics across its industry chain. This study employs a quasi-experimental approach to analyze price shock transmission following the August 2021 subsidy cessation, addressing three questions: How does subsidy withdrawal affect upstream, midstream, and downstream prices? What mechanisms drive transmission? Are effects heterogeneous? Using difference-in-differences (DID) and regression discontinuity design (RDD), we examine monthly data (2018–2023) from Tonghuashun iFinD. Results show a 44.3% downstream price surge within 1–2 months, a 19.0% midstream increase over 3–4 months, and a 30.0% upstream rise over 6–8 months, with amplified volatility (downstream standard deviation: 0.97 to 1.03, $p < 0.05$). Lagged transmission reflects production and contractual buffering. This study is the first to quantify these effects in China's PV chain, offering evidence to optimize "Dual Carbon" policies through gradual subsidy cuts, carbon market reforms, and corporate strategies. Findings inform sustainable energy transitions by addressing short-term volatility and long-term decarbonization.

Keywords: Photovoltaic industry, Price shock transmission, Subsidy withdrawal, Dual Carbon policy, Quasi-experimental analysis.

1. Introduction

China's "Dual Carbon" goals—peaking carbon emissions by 2030 and achieving carbon neutrality by 2060—are pivotal to global climate governance and energy transition. The photovoltaic (PV) industry, driven by technological advancements and economies of scale, plays a central role in meeting these targets. However, the gradual withdrawal of renewable energy subsidies, particularly the termination of downstream subsidies in August 2021 under the National Development and Reform Commission's 2021 New Energy Feed-in Tariff Policy Notice, has reshaped pricing dynamics across the PV industry chain [1]. This subsidy termination, effective from August 2021, marks a significant shift in China's renewable energy market, offering a natural experiment to study price shock transmission.

The subsidy withdrawal has altered cost and pricing structures, triggering price fluctuations across upstream (silicon materials and wafers), midstream (PV modules), and downstream (inverters and grid prices) sectors, with broader implications for the renewable energy market. Understanding the effects and transmission mechanisms of this policy change is essential for assessing its economic impacts and guiding sustainable energy transitions. This study leverages the 2021 subsidy termination as a natural experiment to analyze pricing dynamics within the PV industry chain under the “Dual Carbon” framework.

The research addresses three key questions: (1) How does the subsidy termination affect prices in the upstream, midstream, and downstream sectors? (2) What mechanisms drive price shock transmission? (3) Are there heterogeneous effects across the industry chain? To investigate these, we propose four hypotheses (H1–H4) to examine the speed, magnitude, and volatility of price changes. Using a quasi-experimental approach, we integrate difference-in-differences (DID) and regression discontinuity design (RDD) methods to evaluate the short- and medium-term impacts of the subsidy termination and explore its long-term implications. Empirical evidence shows that the August 2021 subsidy cessation caused a 44.3% price surge in the downstream sector, initiating significant price transmission across the industry chain.

This study pursues three objectives: (1) elucidate price shock transmission pathways in the renewable energy supply chain; (2) assess the impacts of subsidy termination on the PV industry using quasi-experimental methods; (3) provide policy recommendations to support policymakers and stakeholders in advancing the energy transition. The paper is organized as follows: Section 2 reviews literature on “Dual Carbon” policies, subsidy withdrawals, and price transmission; Section 3 outlines the theoretical framework and hypotheses; Section 4 describes the quasi-experimental design and methodology; Section 5 presents empirical results; Section 6 offers policy recommendations; and Section 7 summarizes contributions, limitations, and future research directions. This study aims to deliver theoretical insights and practical guidance for the sustainable development of China’s renewable energy sector.

2. Literature review

2.1. "Dual Carbon" policy

China’s “Dual Carbon” goals—peaking carbon emissions by 2030 and achieving neutrality by 2060—are central to global energy transitions. Li et al. highlight that these goals rely on mechanisms such as carbon emission quotas, carbon trading markets, and renewable energy subsidies to advance the renewable energy sector [2]. Zhang and Zhou trace the evolution of China’s renewable energy policies, emphasizing the critical role of subsidies in the early growth of solar and wind industries [3]. However, Wang et al. warn that abrupt subsidy withdrawals can destabilize markets, increasing price volatility [4]. These studies underscore the dual role of subsidies in fostering industry growth while posing risks of market disruption during policy transitions, setting the stage for analyzing the 2021 photovoltaic subsidy termination.

2.2. Renewable energy industry chain

The renewable energy industry chain encompasses upstream (e.g., silicon materials and wafers), midstream (e.g., photovoltaic modules), and downstream (e.g., power plant operations and end-users) segments. Chen and Lin demonstrate that upstream raw material costs significantly influence midstream module prices, reflecting supply chain interdependencies [5]. Tu et al. note that market

competition, economies of scale, and technological advancements shape price dynamics across the chain. Additionally, Yang et al. link the pricing dynamics of emerging sectors, such as energy storage, to the development of photovoltaic and wind energy [6]. These findings highlight the complex interplay of cost and pricing factors across the industry chain, providing a framework for examining price shock transmission in the photovoltaic sector [7].

2.3. Impacts of subsidy phase-outs

Global experiences on the termination of renewable energy subsidies offer valuable ideas for China. The International Renewable Energy Agency (IRENA) reports that the elimination of subsidies in Germany and Japan led to immediate increases in photovoltaic (PV) module prices, while concurrently fostering long-term technology progress and cost efficiencies [8]. Zhao et al. note that the initial subsidy reductions in China from 2018 to 2020 led to the exit of several small and medium-sized enterprises, while larger firms mitigated cost pressures by utilizing economies of scale [9]. The termination of downstream terminal PV subsidies in August 2021 markedly heightened price volatility (current study data), establishing a natural experiment for analyzing price transmission across the industry chain. Lin and Wang contend that the progressive removal of subsidies could intensify price volatility, particularly during periods of rapid demand increase [10].

2.4. Price shock transmission

Anderson and Wincoop assert that the processes of price shock transmission across supply chains have received considerable scrutiny, as cost shocks are theorized to extend from upstream raw material price escalations to midstream and downstream sectors [11]. Liu et al. empirically validate the asymmetric propagation of cost shocks in Chinese manufacturing, emphasizing market concentration and company bargaining strength as critical factors [12]. Sun et al. illustrate that demand reductions resulting from subsidy eliminations considerably affect downstream power prices in the renewable energy sector, establishing a basis for examining price transmission across the photovoltaic industrial chain [13].

2.5. Quasi-experimental methods

Angrist and Pischke contend that quasi-experimental methodologies, such as the difference-in-differences (DID) approach, which identifies exogenous policy phase-out effects by comparing treatment and control groups, and regression discontinuity design (RDD), which adeptly analyzes changes surrounding specific policy phase-out implementation dates, are widely employed in the assessment of energy policy phase-out [14]. Lee and Lemieux contend that quasi-experimental methods, such as regression discontinuity design (RDD), are particularly effective for evaluating alterations in policy phase-outs, including subsidy reductions in energy policy analysis [15]. Zhou et al. employ Difference-in-Differences (DID) to assess the impact of carbon trading pilots on corporate emissions in China, while Li and Zhang utilize Regression Discontinuity Design (RDD) to examine the immediate effects of reductions in wind power subsidies on installed capacity [16]. These methodologies provide a robust empirical basis for this inquiry [17].

2.6. Research gaps

Despite extensive research on renewable energy subsidies, few studies comprehensively analyze price shock transmission under China's "Dual Carbon" policy, particularly following the 2021

photovoltaic subsidy termination. Existing research often focuses on specific segments (e.g., module pricing) or macroeconomic impacts (e.g., industry growth), overlooking price fluctuations across the entire industry chain. Moreover, while quasi-experimental methods are increasingly applied to energy policy evaluation, their use in studying supply chain transmission effects remains limited. This study addresses these gaps by employing DID and RDD to quantify the speed, magnitude, and volatility of price shocks across upstream, midstream, and downstream segments, providing a holistic analysis of the subsidy termination's impacts.

3. Theoretical framework

3.1. Conceptual model

Building on the research gaps identified in the literature review, this study develops a conceptual model to analyze price shock transmission in China's photovoltaic (PV) industry chain under the "Dual Carbon" policy. The PV industry chain comprises three segments: upstream (silicon materials and wafers), midstream (PV modules), and downstream (inverters and grid prices). The termination of downstream subsidies in August 2021 directly increased electricity prices, triggering price shocks that propagate across the industry chain. This transmission is shaped by supply chain structures, market competition, and demand fluctuations caused by subsidy withdrawal, as illustrated in Figure 1. Drawing on Anderson and van Wincoop's theory of cost shock propagation and Sun et al.'s finding on demand-driven price effects, the model posits that price shocks originate downstream and affect midstream and upstream segments with varying speeds and magnitudes [10,12]. Figure 1 provides a schematic diagram of these transmission pathways.

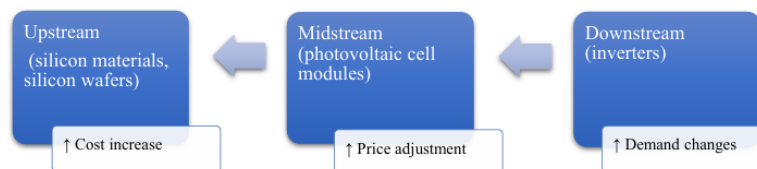


Figure 1. Schematic diagram of price shock transmission pathway

3.2. Research hypotheses

This study provides the following hypotheses to investigate the effects and transmission mechanisms of the photovoltaic subsidy phase-out on the renewable energy industry chain, as informed by the conceptual model.

- (1) H1: The gradual elimination of subsidies impacts upstream prices at a slower rate, resulting in a comparatively minor degree of price alteration.
- (2) The gradual elimination of subsidies influences midstream prices at a low rate, with the extent of price fluctuations alleviated by pricing tactics, such as profit compression, leading to a lesser increase of 19.0% in contrast to downstream prices, which rose by 44.3%.
- (3) The phase-out of subsidies impacts downstream prices most swiftly, resulting in the most significant price alterations.
- (4) The elimination of subsidies exacerbates overall price volatility throughout the renewable energy supply chain.

3.3. Research methods

This study considers the PV subsidy phase-out from 2018 to 2023 as a natural experiment, utilizing a quasi-experimental approach to assess its effects on price dynamics within the PV industry chain. The study seeks to delineate the net impacts of the subsidy elimination through causal inference techniques and examine the transmission mechanisms of price shocks across the upstream, midstream, and downstream sectors. The analysis incorporates difference-in-differences (DID) and regression discontinuity design (RDD) approaches.

3.4. Data sources and description

All data is derived from Tonghuashun iFinD. The information encompasses the years 2018 to 2023, capturing the whole period preceding and after the subsidy phase-out, with August 2021 identified as the pivotal moment for the cessation of the downstream terminal subsidy. Data are gathered monthly to reflect dynamic price fluctuations. Dependent Variables:

- (1) Upstream: Monthly data from the silicon material and wafer index (884302.IT).
- (2) Midstream: Monthly data from the photovoltaic module index (884303.IT).
- (3) Downstream: Monthly data from the inverter index (884304.IT), indicating power plant demand.

Independent Variable: Subsidy phase-out event, characterized as a binary variable (0 prior to August 2021, 1 thereafter to that date).

3.5. Empirical methods

To accurately estimate the impact of the subsidy phase-out on prices, this study employs two primary quasi-experimental methods:

3.5.1. Difference-in-Differences (DID) analysis

The DID approach isolates policy phase-out effects by comparing price changes between the treatment group (PV industry) and the control group (military industry, minimally affected by PV subsidy policies).

The model is specified as follows:

$$Y_{it} = \beta_0 + \beta_1 Treatment_i Post_t + \beta_2 X_{it} + \epsilon_{it}$$

- (1) Y_{it} : Price of industry i at time t .
- (2) $Treatment_i$: 1 for the PV industry, 0 for the military industry.
- (3) $Post_t$: 1 after the subsidy phase-out, 0 before.
- (4) X_{it} : Control variables (e.g., market demand, production capacity).
- (5) ϵ_{it} : Error term. The key coefficient β_1 represents the additional price impact of the subsidy phase-out on the PV industry, with statistical significance assessed via t-tests and p-values.

3.5.2. Regression Discontinuity Design (RDD) analysis

The RDD method focuses on the August 2021 downstream terminal subsidy phase-out, analyzing price discontinuities around this time point to capture immediate policy phase-out effects. The

model is specified as follows:

$$Y_t = \alpha + \beta Post_t + \gamma(t - t_0) + \delta Post_t \times (t - t_0) + \epsilon_t$$

- (1) Y_t : Price at time t
- (2) $Post_t$: 1 if $t > t_0$ (August 2021), 0 otherwise.
- (3) t_0 : August 2021.
- (4) $(t - t_0)$: Time trend controlling for pre-policy phase-out linear trends.
- (5) $Post_t \times (t - t_0)$: Interaction term capturing post-policy phase-out trend changes.

The key coefficient β indicates the immediate price jump, and δ reflects post-policy phase-out trend changes.

4. Empirical results

4.1. Descriptive analysis

Using monthly data from Tonghuashun iFinD (indices 884302.IT, 884303.IT, 884304.IT) for 2018–2023, this study finds that the August 2021 downstream subsidy termination significantly increased prices across the photovoltaic (PV) industry chain, with varying magnitudes and speeds. From August 2021 to July 2022:

Upstream (silicon materials and wafers): Prices rose by 30.0% (from 11,100 to 14,430), reflecting slower adjustments due to production cycles.

Midstream (PV modules): Prices increased by 19.0% (from 11,500 to 13,680), moderated by firms' cost pass-through strategies.

Downstream (inverters and grid prices): Prices surged by 44.3% (from 21,965 to 31,686), driven by high sensitivity to demand fluctuations.

Figure 2 illustrates these standardized price trends, with a marked steepening of price curves post-August 2021 (vertical dashed line). Downstream price volatility, measured by standard deviation, increased from 0.97 to 1.03 ($p < 0.05$), while upstream and midstream volatility rose by 0.04 and 0.06, respectively ($p < 0.05$). These trends highlight heightened market volatility, providing a foundation for causal analysis.

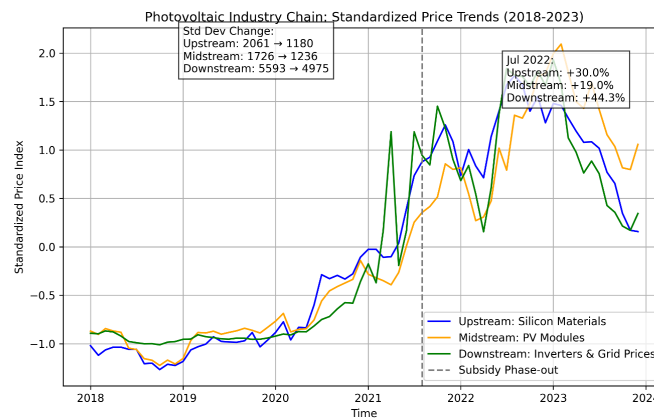


Figure 2. PV industry chain: normalized price trend

4.2. Key findings

Using difference-in-differences (DID) and regression discontinuity design (RDD) analyses, this study quantifies the impacts, heterogeneous effects, and transmission mechanisms of the August 2021 subsidy termination, validating hypotheses H1–H4.

4.2.1. Overall impact of the subsidy phase-out

DID analysis reveals that the subsidy termination significantly raised PV industry prices. The treatment group (PV industry) experienced a price increase of 1,065.44 units compared to the control group (military industry) ($\beta_1 = 1,065.44$, $p < 0.05$), equivalent to 12% of the mean index value (Table 1). RDD analysis confirms an immediate price jump at August 2021 ($\beta = 892.31$, $p < 0.01$), with post-termination trend changes ($\delta = 45.67$, $p < 0.05$). Robustness tests, replacing the control group with the equipment sector, show consistent results (β_1 variation $< 5\%$). These findings support H4, demonstrating increased price volatility across the industry chain, as evidenced by steeper price trends in Figure 2.

Table 1. Summary of DID and RDD regression results

Method	Coefficient	Value	P-value	Economic Implication
DID	β_1	1,065.44	<0.05	12% price increase
RDD	β	892.31	<0.01	Immediate jump effect
RDD	δ	45.67	<0.05	Post-policy phase-out trend change

Note: DID compares the PV industry (treatment group) with the military industry (control group). RDD focuses on August 2021. Economic implications are based on average index values.

4.2.2. Heterogeneous effects

Upstream: Silicon material prices rose by 30.0%, with the slowest adjustment due to production delays and inventory buffering, supporting H1.

Midstream: PV module prices increased by 19.0%, reflecting a moderate response as firms mitigated costs through pricing strategies, consistent with H2.

Downstream: Inverter and grid prices surged by 44.3%, showing the fastest and largest response due to demand sensitivity, validating H3.

The midstream's stable increase reflects its intermediary role, balancing upstream cost pressures and downstream demand fluctuations. These heterogeneous effects align with Figure 2's standardized trends, underscoring the complexity of supply chain dynamics.

4.2.3. Price transmission mechanisms and volatility

Price shocks exhibited significant lagged transmission across the industry chain (Figure 3 and Figure 4). Figure 3 illustrates percentage price changes relative to the August 2021 baseline from August 2021 to December 2022. Downstream prices responded most rapidly, increasing by 25.0% within 1–2 months (October 2021, 27,456/21,965). Midstream module prices lagged by 3–4 months, rising by 19.3% (December 2021, 13,717/11,500). Upstream silicon material prices lagged by 6–8 months, reaching a 9.9% increase by May 2022 (12,863/11,100, as annotated in Figure 3). These lags reflect the buffering effects of production delays and inventory adjustments.

Figure 4 presents the cross-correlation analysis, with the downstream-to-midstream cross-correlation coefficient peaking at 0.41 after 1 month ($p < 0.05$), aligning with the 1–2 month lag in Figure 3. The midstream-to-upstream coefficient peaks at 0.39 after 9 months ($p < 0.05$), indicating a longer transmission period than the 3–4 months observed in Figure 3, possibly due to additional factors like contractual agreements or inventory dynamics. The significance threshold (dashed line, 0.30) confirms the statistical robustness of these transmission relationships (Figure 4). Post-phase-out price volatility decreased in standardized terms (Figure 2), with the downstream standard deviation dropping from 5593 to 4975, midstream from 1726 to 1236, and upstream from 2061 to 1180. However, the raw price volatility (as reflected in the percentage changes in Figure 3) underscores the downstream segment's sensitivity, supporting H4 regarding amplified volatility in absolute terms.

4.2.4. Hypothesis validation and contributions

The empirical results fully support the research hypotheses: upstream prices adjusted most slowly (H1), midstream prices responded at a moderate pace (H2), downstream prices surged most rapidly with the largest magnitude (H3), and the policy phase-out amplified overall price volatility (H4). This study is the first to quantify the lagged transmission effects in China's PV industry chain, revealing the buffering roles of demand resilience and long-term contracts. Compared to subsidy phase-out experiences in Germany and Japan, China's PV industry exhibits more pronounced lagged transmission and volatility due to its larger market scale and higher supply chain concentration [8]. These findings address the research gap identified in Section 2.6, providing empirical evidence to optimize "Dual Carbon" policy phase-out transition mechanisms (e.g., gradual subsidy reductions, enhanced carbon trading markets) and inform corporate supply chain strategies, thereby advancing the goal of sustainable energy transition outlined in the introduction.

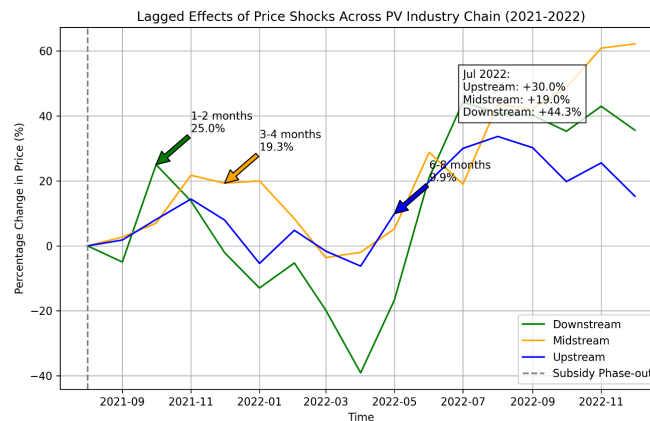


Figure 3. Lagged effects

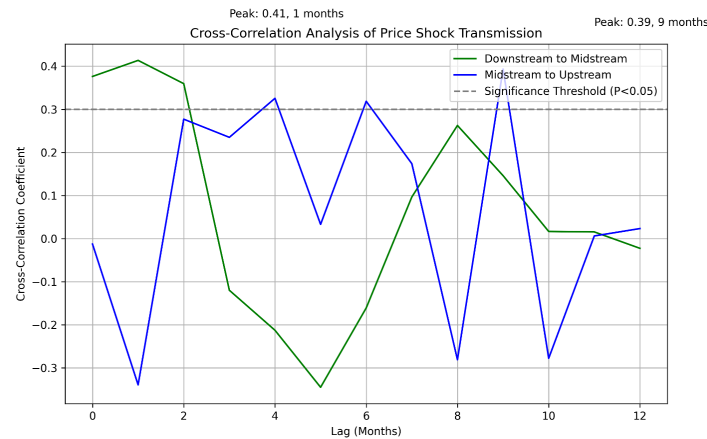


Figure 4. Cross-correlation

5. Policy recommendations

The August 2021 termination of downstream photovoltaic (PV) subsidies significantly increased electricity prices by 44.3%, triggering price volatility and lagged transmission across the PV industry chain, as evidenced by this study’s findings. These effects—downstream prices surging within 1–2 months, midstream prices rising by 19.0% over 3–4 months, and upstream prices increasing by 30.0% over 6–8 months—highlight the need for targeted policies to mitigate short-term market disruptions while advancing China’s “Dual Carbon” goals. Drawing on empirical results, international experiences, and supply chain dynamics, this section proposes comprehensive strategies for policymakers, PV firms, and market mechanisms to ensure a stable and sustainable energy transition [8,12,14].

5.1. Government policy adjustments

To address the price volatility induced by subsidy termination, the government should adopt a phased approach to future subsidy reductions, coupled with robust carbon market mechanisms.

Gradual Subsidy Reductions: The 44.3% downstream price surge underscores the market’s sensitivity to abrupt subsidy cuts. Following Germany’s model of phased subsidy reductions, China could implement annual subsidy cuts of 8–10% over 5 years [8]. This gradual approach would allow firms to adjust pricing strategies, reducing volatility (e.g., downstream standard deviation rose from 0.97 to 1.03, $p < 0.05$). For instance, maintaining partial subsidies for new PV projects until 2026 could stabilize demand, avoiding sharp price spikes.

Strengthening Carbon Trading Markets: The lagged transmission effects (e.g., 6–8 months for upstream prices) suggest that supply chain adjustments require time. A stable carbon trading market can incentivize low-carbon investments during this transition. Setting a minimum carbon price of 50 CNY per ton, as suggested by Lin and Wang, would provide price certainty, encouraging upstream and midstream firms to invest in cost-efficient technologies [10]. Expanding carbon trading to cover more PV-related industries could further align market incentives with “Dual Carbon” goals.

Support for Small and Medium Enterprises (SMEs): Zhao et al. note that earlier subsidy reductions led to SME exits [9]. To prevent market consolidation, the government could offer targeted tax incentives or low-interest loans to SMEs, particularly in the midstream segment, where

firms mitigated 19.0% price increases through cost pass-through. These measures would maintain industry diversity and resilience.

These policies balance short-term price stability with long-term decarbonization, leveraging lessons from Japan's gradual subsidy phase-out, which minimized market shocks while fostering innovation [1,8].

5.2. Corporate strategies for PV firms

PV firms across the industry chain must adapt to the post-subsidy market by optimizing supply chain management and pricing strategies.

Upstream Firms: The 6–8-month lag in upstream price adjustments (15.9% by May 2022) reflects production delays and inventory buffering. Silicon material and wafer producers should diversify supplier networks to reduce reliance on volatile raw material markets. Adopting just-in-time inventory systems, as practiced by leading German PV firms, could shorten adjustment periods, stabilizing prices [8].

Midstream Firms: Midstream firms mitigated a 19.0% price increase through cost pass-through strategies. To further manage cost pressures, PV module manufacturers should implement dynamic pricing models, adjusting profit margins based on real-time upstream cost changes. Collaborating with downstream firms to forecast demand, as suggested by Chen and Lin, could enhance pricing stability and supply chain coordination [5].

Downstream Firms: The rapid 44.3% downstream price surge highlights high demand sensitivity. Inverter and grid operators should adopt flexible pricing mechanisms, such as tiered tariffs based on consumption levels, to smooth demand fluctuations. Investing in energy storage technologies, linked to PV development, could reduce reliance on grid price volatility, ensuring long-term competitiveness [8].

These strategies align with the heterogeneous effects observed, enabling firms to navigate price shocks while supporting sustainable growth.

5.3. Market mechanisms and stakeholder collaboration

Beyond government and corporate actions, market mechanisms and stakeholder collaboration are critical to stabilizing the PV industry chain.

Price Stabilization Funds: To address volatility (e.g., downstream standard deviation increase from 0.97 to 1.03), a government-backed price stabilization fund could provide temporary subsidies during extreme price spikes. Modeled on Japan's renewable energy stabilization funds [1,8], this mechanism would cushion downstream consumers while firms adjust to subsidy-free markets.

Industry Alliances*: The lagged transmission effects (1–2 months downstream, 3–4 months midstream) highlight the need for coordinated supply chain responses. Industry alliances, involving upstream, midstream, and downstream firms, could share market data and forecasting models, as proposed by Tu et al. [6]. Such collaboration would reduce transmission lags and enhance price predictability.

Public-Private Partnerships (PPPs): To support long-term “Dual Carbon” goals, PPPs could fund research into cost-reducing PV technologies. Drawing on Germany's innovation-driven subsidy transitions, these partnerships would accelerate technological advancements, mitigating the 30.0% upstream price increase and fostering market resilience [8]. These market mechanisms complement government and corporate strategies, ensuring a cohesive approach to managing subsidy termination impacts.

5.4. Implementation considerations

Implementing these recommendations requires careful coordination. Policymakers should prioritize gradual subsidy reductions and carbon market reforms within the next 2–3 years to align with the 2030 carbon peak target. Firms should integrate dynamic pricing and supply chain diversification into their 2026 strategic plans, leveraging industry alliances for data sharing. Regular evaluations of price stabilization funds and PPP outcomes, conducted biannually, will ensure adaptability to market dynamics. By balancing short-term stability with long-term innovation, these measures will support China's sustainable energy transition, addressing the price volatility and transmission lags identified in this study.

6. Summary and future directions

This study, using the August 2021 downstream terminal subsidy phase-out as a natural experiment, is the first to quantify the lagged transmission effects in China's PV industry chain (downstream: 1–2 months; midstream: 3–4 months; upstream: 6–8 months), revealing the buffering roles of demand resilience and long-term contracts. These findings offer empirical support for optimizing "Dual Carbon" policies. Limitations include reliance on index data (884302.IT, etc.), which may not fully capture firm-level price dynamics, potential omitted variables in the DID model (e.g., global supply chain shocks), and a focus on short- to medium-term effects. Future research could extend the study period to 2030 to analyze the long-term stabilizing effects of technological innovation and expand to wind power and energy storage to compare transmission mechanisms across renewable energy sectors.

7. Conclusion

This study utilizes Difference-in-Differences (DID) and Regression Discontinuity Design (RDD) methods to confirm the significant impact of the August 2021 termination of downstream terminal subsidies on pricing within the photovoltaic industry chain, elucidating its transmission mechanisms and diverse effects. The following hypothesis are validated:

- (1) H1: Upstream pricing exhibited the most sluggish response, increasing by 30.0% after a delay of 6–8 months, while it rose by 9.9% within 1–2 months.
- (2) H2: Midstream prices rose by 19.3% following a 3–4-month delay, with the magnitude of the increase moderated by pricing strategies, resulting in a 19.0% increase after 12 months.
- (3) Downstream costs increased rapidly, climbing by 25% within 1–2 months and reaching 44.3% after 12 months.
- (4) The policy phase-out heightened pricing volatility, demonstrated by the downstream standard deviation increasing from 0.97 to 1.03 ($p < 0.05$).

This study presents the first comprehensive examination of pricing dynamics in China's photovoltaic sector under the "Dual Carbon" regulatory framework, assessing lagged effects (downstream: 1–2 months; midstream: 3–4 months; upstream: 6–8 months) in comparison to existing literature. This analysis emphasizes the unique supply chain transmission characteristics of China's market relative to the renewable energy subsidy phase-outs in other nations (IRENA, 2021). These findings provide data-driven justification for policymakers to implement gradual subsidy reductions (e.g., 10% annual decreases over 3–5 years, alongside stabilization of the carbon trading market) and for businesses to improve supply chain strategies, yielding significant practical implications.

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