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Pathways to livelihoods or barriers to benefits? Smallholder participation in a forestry PPP project in China's Loess Plateau

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Abstract

Smallholder participation in forestry programs is widely promoted as a pathway out of poverty, yet the conditions under which different livelihood pathways succeed remain poorly understood. Drawing on monitoring records and 23 semi-structured interviews from a large-scale forestry PPP project in China's Loess Plateau (2017–2025), this study examines how smallholders engage with four livelihood pathways—forest-based farming, carbon trading, eco-tourism, and processing—and why their livelihood outcomes diverge. We find pronounced heterogeneity: low-threshold pathways such as forest-based farming and basic processing reach more than 530,000 rural households, generating per-mu income increases of 3,000–5,000 RMB, while high-threshold pathways including carbon trading and eco-tourism remain constrained by institutional fragmentation, infrastructure deficits, and cooperative dissolution. We propose a pathway-threshold framework centered on the concept of threshold production failure, which specifies not only the conditions smallholders must meet but also whether the governance structure takes responsibility for producing those conditions. The framework explains why participation alone does not guarantee benefit and identifies the sequencing and enabling conditions that can make forestry programs more inclusive. Policy implications include institutionalizing village-level information assistance, designing cooperative support around long-term viability, and simplifying disbursement responsibility.

1. Introduction

Globally, forests cover approximately 31% of the Earth’s land surface and provide an estimated USD 4.7 trillion annually in ecosystem services [1]. For smallholders in ecologically fragile regions, forests represent both a livelihood resource and a pathway out of poverty, yet the translation of forest ecosystem services into household-level benefits remains uneven [2,3]. China‘s Loess Plateau exemplifies this tension: 58 nationally designated poor counties overlap with ecologically sensitive zones, and existing Payment for Ecosystem Services (PES) schemes have struggled to reconcile short-term livelihood needs with long-term restoration goals.

In response, China has increasingly deployed Public-Private Partnership (PPP) models in the forestry sector, with smallholder cooperatives positioned as the primary implementing agents [4,5]. The Shanxi Forestry Ecological Poverty Alleviation PPP Project, initiated in 2017, is the first provincial-level PPP project in China‘s forestry sector and ranks among the nation’s largest ecological initiatives, covering 1.08 million hectares at a total investment of 17.4 billion RMB. While the project has generated substantial household income through forest-based farming and processing, other pathways, carbon trading and eco-tourism, have underperformed, and the dissolution of some implementing cooperatives has disrupted benefit delivery.

Monetizing forest ecosystem services in such contexts requires moving beyond timber extraction toward diverse livelihood pathways: forest-based farming, carbon trading, eco-tourism, non-timber forest products, and value-added processing [6,7]. Four principal mechanisms connect ecosystem services to

smallholder welfare. Direct-use pathways involve harvesting non-timber forest products or engaging in forest-based agricultural activities such as agroforestry, mushroom cultivation, or apiculture. These generate subsistence and cash income with low entry barriers [8]. Payment-based pathways involve PES or carbon offset markets, where households receive transfers for maintaining or restoring ecosystem functions, but are subject to transaction costs and institutional requirements [7]. Service-based pathways include eco-tourism and forest wellness, which monetize cultural and regulating services but often require tourism infrastructure and marketing [9]. Upgrading pathways encompass value addition through processing, branding, and market integration [6].

A substantial body of evidence indicates that pathway-specific success depends on enabling conditions. For direct-use pathways, secure tenure and access rights are foundational; households lacking clear property rights under-invest in forest management and product development [10]. Household human capital, particularly agricultural skills and business capacity, strongly influences uptake and returns [11]. For payment and market-based pathways, institutional infrastructure matters critically: PES programs require clear rules regarding conditionality, monitoring, and payment delivery, and transaction costs can erode poverty benefits [12]. Carbon offset projects additionally require demonstration of additionality, permanence, and quantification capacity — costly scientific functions rarely available in remote areas [13]. For service-based and upgrading pathways, physical public infrastructure—roads, telecommunications, electricity, cold-chain logistics—conditions viability, and collective action capacity is needed to generate sufficient supply volumes, standardize quality, and negotiate with buyers [14,15].

Cooperatives play a central role in connecting smallholders to these pathways in China's collective forest sector. As intermediaries, they reduce transaction costs, aggregate supply, and negotiate with buyers [15]. However, their effectiveness depends on governance quality, financial capacity, and long-term viability. Forestry cooperatives established under poverty alleviation programs face particular challenges: they often lack independent financial resources, rely on government subsidies, and may dissolve once project funding ends, leaving smallholders without a stable channel for benefit delivery.

While a growing literature examines the livelihood impacts of individual pathways, PES in Mexico and Costa Rica [16], community forestry in Nepal [17], and eco-tourism in sub-Saharan Africa [9], few studies systematically analyze multiple pathways operating simultaneously within a single large-scale program. Moreover, the barriers constraining pathway success, biophysical constraints, institutional fragmentation, and market infrastructure deficits, remain insufficiently theorized, particularly in integrated ecological-poverty contexts [12,18].

Three gaps structure our study. First, existing literature predominantly analyzes single pathways in isolation; there is limited empirical understanding of how multiple pathways interact and differ within a single program. Second, the pathway "failure" dimension is under-theorized—most studies examine successful cases, generating risks of selection bias and over-optimistic conclusions. Third, the conditions under which smallholders benefit from participation remain poorly understood, particularly regarding how cooperative governance, financial capacity, and long-term viability shape benefit delivery.

Based on the preceding review, we construct an analytical framework that distinguishes four livelihood pathway types—direct-use, market-based, service-based, and upgrading—and evaluates each against three threshold dimensions: knowledge and capability thresholds (the technical skills and management capacity required), infrastructure thresholds (the physical and market infrastructure prerequisites), and institutional thresholds (the coordination mechanisms, property rights clarity, and regulatory conditions required for operation). Existing studies of forest-based livelihoods typically treat pathway success as a function of household endowments or program design. We argue that this misses a prior question: where do the thresholds that separate successful from unsuccessful pathways come from, and who is responsible for producing the conditions that allow smallholders to cross them?

We make two claims about how thresholds operate. First, thresholds are not natural constraints but institutional products. A carbon-trading pathway requires verification capacity, registry access, and benefit-sharing rules; none of these are biophysical limits. They are institutional requirements that must be actively produced by governance arrangements. When they are not produced, the pathway does not fail because smallholders lack ability; it fails because the governance structure did not generate the conditions for participation.

Second, low-threshold pathways are not threshold-free. Forest-based farming succeeds because it builds on capabilities and market access that have already been historically produced—village extension networks, land allocation, local traders. The threshold has been crossed, but not by the project.

This reframing has implications for how we interpret PPP governance. A PPP is not simply a financing instrument; it is a governance structure that allocates responsibility for threshold production across public and private actors. Our case shows that this allocation can fail in a specific way: each actor fulfills its own contractual obligations, yet no actor is responsible for the cross-cutting conditions—information infrastructure, cooperative viability, tenure clarity—that determine whether smallholders can actually benefit. We call this threshold production failure, and it explains why participation alone does not guarantee benefit.

We operationalize the framework by assessing each pathway's performance along these dimensions, proposing that pathway success is conditional not merely on threshold crossing, but on whether the governance structure takes responsibility for producing the conditions that allow thresholds to be crossed. Figure 1 visualizes this analytical framework. The study draws on both project monitoring records and 23 semi-structured interviews, allowing us to connect household-level outcomes to the institutional arrangements that produced them.

This study analyzes the Shanxi PPP project (2017–2025) to identify its livelihood pathways, assess their outcomes, and explain their differential performance. The Loess Plateau case is instructive for dryland regions globally, combining severe ecological fragility with deep poverty under a distinctive 30-year PPP governance structure. Our contribution is twofold. Theoretically, we propose a “pathway-threshold” framework centered on the concept of threshold production failure, which specifies not only the conditions smallholders must meet but also whether the governance structure takes responsibility for

producing those conditions. Practically, we generate evidence-based policy recommendations for matching pathway selection to local conditions, strengthening cooperative viability, and institutionalizing the information-assistance functions that currently rely on informal networks.

2. Study Area and Methods

2.1 Study area

The Shanxi Forestry Ecological Poverty Alleviation PPP Project operates across Shanxi Province in north-central China, situated on the Loess Plateau. The province‘s topography is dominated by mountains and hills (80%), with the Lüliang Mountains in the west and the Taihang Mountains in the east. The region has a temperate continental monsoon climate with mean annual precipitation of 400–500 mm, 80% concentrated from July to September. Soils are predominantly loess with 0.6%–1.2% organic matter, significantly below the national average of 1.8%.

The project covers 98 counties across 11 prefecture-level cities—including all 58 nationally designated poverty counties—and aims to restore 1.08 million hectares (16.28 million mu) of degraded land through reforestation, forest management, and economic tree improvement. Total investment is 17.44 billion RMB financed through a PPP structure: provincial government equity (49%), social capital consortium (51%), with debt financing from the China Development Bank (6.176 billion RMB) and commercial banks.

The project’s governance structure follows a four-tier model: government steering through policy formulation, performance monitoring, and budget allocation; financial support through development bank lending; enterprise operation through a Project Company (SPV) established by the government and social capital consortium; and local implementation through county forestry bureaus and specialized forestry cooperatives. The concession period is 30 years under the Build-Operate-Transfer (BOT) model.

Ecologically, the region encompasses three major restoration zones: the Lüliang Mountains (semi-arid, severe water erosion), the Taihang Mountains (rocky, shallow soils), and the northwest wind-sand area (sandy soils, wind erosion). The project has implemented 315,300 hectares of reforestation on former cropland, 518,400 hectares of ecological forest management, and 266,700 hectares of economic forest upgrading.

2.2 Data sources

Project administrative records include the project’s Implementation Plan (2017), Investment and Financing Report, Performance Evaluation Reports, and third-party audit reports. These documents provided information on area planted, survival rates, expenditure allocations, and program outputs. Project completion verification reports submitted through June 2025 were used for area coverage.

Household economic data originate from the project’s beneficiary tracking system. The system records participation in planting labor (workdays per household), forest management contracts, subsidy receipts

(reforestation payments), and cooperative dividends (economic forest income). We use aggregate figures drawn from the project's beneficiary database rather than individual-level microdata.

Ecological monitoring data include forest inventory statistics, soil erosion monitoring (from 21 monitoring stations established during the project), biodiversity surveys, and forest carbon stock estimates produced by the Shanxi Academy of Forestry. Carbon stock estimates were derived through standard forest inventory methods (biomass expansion factors and allometric equations for local species).

Program evaluation documents include four annual project reviews and two mid-term evaluation reports. The project's cooperation agreement, management regulations, and implementation guidance provided institutional information.

In addition to project administrative records, this study draws on two official implementation reports submitted by the project company to the Shanxi Forestry and Grassland Bureau: the Q4 2023 implementation report (Jin Lin Sheng Han [2024] No. 6) and the 2024 annual implementation report (Jin Lin Sheng Han [2025] No. 1). These reports provide updated data on verification progress, fund disbursement, loan financing gaps, and cooperative dissolution—details not available in public monitoring statistics.

To capture the institutional mechanisms that administrative records cannot reveal, we also conducted semi-structured interviews with 23 stakeholders in 2025 across three counties (Shuozhou, Zuoquan, and Youyu). The sample was purposively selected to cover different positions within the project's delivery chain: six staff from the project company (SPV), five county forestry officials, and twelve smallholder households, three of whom had held positions in implementing cooperatives. Interviewees were selected to represent both cooperatives that had dissolved and those still operating.

The interviews focused on three themes: how cooperatives were organized, financed, and governed in practice; how subsidy disbursement and information verification worked at the household level; and what happened to forest management and benefit delivery after cooperative dissolution. Interviews were conducted in Chinese, lasted 45–90 minutes, and were transcribed and coded thematically. We use these interviews for mechanism identification rather than distributional estimation. The sample is purposively selected and is not statistically representative; it is intended to reveal how institutional arrangements operate, not to estimate their prevalence across the project area.

2.3 Analytical approach

Our analysis follows a structured case-study design that compares pathway performance. Pathway identification first classified livelihood interventions according to the four-type framework (direct-use, market, service, upgrading). For each pathway, we compiled: (a) scale metrics (area or volume); (b) household participation and income data; and (c) enabling condition status.

The qualitative interviews were used to explain the mechanisms behind the patterns observed in the monitoring data. Specifically, they helped identify how cooperatives were governed in practice, why they dissolved, and how households absorbed the procedural costs that cooperatives had previously carried. In the analysis that follows, interview evidence is presented alongside monitoring data, but the two are kept analytically distinct: monitoring data establish scale and outcome patterns, while interviews explain the institutional processes that produced them.

Barrier identification drew on the implementation challenges documented in the project's performance evaluations and official implementation reports. This was structured around the threshold framework dimensions: biophysical/ecological barriers; institutional/coordination barriers; and market/infrastructure barriers.

Comparison and framework development examined variation across pathways on the enabling conditions and outcomes axes, drawing comparisons with established findings in the ecosystem services literature [7,12], which serves as the empirical basis for developing our “pathway-threshold” framework.

2.4 Validity considerations

Single-case study findings face generalizability limitations. We address this through three strategies. First, the project‘s systematic administrative monitoring covers all 98 counties, which reduces the selection bias risk common in small-N case studies. Second, we examine inter-county variation in pathway outcomes as counter-evidence. Third, we triangulate quantitative monitoring data with official evaluation reports and 23 semi-structured interviews, using the qualitative evidence to identify mechanisms that the monitoring data cannot capture, particularly how cooperatives were governed, why they dissolved, and how households navigated the digital disbursement system.

3. Results

3.1 The four livelihood pathways and their outcomes

Our analysis identifies four distinct livelihood pathways operating within the project, each with different input requirements, scale, and household welfare outcomes.

These findings highlight a crucial distinction for small-scale forestry: participation in a forestry program does not automatically translate into livelihood improvement. Smallholders may participate in afforestation and management activities—and even receive initial subsidies—yet fail to benefit if the pathway they engage with requires conditions they cannot meet. Low-threshold pathways succeed because they build on what smallholders already have: labor, traditional skills, and access to local markets. High-threshold pathways fail because they require infrastructure, institutional coordination, and market access that smallholders and their cooperatives do not possess. The pathway-threshold

framework thus reframes the question from “do smallholders participate?” to “under what conditions does participation deliver benefits?”

3.1.1 Pathway 1: Direct-use forest-based farming

Forest-based farming represents the largest and most diversified pathway. The project has implemented six sub-models: forest-medicinal herb, forest-mushroom, forest-poultry/livestock, forest-apiculture, forest-forage, and forest-vegetable. Table 1 summarizes key characteristics for each sub-model.

Table 1
Forest-based farming sub-models: scale, outcomes, and household income

Sub-model	Primary counties	Area/Scale	Households reached	Avg. household income increase (RMB/yr)	Income per mu (RMB/yr)
Forest-medicinal herb	Pingding, Jiaokou	80,000 ha	32,000	4,000–6,000	3,000–5,000
Forest-mushroom	Qinshui, Wutai	1,333 ha	15,000	4,000	40,000–48,000
Forest-poultry	Wuzhai, Zuoyun	500,000 birds	8,000	3,000–5,000	2,500–3,000
Forest-apiculture	Lingshi, Qinshui	20,000 boxes	3,000	3,000–5,000	3,000–4,500
Forest-forage	Youyu	3,333 ha	1,200	2,000+	2,000+
Forest-vegetable	Wanrong	1,333 ha	1,500	1,500–2,000	1,500–2,000

The forest-medicinal herb model was the most extensive. In Pingding County, 12,000 ha of walnut forest were interplanted with Codonopsis pilosula, generating total output value of 1.8 billion RMB in 2024, with per household income increases of 5,600 RMB. The interplanting improves herb quality—active ingredient concentrations 20%–30% higher than field-grown counterparts—while herb root systems reduce soil erosion. In Jiaokou County, 8,000 ha of jujube forest interplanted with Scutellaria baicalensis achieved average yields of 200 kg/mu and income of 4,000 RMB/mu.

Forest-mushroom cultivation proved particularly profitable per unit area but more capital-intensive. Qinshui County's 2,000 standardized greenhouses produced 50,000 tons of mushrooms in 2024, total value 600 million RMB, with participating households earning 4,000 RMB on average. Wutai County's walnut-forest mushroom production generated high per-unit-area returns, with participating households earning 5,000–8,000 RMB annually, but required substantial upfront investment in greenhouse structures and spawn.

Forest-poultry and apiculture generated the highest household-level returns, reflecting larger per-household scale. Wuzhai County's 500,000 free-range chickens under apricot forest generated net profits of 50 RMB per bird, with participating households earning 3,000–5,000 RMB annually. Lingshi County's honey production from walnut and locust forests achieved box incomes of 5,000 RMB, with households keeping 6–10 boxes.

Forest-forage and vegetable models served supplementary roles. Youyu County's 5,000 mu of sweet clover under seabuckthorn forest produced animal feed for goat production, generating comprehensive income increases of 2,000 RMB/mu. Wanrong County's young jujube forests interplanted with spinach generated 1,500–2,000 RMB/mu in vegetable income during the 3–5 year jujube pre-bearing period.

The success of forest-based farming reflects a threshold that had already been crossed by existing village networks, land allocation, and local markets—not by the project itself.

3.1.2 Pathway 2: Market-based carbon trading

Carbon trading represents a nascent market-based pathway. The project's restored forests—including 315,000 ha of reforested cropland and 518,400 ha of ecological forest management—sequester an estimated 800,000 tons of CO_2 annually, calculated using provincial forest inventory coefficients for the dominant species

The project has completed carbon accounting and third-party verification for 50,000 ha of carbon-sink forest, including 15,000 ha of Pinus tabuliformis plantation with verified annual sequestration of 27,000 tons. Formal registration under the national CCER (China Certified Emission Reduction) framework remains pending: as of mid-2026, no forestry carbon sink project had yet obtained registered emission reductions under the national CCER mechanism (NDRC, 2026).

Despite the absence of formal CCER issuance, the project has secured bilateral purchase agreements with provincial enterprises at negotiated prices of 60–80 RMB/ton, covering approximately 800,000 tons. An innovative "Pinus tabuliformis carbon-specific" product was developed through a three-year agreement with a Datong-based coal enterprise, involving 30,000 tons annually (including 20,000 tons of pine-specific credits). Revenue from these agreements is distributed with 60% allocated to participating households (as cooperative dividends) and 40% reinvested in forest management, reaching approximately 20,000 households in 2024 with average dividends of 750 RMB per household.

Carbon sink development has entered a pilot phase. The project company has completed vector data collection for forest parcels in selected counties and is piloting development models in Youyu and Linxian counties, in cooperation with local governments. However, forestland tenure and benefit-sharing arrangements remain unresolved, and no formal carbon revenue has been realized.

Overall, however, the carbon livelihood pathway remains largely untapped. Only 5% of the total project area has achieved carbon certification; the remaining 95% awaits completion of baseline documentation

and third-party verification. The project has invested in carbon accounting infrastructure but faces persistent delays in the validation process for heterogeneous land parcels across 98 counties.

The carbon pathway remains constrained not by smallholder capability but by institutional requirements—verification capacity, registry access, and benefit-sharing rules—that the governance structure has not yet produced.

3.1.3 Pathway 3: Service-based eco-tourism and forest wellness

The project has developed forest wellness bases in high forest-cover areas: the Pangquangou Forest Wellness Base (Lüliang Mountains), Wangmangling Forest Wellness Base (Taihang Mountains), and Guandishan Pinus tabuliformis Wellness Base (Table 2).

Table 2
Forest wellness and ecotourism performance

Site	Forest cover	Annual visitors	Tourism income (Million RMB)	Households reached	HH income avg (RMB/yr)
Pangquangou	> 90%	100,000	50	500	15,000
Guandishan	85%	60,000	30	300	10,000
Youyu (seabuckthorn forest)	~ 60%	150,000	80	500	8,000–30,000

Note: Tourism income figures represent total project-related revenue including ticketing, accommodation, hospitality, and product sales (e.g., seabuckthorn products in Youyu). Household income refers to the share retained by participating households through cooperatives, wages, and direct service provision. Youyu figures reflect the range across different household participation levels.

The Pangquangou base features forest boardwalks, wellness cabins, and a Pinus tabuliformis leaf hot spring, with wellness packages combining forest bathing, Pinus tabuliformis-based aromatherapy, and traditional Chinese medicine therapy. The Youyu seabuckthorn forest site has similarly attracted visitors through its distinctive agro-tourism model, combining fruit-picking experiences with processed product sales.

Ecological agritourism clusters have emerged through integration with surrounding villages‘ homestays and farm restaurants. Fifteen demonstration villages with unified planning for accommodation standards and service requirements have been developed through an integrated “ecotourism + homestay + local cuisine + agricultural procurement” model. Pingding County’s Yuejiazhai Village has become a model: leveraging Taihang Mountain landscapes and forest-medicinal herb cultivation, it received 150,000 visitors in 2024, generating 50 million RMB in total tourism income, with participating households earning approximately 15,000 RMB annually.

Overall, ecotourism attracted 1.5 million visitors in 2024, with total tourism income growing 35% year-on-year, generating significant local economic multipliers (lodging, food, transport). Preliminary estimates for 2025 suggest continued expansion. However, it remained geographically concentrated in areas with existing scenic resources and road access.

Eco-tourism succeeds where scenic assets and road access already exist; it cannot be replicated widely because the infrastructure and market conditions it requires are spatially concentrated and not produced by the project.

3.1.4 Pathway 4: Upgrading through processing and branding

The project has invested heavily in processing infrastructure (Table 3). Standardized primary processing facilities include 450 drying houses, 80 traditional medicine primary processing workshops, and 50 edible fungus sorting and packaging centers. These reduced post-harvest loss rates from approximately 25% to below 10%.

Table 3
Processing infrastructure development

Infrastructure	Units built	Annual capacity	Post-harvest loss reduction	Value addition
Drying houses (nuts)	450	200,000 tons	From 25% to < 10%	0.5–1 RMB/jin price increase
Medicine processing	80	50,000 tons	30% quality improvement	20%+ value addition
Mushroom packaging	50	100,000 tons	—	—

Note: Infrastructure figures are compiled from project implementation records and county-level procurement notices for primary processing facilities supported under the PPP framework.

Twelve deep-processing product lines have been launched, producing walnut oil (150 RMB/liter, generating approximately 3,000 RMB per mu in processing value), seabuckthorn juice (80 RMB/jin), and jujube fermented beverages. In 2024, processed product sales reached 2.5 billion RMB, accounting for 45% of total forestry product sales.

Regional branding has been strengthened through geographical indication certifications for “Shanxi Walnut” and “Lüliang Jujube,” achieving price premiums of 30%–50%. E-commerce performance has also expanded: official flagship stores on Taobao, JD.com, and Pinduoduo generated 1.8 billion RMB in sales in 2024 (35% of total product sales). Logistics infrastructure investments have included four regional agricultural logistics centers with cold storage, 100 cold storage units, and 200 refrigerated vehicles, reducing walnut transport costs from 0.8 RMB/jin to 0.5 RMB/jin and enabling refrigerated delivery to Shanghai within two days.

Processing and e-commerce upgrades depend on cold-chain logistics and digital marketing capacity that remain unevenly available, indicating that the threshold for upgrading pathways is produced by public infrastructure and market institutions rather than by household effort alone.

3.1.5 The cooperative as an implementation shell: governance, finance, and dissolution

Across the four pathways, cooperatives were the primary organizational channel through which smallholders engaged with the project. Yet interviews reveal that cooperatives functioned less as self-governing member organizations than as implementation shells for project delivery.Decision-making authority was concentrated outside the membership. In Youyu County, a former cooperative leader explained that major decisions—which plots to contract, how to allocate labor, and how to distribute payments—were made by village cadres and county forestry officials, not by the cooperative's board. Members were informed of decisions rather than participating in them. This pattern was consistent across the cooperatives we visited in Youyu and Zuoquan.Financially, most cooperatives had no independent revenue base. They operated on project disbursements channeled from the project company through county finance to the cooperative account. A few had small income from forest product sales, but this was insufficient to cover operating costs. As one county forestry official put it, without the project money, the cooperative had nothing to run on.This financial dependence shaped what happened when disbursements slowed or stopped. In Youyu County, the cooperative dissolved after project payments were delayed for more than six months. The immediate trigger was not a formal decision to close, but the exhaustion of funds to pay for management work and administrative costs. As payments stopped, members stopped working, and the organization effectively ceased to function.Dissolution did not leave a vacuum. County forestry bureaus arranged for third-party companies or village committees to take over forest management tasks. Benefit distribution—particularly dividends from forest tenure assets—was reassigned to village committees, which reported to county authorities for disbursement. Households either managed their own plots or sold products to local buyers without cooperative intermediation. These substitute arrangements maintained basic continuity, but they were varied and improvised rather than designed.A further friction emerged at the point of subsidy disbursement. The digital system required households to submit bank account and identity information. County officials reported that a common reason for returned applications was incorrect information—a misspelled name or wrong account number—which required re-submission and extended an already lengthy process. Interviewees reported an average disbursement period of approximately six months. Households did not respond by withdrawing; they sought help from children, neighbors, and village cadres, and in most cases the problem was eventually resolved. But this assistance came from informal networks, not from institutional arrangements.

3.2 Barriers constraining pathway success

3.2.1 Ecological-biophysical barriers

Site quality constraints—The Loess Plateau's thin soils (average 25–30 cm in many project areas) and 400–500 mm annual precipitation create high survival risks. In Lüliang and Taihang areas, plantation survival rates ranged from 75–80% in 2022–2024 monitoring—5–10 percentage points below the provincial average of 85%. In Jingle County, a 2023 reforestation plot on 30° slopes experienced spring seedling drought and summer flood scouring; first-year survival fell below 60%, requiring supplementary planting that increased unit costs from 800 to 1,200 RMB/mu. In northwest wind-sand areas (Youyu, Zuoyun), wind erosion further depresses survival: a 2024 sand-control plot lost 30% of 2,000 mu of Pinus sylvestris seedlings to sand burial and root exposure during spring sandstorms; subsequent replanting added 1.5 million RMB in unplanned costs.

Species configuration failures—The intended multi-species mixed forest proved problematic in implementation. In Zuoyun County, 60:40 Pinus tabuliformis:Robinia pseudoacacia mixtures have seen Robinia outcompeting pine—after three years, Robinia diameter reached 8 cm versus 4 cm for pine, with pine survival only 82% compared with 90% in pure pine stands. Pest control costs are 60% higher in mixed stands due to aphid transmission from Robinia to pine. In Lingchuan County, Platycladus orientalis-Populus davidiana mixtures on rocky sites failed because Populus required moisture not available in thin soils; 15% Populus mortality created canopy gaps increasing erosion. These problems stem from design based on generalized provincial guidelines rather than site-specific micro-condition assessment.

3.2.2 Institutional coordination barriers

Inter-agency fragmentation—County-level implementation reveals costly delays from overlapping agency jurisdictions. In Yushe County, a 1,200-mu reforestation project required two months for land-use certification from the Natural Resources Bureau because land records were not synchronized with Forestry Bureau project maps. The delay pushed planting past the spring optimum, reducing survival by 7 percentage points. In Shilou County, rural development statistics required cross-checking forestry labor records to identify participant poverty status for performance targets—records lacked poverty classification, requiring one month of re-verification that delayed performance reporting.

Even more problematic were cases where no lead agency existed. Road construction for forest access became a three-month inter-agency dispute between Forestry (who argued this was transportation infrastructure) and Transportation (who argued access roads served forestry only). The ultimate resolution—Forestry leads construction, Transportation provides technical support—delayed transport for planting material across three townships, raising transport costs by 120 RMB/mu.

Policy conflicts—Contradictory national and provincial policies created implementation friction. The most consequential was conflict between reforestation policy (which requires cropland conversion on slopes > 25°) and agricultural subsidy policy (which requires grain cropping for land fertility subsidies). Households choosing reforestation lose agricultural land fertility subsidies of 120 RMB/mu/year; in Tianzhen County in 2024, 120 households refused reforestation agreements, resulting in only 80% of

planned 5,000 mu achieved. Across the province in 2023–2024, 18% of reforestation targets went unmet due to this policy conflict.

Weak county-level technical capacity—Poverty counties face severe staffing constraints. Forestry bureau staff in Lin County average 50 years old, with only 3 of 45 holding engineering credentials; none have PPP management training. Performance evaluations require assessing 23 indicators across six dimensions (afforestation quality, management effectiveness, poverty outcomes, ecological benefits). While simple quantitative indicators (area planted, survival) are adequately measured, qualitative indicators (biodiversity, soil organic matter) rely on visual estimation due to lack of measurement protocols.

3.2.3 Funding disbursement and financing barriers

Disbursement delays, as detailed above, the seven-stage approval process and the frequent return of household applications for information errors delayed subsidy payments and weakened the institutional chain through which benefits reached households.

Social capital under-participation, Private sector investment accounts for only 30% of total project investment (5 billion RMB out of 17.44 billion). Social capital consists predominantly of small, local firms with weak balance sheets and limited forest operations experience. The dominant concern cited in investor interviews is return uncertainty: forestry projects have 8–15 year payback periods, with returns conditional on ecological factors (drought, pests) and market factors (nut prices), while newer revenue sources (carbon, eco-tourism) remain unproven.

More fundamentally, the project faces a structural financing gap. The China Development Bank recalled 700 million RMB in loans in 2022 after the PPP project was classified as implicit government debt, and a remaining loan balance of 1.276 billion RMB has not been disbursed as of December 2024. The project company has sought credit from multiple commercial banks, but no new credit line has been approved, creating a funding gap that directly threatens subsidy payments to smallholders.

A further barrier emerged at the cooperative level. Some poverty-alleviation forestry cooperatives—the primary channel through which smallholders participate in afforestation and management—have been dissolved. As of December 2024, unresolved advance payments totaling 251 million RMB remained with dissolved cooperatives, and remaining project payments could not be settled. This disrupts the benefit delivery chain: when cooperatives dissolve, smallholders lose both the channel for receiving subsidies and the organizational support for continued forest management.

3.2.4 Market infrastructure and access barriers

Transport deficits—Logistics deficiencies impose heavy costs. Among 98 project counties, 15 have less than 80% township road hard-surface coverage; 200 villages lack paved roads. Transporting walnuts from Shilou County to the nearest rail freight station requires 2.5 hours; to Taiyuan logistics hub, 4 hours, incurring transport costs of 0.8 RMB/jin (10% of walnut sales price) compared with 0.3 RMB/jin on

plains. In 2024, 5,000 tons of walnuts (annual production 20,000 tons) awaited shipment when three roads were washed out by summer rains; stored walnuts spoiled, causing 2 million RMB in losses.

Cold chain deficits are even more severe. Only 12 of 98 counties have cold storage, with combined capacity 100,000 m³—vastly inadequate for 40% of forest products that are perishable. Only 50 refrigerated trucks exist across all project counties. In Jixian County (apple production 100,000 tons), one cold storage unit of 5,000 m³ and two refrigerated trucks serve the entire county. Apples stored in farm basements experience 8% pre-transport spoilage; during conventional truck transport, spoilage increases to 15%, compared with 6.5% national average. Farmers unable to access cold chain sell apples at 1.5 RMB/jin to juice factories (normal market price 3 RMB/jin), losing 2,000 RMB/mu.

E-commerce gaps—Only 30% of poor villages have integrated with e-commerce platforms; rural service stations in Lin County (50 stations) have 30 that are non-operational due to funding and staffing shortages. The 20 operational stations generate under 50,000 RMB/month in online sales. Household e-commerce skills remain inadequate: among 100 training participants, only 10 successfully established online stores, and 8 of these ceased operations within one month due to order processing and logistics difficulties. Professional photography, copywriting, and after-sales service are unavailable. As a result, e-commerce accounts for only 35% of total product sales, despite investments.

Market information asymmetries—Farmers rely on itinerant traders for market information. In 2022, walnut prices fell from 8 to 5 RMB/jin—information that reached project area farmers only in 2023, after they had expanded planting. The lagged response caused walnut surplus and farmer losses. Farmers lack information on quality preferences (thin-shell walnuts now command premium; thick-shell have become discount products), leading to maladaptive variety choices. Market intelligence services at county level are provided by personnel without formal training, and 90% of county agricultural offices lack dedicated market analysis staff. The pattern of “copycat” planting persists, where households observe profitable commodities and expand cultivation without demand signals: jujube acreage tripled from 2019–2021, followed by price collapse (6 RMB/jin to 2 RMB/jin); the seabuckthorn planting boom of 2024 (30% acreage increase) suggests a similar cycle ahead.

4. Discussion

4.1 Explaining pathway heterogeneity: threshold production failure

Our findings reveal a stark dichotomy: forest-based farming and processing have succeeded, generating substantial and well-distributed household income; carbon trading, high-value ecotourism, e-commerce, and cold-chain logistics have underperformed relative to potential. Explaining this heterogeneity through the lens of our pathway-threshold framework leads to two principal observations.

First, low-threshold pathways succeed because they build on existing household and community capabilities, farmers already possess agricultural labor skills, forest land is already allocated and accessible, and markets for raw herbs and fresh produce are local and stable. Supportive institutional arrangements have been built, production training, cooperative formation, procurement contracts, aligning with existing village-level organizations. As a result, transaction costs are low, and value capture is rapid. But these pathways are not threshold-free. Their thresholds have already been crossed by historical processes, land allocation, village extension networks, local trader relationships, that predate the project. The project did not produce these conditions; it inherited them.

Second, high-threshold pathways fail or underperform because the governance structure has not produced the conditions for participation at sufficient scale. Carbon trading presents multiple hurdles—additionality demonstration, verification protocols, registry access, benefit allocation—that require costly institutional infrastructure. E-commerce requires wholesale transformation of marketing and logistics capacities that are absent in most project counties. Ecotourism, while successful in areas with scenic resources, cannot be replicated widely because its success depends on scenic assets, road access, and tourism flows that are spatially concentrated. In each case, the pathway does not fail because smallholders lack ability; it fails because no actor in the governance structure is responsible for producing the cross-cutting conditions that would allow smallholders to cross the threshold.

This is what we call threshold production failure. A PPP is not simply a financing instrument; it is a governance structure that allocates responsibility for threshold production across public and private actors. Our case shows that this allocation can fail in a specific way: each actor fulfills its own contractual obligations, yet no actor is responsible for the cross-cutting conditions—information infrastructure, cooperative viability, tenure clarity—that determine whether smallholders can actually benefit. The project company delivers investment and verification; county forestry bureaus deliver implementation and monitoring; village committees deliver local coordination. But the conditions that cut across these responsibilities—who ensures that cooperatives remain viable after disbursements end, who ensures that households can navigate the digital system, who ensures that tenure disputes are resolved before carbon projects are registered—fall between organizational mandates. They are no one's responsibility, and therefore they are not produced.

This finding extends the PES and community forestry literature in three ways. First, it demonstrates that within a single program, pathway outcomes vary systematically by type—challenging the common assumption that ecosystem services enhance livelihoods as a general proposition. Unlike studies that treat ecosystem service livelihood as a uniform process [6], we show that pathways are inherently heterogeneous and require pathway-specific analysis. Second, the threshold concept offers an analytical complement to conventional institutional design frameworks. Whereas much of the PES literature focuses on institutional design as the primary determinant of success [5], our findings highlight infrastructure and capability thresholds as equally important—particularly in remote, impoverished settings. Third, our case reveals that PPP governance does not automatically resolve coordination deficits; it may amplify them by adding principal-agent complexity. While the PPP literature has

emphasized financial and contractual mechanisms [19], our findings show that coordination failures among government agencies can be as consequential as private sector participation constraints.

4.1.1 Cooperative dissolution as a collective-action failure

The cooperative's dissolution, described in Section 3.1.5, is not a management failure but a structural outcome. The cooperative was designed as an implementation shell, not a self-governing organization. It carried the administrative burden of the project without acquiring the resources or authority to sustain itself beyond the project cycle. It faced a classic collective-action problem: the costs of maintaining the organization were borne locally, while the benefits of its continued existence accrued to a project structure that had no mechanism for ensuring its viability after funding ended[20].

The consequence is that dissolution did not simply remove a service provider. It redistributed procedural costs from the organizational level to the household level. Tasks that the cooperative had performed—aggregating information, verifying eligibility, liaising with county offices—fell back onto individual households. Our interviews show that households absorbed these costs through informal networks: children, neighbors, village cadres. This absorption was effective in the cases we observed, but it was not institutionalized. It depended on social capital that is unevenly distributed. For households with dense networks, the threshold was invisible. For those without, it remained a barrier that monitoring data cannot detect, because the data record only whether payment was eventually made, not how many returns, how much assistance, and whose help were required to get there.

This finding matters for how we understand the role of cooperatives in forestry programs. Cooperatives are often treated as intermediaries that reduce transaction costs and aggregate supply. But in this case, the cooperative was not an intermediary with independent governance capacity; it was a conduit for project resources, with decision-making authority held by village cadres and county officials. When the resources stopped, the conduit collapsed. Building cooperative capacity, therefore, is not simply a matter of training or funding; it requires granting cooperatives genuine governance autonomy and an independent revenue base, so that they can survive the end of a project cycle.

4.1.2 Digital governance and the production of new thresholds

A second mechanism extends the threshold framework in a specific direction. The digital disbursement system presupposed that households could independently complete and verify information entry. When cooperatives functioned, they absorbed this task. After dissolution, the task fell to households, and the threshold became visible. Households with low informational literacy, limited digital access, or thin social networks faced a higher risk of repeated returns.

Crucially, households did not respond by withdrawing. They sought help—from children, neighbors, village cadres—and in most cases the problem was resolved. But this resolution depended on informal social networks rather than institutional support. The threshold was not lowered; it was selectively

crossed through social capital. For households with dense networks, the threshold was invisible. For those without, it remained a barrier that monitoring data cannot detect, because the data record only whether payment was eventually made, not how many times the digital form was returned, how much assistance was needed to complete it, or whose help was relied upon.

This finding extends the threshold framework in a specific direction: digital tools do not merely require infrastructure and skills; they reallocate responsibility for threshold crossing from organizations to individuals and their social networks. Whether this reallocation is acceptable is a governance question, not a technical one. The absence of an institutionalized information-assistance role—such as a village-level information coordinator—is not a minor administrative gap. It reflects the fact that no actor in the PPP structure was assigned responsibility for the household-side conditions of program participation.

4.2 The PPP governance puzzle

The threshold-production perspective developed above also sheds light on the PPP governance puzzle. On the enabling side, the 30-year concession provided a stable institutional frame for large-scale restoration, attracting long-term finance and enabling performance-based contracts that improved planting quality. The introduction of enterprise management was associated with survival rates 5–10 percentage points above traditional government projects, and the partnership with development banks yielded loan terms significantly more favorable than commercial alternatives.

On the constraining side, governance fragmentation is a central barrier to high-threshold pathways. As Ongolo [21] demonstrates in the context of Cameroonian forest governance, such fragmentation is not merely a procedural flaw but can become an entrenched “banality,” as competing state bureaucracies engage in power plays to secure their own interests. The coordination failures among forestry, finance, and rural development agencies—well-documented in the project’s implementation challenges—raise transaction costs and delay disbursement. In PPP theory, effective coordination is often described as a condition for success, but in complex multi-level governance settings—as in this case—the existence of multiple principals (government at two levels, social capital, financial institutions) generates agency problems that are not fully resolved by contractual arrangements. Recent systematic reviews of PPP stakeholder dynamics confirm that contradictory interests, fragmented coordination, and power imbalances are among the most significant governance challenges [22]. The 7-stage payment approval process exemplifies this: each approval point represents a veto opportunity for an agency to assert compliance with its mandate; in practice, this generates costly delays that undermine project effectiveness.

Our case further suggests that social capital participation constraints reflect the fundamental tension between public good purposes and private return requirements in forestry PPPs. This tension is particularly acute in the Chinese context, where power and interest balances between public and private actors must be carefully negotiated to sustain formal cooperation in conservation PPPs [23]. Private investors demand predictable returns within reasonable time horizons; ecological restoration offers returns that are delayed (timber, nuts, carbon) and uncertain (weather, pests, markets). Without strong

financial incentives or risk-sharing mechanisms, private capital gravitates toward higher-return activities (primary processing, selective high-value planting) rather than the core ecological restoration activities with the highest public good value. This creates a “public good under-provision” problem even within a PPP structure—a finding consistent with the public-private partnership literature on infrastructure projects with high positive externalities [19]. Addressing this tension requires deliberate institutional design that aligns private returns with public benefits—a point we return to in the policy implications below.

4.3 Limitations

Four limitations should be acknowledged.

First, as a single case, generalizability requires replication across other contexts; however, the Loess Plateau's characteristics (dryland, poverty, soil degradation) are shared with many regions across Asia, Africa, and Latin America, providing comparative relevance.

Second, our analysis draws on official monitoring data, which may underreport implementation problems and are not designed for causal inference. The beneficiary tracking system records whether payments were eventually made, but not how many times applications were returned, how much assistance households required, or whose help they relied on. Future research using household panels could estimate causal pathway impacts more rigorously and capture these procedural costs directly.

Third, the qualitative interviews, while purposively selected to cover different positions in the delivery chain, are small in number and not statistically representative. We use them to identify mechanisms—how cooperatives were governed, why they dissolved, and how households navigated the digital disbursement system—rather than to estimate the prevalence of these mechanisms across the project area. The findings should be read accordingly.

Fourth, the study period covers only the first eight years of a 30-year project. Pathway dynamics may shift as forests mature and carbon markets develop, and pathway-level aggregation necessarily simplifies household-level complexity. In particular, the cooperative dissolution we document may be partly reversed if new organizational forms emerge as the project matures; our analysis captures a moment of institutional breakdown, not its permanent outcome.

5. Conclusion and Policy Implications

This study examined the pathways and barriers to forest ecosystem service livelihood in the Shanxi Forestry Ecological Poverty Alleviation PPP Project on China‘s Loess Plateau. Our analysis of four livelihood pathways—forest-based farming, carbon trading, eco-tourism and forest wellness, and processing upgrading—reveals pronounced heterogeneity: forest-based farming and processing have generated substantial household income increases (3,000–5,000 RMB/mu) reaching over 500,000 households, while carbon trading remains modest, with approximately 800,000 tons covered by bilateral

purchase agreements against an annual sequestration potential of 800,000 tons, and e-commerce and logistics continue to face structural constraints.

We propose a “pathway-threshold” framework to explain this heterogeneity: low-threshold pathways succeed because they align with existing household capabilities and require limited institutional coordination and infrastructure; high-threshold pathways flounder because they require infrastructure, institutional coordination, and market capacities that are not yet in place in the project’s poverty-stricken counties. Our findings further highlight that PPP governance, while enabling capital mobilization and technical efficiency, introduces coordination costs that are a significant barrier to high-threshold pathway performance—particularly through inter-agency fragmentation, funding disbursement delays, and uncertain private returns.

5.1 Policy implications

Our findings suggest that the central policy problem is not insufficient investment or inadequate smallholder capacity, but the absence of an actor responsible for producing the cross-cutting conditions that allow participation to translate into benefit. Three priorities follow directly from this diagnosis.

First, institutionalize the information-assistance function. The fact that households relied on children, neighbors, and village cadres to complete digital applications reveals a missing role, not a missing capability. Establishing a village-level information coordinator, with a defined mandate, modest funding, and reporting responsibility—would convert an informal workaround into an accountable function. This is not a costly intervention; it is a matter of assigning responsibility where none currently exists.

Second, design cooperative support around viability rather than project cycles. Cooperatives dissolved because they were designed to deliver project tasks, not to survive beyond them. Transition support, covering financial management, independent revenue generation, and legal restructuring, should begin before project disbursements end, not after dissolution. This requires the project company and county governments to treat cooperative viability as a project outcome, not an externality.

Third, clarify and simplify disbursement responsibility. The seven-stage approval process and the frequent return of applications for information errors are symptoms of a system in which each stage can veto but no stage is accountable for overall timeliness. Reducing approval stages and designating a single county-level office as responsible for household-side verification would shorten payment cycles and reduce the procedural burden that currently falls on households.

5.2 Research directions

Future research should examine pathway dynamics through longitudinal household surveys that track income sources and the coping strategies households employ when market conditions change. Such surveys could also capture the procedural costs that our monitoring data cannot measure—how many times applications are returned, how much assistance households require, and whose help they rely on.

Multi-case comparisons across China's other forestry PPP projects (Yunnan, Guizhou) and with international cases would test the generalizability of the threshold production failure framework. As carbon markets mature and the project's forests approach timber harvest and full canopy closure, research on the interaction between carbon payments and other ecosystem services could illuminate trade-offs and synergies. Finally, the role of digital technologies—precision monitoring, mobile payment platforms, blockchain supply chains—in lowering pathway thresholds merits investigation, with attention to whether they reduce or reproduce the procedural inequalities documented here.

Declarations

Author Contribution

Conceptualization, J.Z. and Z.S.; methodology, J.Z.; formal analysis, J.Z.; investigation, J.Z. and Z.S.; data curation, J.Z.; writing—original draft preparation, J.Z.; writing—review and editing, J.Z. and Z.S.; visualization, J.Z.; project administration, J.Z. All authors have read and agreed to the published version of the manuscript.

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Figures

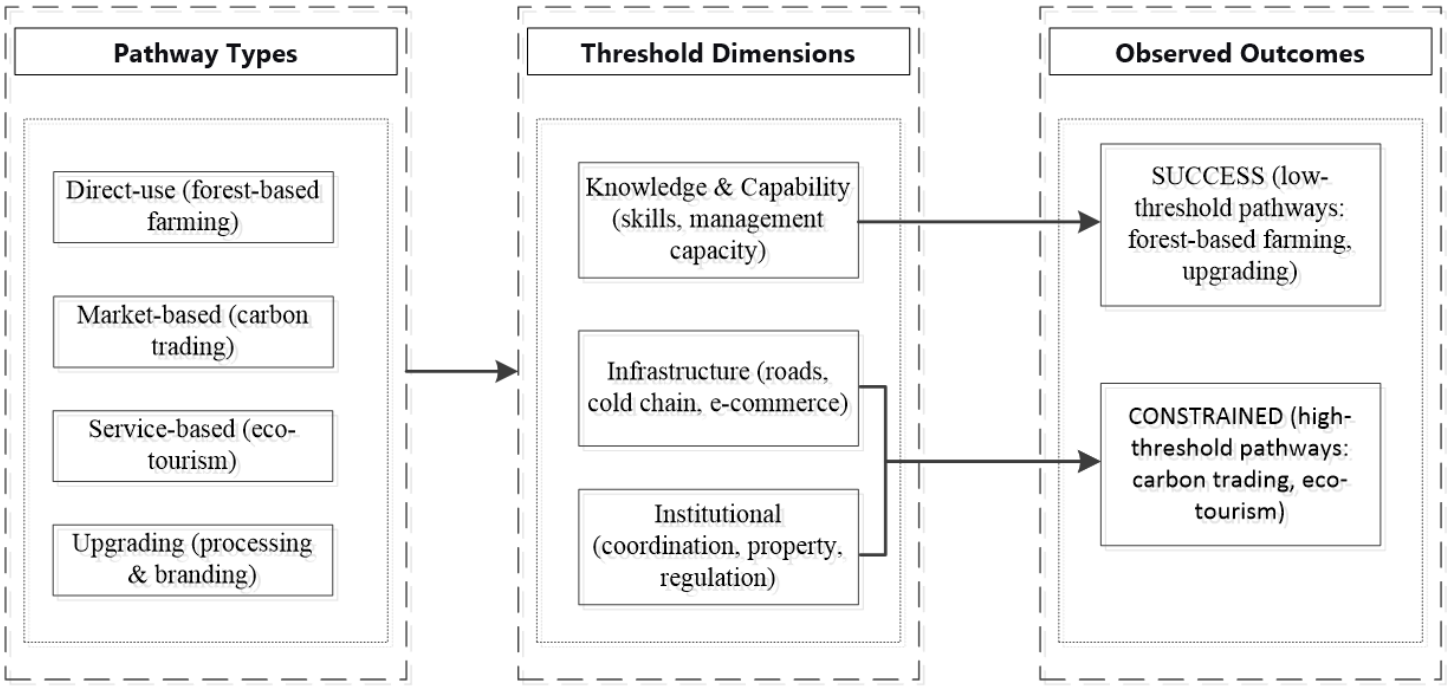

Figure 1

A pathway-threshold framework for forest ecosystem service livelihood.