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Environmental Infrastructure as a Catalyst for Rural Financial Resilience: Longitudinal Evidence from the Health–Credit–Income Channel

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Abstract

Sustainable rural development requires households to move beyond defensive medical spending and emergency borrowing toward more productive, forward-looking resource allocation. This study uses panel data from the China Household Finance Survey (CHFS), covering the 2017, 2019, and 2021 waves plus a newly released 2023 green-channel wave. We examine whether improvements in safe drinking water, clean cooking energy, and sanitation are associated with lower rural household economic vulnerability. We employ a staggered difference-in-differences design with household and year fixed effects, complemented by event–study tests, mediation analysis, and robustness checks. Environmental infrastructure improvements are significantly associated with lower child hospitalization and out-of-pocket medical expenditure, reduced reliance on high-cost informal credit, and higher income-generating asset shares. Mechanism analysis supports a "health–credit–income" channel, in which environmental improvements reduce preventable health shocks, ease emergency borrowing, and relax liquidity constraints on productive asset allocation. Threshold results further show that these financial-resilience benefits are strongest among households with the lowest baseline resource endowments. The study focuses on rural China, yet the identified health–credit–income mechanism offers a broader, scalable framework. Environmental infrastructure first reduces preventable disease burden, then eases emergency informal borrowing, and finally frees liquidity for income-generating assets. This sequence helps explain how environmental investment can create the financial preconditions for sustainable consumption and investment across developing economies. These findings offer micro-level evidence for integrating environmental infrastructure, rural financial resilience, and ESG social-value assessment.

Keywords: environmental infrastructure; rural financial resilience; health–credit–income channel; economic vulnerability; ESG social value; longitudinal analysis; rural China

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1. Introduction

Sustainable rural development depends not only on access to green technologies and public services, but also on whether households have sufficient financial resilience to absorb shocks. This resilience lets households make forward-looking consumption and investment decisions rather than purely defensive ones, since preventable health shocks and emergency borrowing often amplify rural economic vulnerability. When a child suffers an avoidable illness, the resulting medical costs can push households into informal credit, reduce productive investment, and reinforce a health–credit–income cycle of vulnerability [1–5].

Environmental infrastructure—access to safe drinking water, clean cooking energy, and improved sanitation—has long been recognized as a primary driver of preventable disease burden in rural areas [6–8]. Unsafe water sources cause much of the child diarrheal disease, typhoid, and acute respiratory infection observed in these settings [7,8]. Solid-fuel cooking stoves generate indoor air pollution linked to childhood pneumonia and chronic respiratory disease, while inadequate sanitation spreads pathogens tied to intestinal parasites and waterborne illness [7,8]. Targeted upgrades address each risk directly: piped or treated water, combined with point-of-use household treatment technologies, reduces fecal–oral pathogen exposure. Replacing solid fuels with electricity, gas, or LPG lowers indoor PM2.5, while upgrading toilets to hygienic flush facilities, backed by village sanitation infrastructure, interrupts pathogen transmission [6–12]. Together, these engineering and behavioral interventions constitute the household-level environmental infrastructure improvements whose financial-resilience consequences we examine in this study. Each disease pathway translates directly into child hospitalization events, generating the medical expenditure shocks that initiate the health–credit–income spiral described above.

Despite this intuitive connection, the existing literature has largely examined the environmental, health, and financial dimensions of rural vulnerability in isolation [1,2,6–8]. The structural roles that health shocks and informal credit play in the infrastructure–vulnerability relationship therefore remain unresolved. A systematic review of the four core variables and their pairwise relationships reveals both the empirical foundations and the critical gaps this study addresses.

Prior research links environmental infrastructure to health outcomes: a substantial body of evidence shows that safe water, improved sanitation, and clean cooking energy significantly reduce preventable disease burden, especially among children. Prüss–Ustün et al. [8] document that inadequate water, sanitation, and hygiene account for substantial preventable morbidity and mortality worldwide, with children disproportionately affected through waterborne, airborne, and sanitation-related pathways. Ma et al. [7] show that access to sanitary toilets significantly reduces health-poverty vulnerability among rural residents in western China, via reduced pathogen exposure and improved nutrition. Li et al. [6] find that energy poverty, including reliance on solid cooking fuels, significantly drives household health inequality and economic deprivation in rural China, while clean-energy transitions generate measurable welfare gains. These studies confirm that environmental infrastructure improvements reduce preventable illness, but they mostly measure disease incidence and access rates, rarely tracing downstream effects on household borrowing or asset allocation. To make these abstract relationships concrete, the consequences of environmental deprivation in our CHFS rural sample appear as recurring, household-specific events rather than aggregate statistical risks. Typical events include a child hospitalized overnight for rotavirus or norovirus diarrhea after drinking untreated well water. Average inpatient out-of-pocket costs run roughly 1200–1800 yuan per episode, often financed through informal loans at 18–24 percent annualized implicit interest. Other cases include a toddler diagnosed with bacterial pneumonia after sustained PM2.5 exposure from an unventilated coal- or crop-residue-burning kitchen stove. A further case is a school-age child with persistent helminthic infection—ascariasis or trichuriasis—traceable to soil contamination around an unimproved pit latrine. No single event is rare or catastrophic on its own. But two to three episodes per child per year impose a financial burden that crowds out much of the household's monthly liquidity and triggers the borrowing-and-deleveraging cycle this study quantifies. These concrete events are the household-level

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units that aggregate into the "preventable disease burden" and "downstream financial consequences" discussed in the literature above.

Health shocks are also central to household economic vulnerability. Emergency medical expenditure arising from preventable illness is a well-documented pathway through which health risk drives poverty and financial fragility in developing economies. Kochar [3] shows that illness-related expenses in low-income settings can reduce household savings, increase reliance on informal borrowing, and limit the accumulation of income-generating assets, weakening future earning capacity. This evidence suggests that health shocks' financial consequences extend beyond the immediate medical payment, contributing to longer-term income losses consistent with precautionary saving theory. Zhao et al. [4] confirm this pattern in rural China, showing that health shocks significantly raise poverty vulnerability, with the largest effects among households facing weak insurance coverage and tight liquidity constraints. Qiu and Zhang [5] further show that health-related expenditure reshapes household consumption, shifting resources away from investment and durable goods toward immediate medical needs. Yang and Mukhopadhaya [2] document that health deprivation is a significant dimension of multidimensional poverty among rural Chinese households. However, these studies often treat health shocks as externally given, rather than as outcomes partly reducible through environmental improvements, understating the scope for structural policy intervention.

Three further questions follow directly from this evidence base and motivate the focus of this study. First, consider demographic and geographic context: the financial consequences of health shocks are not evenly distributed. Rural households in central and western China, female-headed households, families with young children or chronically ill members, and households in the lowest income and asset quartiles consistently bear disproportionately large out-of-pocket medical costs and rely most heavily on informal credit [2,4,5,7]. These same household types also experience the most concentrated environmental deprivation—unsafe drinking water, solid-fuel cooking, and inadequate sanitation. This joint distribution of environmental risk and financial fragility identifies them as the policy-relevant target population for this study. Second, consider the relationship between health shocks and environmental conditions: the three environmental dimensions act through identifiable biological pathways. Fecal–oral disease stems from unsafe water, indoor air pollution from solid cooking fuels, and pathogen exposure from inadequate sanitation. Together, these pathways jointly determine the incidence of preventable child illness and its out-of-pocket cost, making realized health shocks partly endogenous to environmental quality rather than purely exogenous events [6–8]. Third, consider how remediable environmental conditions reduce household economic vulnerability: the mechanism unfolds sequentially. Clean water, clean cooking energy, and improved sanitation lower the probability and cost of preventable illness. This reduces the demand for emergency informal borrowing and its associated interest and rollover burden. The resulting liquidity release then enables a shift from precautionary cash holdings toward income-generating assets such as agricultural capital, livestock, and micro-enterprise investments. This three-stage health–credit–income channel is the central object of investigation in the remainder of the paper. To make the target population more concrete, we specify its demographic and geographic profile along five overlapping dimensions. (a) Provincial concentration: A total of 58.3 percent of sample households is located in the central and western macro-regions, with the highest density in Gansu, Guizhou, Yunnan, Sichuan, Shaanxi, and Henan, which together account for most households with a 2017 baseline EII of zero. (b) Pediatric exposure: Our analytical sample includes only households with at least one child under age 18, of whom about 41 percent are under age five—the age band most biologically sensitive to waterborne, indoor air, and sanitation-related disease.

(c) Household-head profile: A total of 31.4 percent of sample households is female-headed, and these households show a stronger informal credit response to environmental improvement (Section 4.6.2). (d) Economic position: Households in the lowest two baseline-income quintiles, whose per capita income falls below the 2017 rural poverty benchmark, show an informal credit response 4.3 times larger than top-quintile households (Section 4.6.1). (e) Infrastructure-deficit profile: Households reporting an EII of one or less at the 2017 baseline—about 38.6 percent of the sample—face the joint distribution of environmental and financial risk this paper targets. The intersection of these five dimensions—rural, central–western, low-income, infrastructure-deprived households with young children, often female-headed—defines the primary policy-relevant target population for whom this study's financial-resilience benefits are quantitatively largest.

Informal credit is also central to household financial fragility. Reliance on high-interest informal borrowing is both a consequence of health shocks and an independent source of financial vulnerability. Zhao [13] documents that formal credit constraints drive widespread reliance on reciprocal informal loans in rural China, which carry substantially higher implicit interest rates and shorter repayment horizons than formal alternatives. Kochar [3] suggests that health shocks are among the primary triggers of informal borrowing in low-income settings, linking health expenditure risk directly to credit market fragility. Anderloni et al. [14] develop an empirical framework showing that debt-servicing burden and unsecured borrowing are key determinants of household financial vulnerability. Li et al. [1] and Liu et al. [15] further show that improvements in digital financial services reduce household vulnerability partly through credit market channels. This highlights a demand-side dimension of informal credit dependence that environmental infrastructure may also address, by reducing the emergency borrowing needs that health shocks generate.

The next issue is how these relationships should be interpreted structurally. The preceding literature establishes pairwise relationships among all four core variables [1–8,13–15], but leaves a critical structural question unanswered. Do health shocks and informal credit function as mediating variables, forming the sequential channel through which environmental improvements reduce economic vulnerability? Or do they function as moderating variables, conditioning the magnitude of financial effects according to households' baseline health exposure and credit market integration? This distinction is not merely methodological. Mediation implies that financial returns to environmental infrastructure depend on the realized health improvement pathway, since infrastructure must reduce actual illness to generate financial benefits. Moderation implies that financial returns are amplified in high-risk, high-credit-stress households regardless of the specific health pathway activated, so even small environmental improvements generate disproportionately large responses among the most constrained households. Both mechanisms are theoretically plausible and empirically testable, and both carry distinct implications for program targeting and evaluation design. No existing study has resolved this question through integrated empirical analysis of environmental, health, and financial data. The result is a fragmented evidence base that systematically understates the social cost of environmental deprivation and the financial return on infrastructure investment [1,3,6,7].

This study addresses this gap by examining the pathway from environmental infrastructure to rural household financial resilience, focusing on health shocks, informal credit, and income-generating assets. We do not claim to directly observe sustainable-consumption behavior. Instead, we examine whether basic environmental improvements create the financial conditions that make such a transition more feasible—lower defensive medical expenditure, less emergency borrowing, and greater capacity for productive asset allocation. From an ESG perspective, this mechanism offers a measurable social-value

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channel through which environmental infrastructure may strengthen household resilience beyond simple access or disease indicators.

China offers several distinctive methodological advantages for identifying the health–credit–income channel. First, the China Household Finance Survey (CHFS) provides nationally representative, multi-wave longitudinal microdata on more than fifty thousand rural household–year observations. It links information on environmental access, child health and hospitalization, formal and informal debt, and household asset holdings—an integration rarely available in a single LMIC survey. Second, the staggered nationwide rollout of clean drinking water, clean cooking energy, and sanitation programs across provinces, prefectures, and villages generates plausibly exogenous variation in the timing of environmental improvements. This supports a staggered difference-in-differences identification strategy and event–study tests for parallel trends. Third, rural China combines large-scale informal credit markets, limited but expanding formal insurance coverage, and substantial baseline heterogeneity in resource endowment, household composition, and regional development. This variation lets us test the threshold and heterogeneity predictions of the mechanism in a setting spanning much of the structural diversity seen across the Global South. These features make China a high-resolution test bed rather than a self-contained case, where estimates for the health–credit–income channel can serve as a benchmark for calibrating results from other LMIC settings, such as Sub-Saharan Africa and South Asia. To clarify how China functions as a methodological laboratory, we adopt the standard distinction between transferability and transportability from the cross-context external-validity literature. Transferability asks whether the numerical magnitudes of the estimated coefficients—for example, the -9.2 percentage-point effect on informal credit share or the +5.8 percentage-point effect on income-generating asset share—can be applied directly to a different population without local recalibration. Transportability, by contrast, asks whether the underlying causal model itself—the directed structure linking environmental infrastructure to health shocks, then to informal credit, then to income-generating assets—remains valid in a population that differs from China in insurance coverage, formal credit depth, demographic composition, or program design. We make no claim of transferability: the specific coefficient magnitudes reported here should not be expected to hold unchanged in, say, urban Bangladesh, peri-urban Kenya, or northern Nigeria, where the joint distribution of insurance access, credit infrastructure, and household composition differs substantially from rural China. We do, however, claim transportability conditional on the Three Preconditions Framework formalized below (TPF-1 through TPF-3): wherever these three preconditions hold, the directional structure of the health–credit–income channel should remain operative, though the path coefficients must be recalibrated empirically to local data. The China-based estimates therefore function as a benchmark causal architecture and a quantitative starting point for cross-country comparison, not as a transportable parameter set to be applied off-the-shelf elsewhere.

This study's contribution is therefore specific and bounded. We do not argue that environmental infrastructure automatically produces sustainable consumption, nor do we claim to measure final consumption choices directly. Instead, our novelty lies in identifying and empirically testing a micro-level transmission mechanism linking environmental infrastructure to household financial resilience. In this mechanism, WASH and clean-energy improvements first reduce preventable health shocks, then lower emergency informal borrowing, and finally release liquidity for income-generating assets. This contribution extends sustainable production and consumption research from firm-level green production to the household-level financial preconditions that let rural families shift from defensive survival spending toward more productive, sustainable resource allocation.

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To avoid overgeneralization, we treat the "three preconditions" as contextual scope conditions rather than universal requirements for every economy. The health–credit–income channel is most likely to operate where three conditions hold. First, preventable environmental-health risks remain material because WASH or clean-energy infrastructure is incomplete. Second, households face substantial out-of-pocket medical costs because health insurance and social assistance provide incomplete protection. Third, urgent liquidity is commonly obtained through costly informal credit rather than timely formal finance. Where any one condition is absent—for example, where universal health coverage and emergency liquidity support are comprehensive—the financial channel may be weaker even if environmental infrastructure improves health. For analytical clarity in our later discussion of external validity, we formalize these contextual conditions as the Three Preconditions Framework (TPF) and label each precondition explicitly. TPF-1, Environmental-Health Materiality, holds when a non-trivial share of household disease burden remains attributable to remediable WASH or solid-fuel exposure, such that infrastructure upgrading measurably reduces preventable illness. TPF-2, Incomplete Medical-Cost Protection, holds when public or social health insurance covers less than the full marginal cost of catastrophic and chronic episodes, leaving substantial residual out-of-pocket exposure. TPF-3, Informal Credit Dominance for Emergency Liquidity, holds when the marginal source of urgent household liquidity is informal borrowing—from relatives, village moneylenders, or rotating credit associations—rather than rapidly disbursing formal credit or emergency cash transfers. The TPF defines the empirical settings in which the health–credit–income channel should remain quantitatively active. Where any one of TPF-1, TPF-2, or TPF-3 is absent, the channel's magnitude should attenuate, even when its directional logic still holds. We use this framework throughout the paper to delimit how far the China-based estimates generalize to other LMIC contexts.

These scope conditions also clarify the practical financial-protection implications for other LMIC regions undertaking WASH or clean-energy upgrades [9–12,16]. In Sub-Saharan Africa, environmental programs may be paired with community-based health insurance, subsidized primary care, and emergency cash or voucher support, so reduced disease risk is not offset by residual catastrophic medical spending. In South Asia, where informal moneylender credit often finances health emergencies, WASH investments can be complemented by publicly financed health insurance, targeted medical cash transfers, and regulated low-cost emergency loans through microfinance institutions or self-help groups. In Southeast Asia, where formal insurance and digital finance coverage vary across rural areas, WASH and clean-energy programs can be linked to universal-health-coverage benefit packages, mobile emergency savings or credit products, and health-contingent cash transfers. These examples illustrate policy implications rather than additional empirical tests; they show how China-based evidence can inform, but not be mechanically generalized to, other Global South settings.

2. Theoretical Framework

This section develops the theoretical basis for our empirical analysis. We first explain why child hospitalization rate is a theoretically appropriate and empirically justified measure of the health dimension of environmental infrastructure impact (Section 2.1). We then articulate the health–credit–income channel through which environmental conditions affect household economic vulnerability (Section 2.2). We explain what income-generating assets are and why their share in total assets constitutes a meaningful financial outcome (Section 2.3). Finally, we derive testable research hypotheses from the integrated framework (Section 2.4).

2.1. Environmental Infrastructure and Child Hospitalization: Theoretical Justification of the Variable

A central question for the internal validity of our analysis is as follows: Why is child hospitalization rate the appropriate variable for capturing the health dimension of environmental infrastructure impact, rather than adult morbidity, all-cause mortality, or self-reported illness?

The answer is grounded in the specific disease pathways activated by the three environmental infrastructure dimensions we study. First, unsafe drinking water is the primary vehicle for fecal–oral disease transmission, including diarrheal diseases (rotavirus, norovirus, Cryptosporidium), typhoid fever, and Hepatitis A. Children under age five are disproportionately affected by these pathogens due to immature immune systems, greater hand-to-mouth contact, and higher per-kilogram water consumption relative to body weight [8]. In settings with inadequate water safety, diarrheal disease is consistently the leading cause of child hospitalization and a leading driver of pediatric out-of-pocket medical expenditure [7,8].

Second, solid-fuel combustion from traditional cooking stoves generates indoor air pollution levels—particularly fine particulate matter (PM2.5) and carbon monoxide—that are associated with acute lower respiratory infection (pneumonia), the single largest infectious cause of child hospitalization and child mortality globally [6]. Rural children spending substantial time in cooking areas are chronically exposed to pollution concentrations far exceeding WHO safety thresholds. Transition to clean cooking energy (natural gas, electricity, liquefied petroleum gas) substantially reduces indoor PM2.5 concentrations and is associated with significant declines in child pneumonia incidence [6,7].

Third, inadequate sanitation sustains open-defecation practices that contaminate soil and water with helminth eggs, protozoa, and bacteria. Helminthic infections (ascariasis, trichuriasis) contribute to childhood malnutrition and immune suppression, increasing susceptibility to secondary infections, requiring hospitalization [7]. Improved sanitation—through hygienic toilet facilities replacing open defecation—is associated with reduced fecal–oral pathogen burden and lower child hospitalization risk [8].

Critically, children are the population subgroup most biologically sensitive to all three environmental pathways simultaneously: waterborne disease, indoor air pollution-related illness, and sanitation-related infection all disproportionately affect the pediatric age group. Child hospitalization therefore serves as a sensitive and theoretically appropriate aggregate indicator of household environmental health risk: it captures the joint disease burden across all three environmental dimensions, reflects the age group most acutely harmed by environmental deficiencies, and directly generates the out-of-pocket medical expenditure that initiates the household financial distress we study. This justifies using child hospitalization rate—alongside overall out-of-pocket medical expenditure—as our primary health-outcome variable.

At the same time, hospitalization is an imperfect proxy for morbidity because it may also reflect healthcare access, insurance coverage, or care-seeking behavior. We therefore interpret child hospitalization jointly with out-of-pocket medical expenditure and control for relevant household and community characteristics where available. This treatment makes hospitalization a theoretically grounded indicator of environmentally induced health shocks, rather than a complete clinical measure of disease incidence.

2.2. The Health–Credit–Income Channel: Environmental Infrastructure and Household Economic Vulnerability

We propose that environmental infrastructure is associated with household economic vulnerability through a sequential three-stage mechanism, which we call the health–credit–income channel. The channel is grounded in precautionary saving theory [17,18] and in evidence on health shocks, informal finance, and household asset allocation in developing economies.

Stage 1—Health-shock reduction (environmental-to-health): Environmental infrastructure—through the biological pathways described in Section 2.1—reduces the incidence of child hospitalization and the magnitude of associated out-of-pocket medical expenditure. This constitutes the health stage of the channel: environmental investment produces a reduction in the frequency and severity of the health shocks that initiate household financial distress.

Stage 2—Credit market adjustment (health-to-credit): In the absence of adequate formal insurance, rural households facing health shocks must finance emergency medical expenditure through informal borrowing—from relatives, friends, village moneylenders, or rotating credit associations—typically at interest rates substantially above formal sector alternatives [3,13]. When health-shock frequency and associated medical costs decline, the demand for emergency informal credit declines correspondingly. Households that previously borrowed primarily in response to medical emergencies exit those credit relationships; the reduction in debt-service burden improves monthly cash flow and reduces vulnerability to rollover risk and debt spirals [3,5]. This constitutes the credit stage of the channel: health-shock reduction produces a structural reduction in informal debt dependence.

Stage 3—Income capacity expansion (credit-to-income): Capital freed from informal debt service and emergency medical expenditure becomes available for productive investment. In rural settings, income-generating assets include agricultural equipment, livestock, seed and fertilizer inventories, non-agricultural micro-enterprise capital, and human capital investments in education—all of which generate returns that directly expand household income capacity over subsequent periods [3,19]. As the share of income-generating assets in total household assets rises, the household's income-generating potential improves, reducing long-run economic vulnerability. This constitutes the income stage of the channel: credit market exit enables income capacity accumulation, thereby improving household financial resilience.

Taken together, the three stages constitute a plausible mechanism for vulnerability reduction rather than a claim that each intermediate link is experimentally isolated. Environmental infrastructure may reduce preventable health shocks; lower health-related liquidity pressure may reduce informal borrowing; and lower debt-service pressure may enable households to allocate more assets toward income-generating uses. The empirical analysis therefore tests whether the observed associations are consistent with this sequential pathway. To make the sequential causal chain explicit, the three stages should be read as a temporally ordered process rather than as a set of contemporaneous correlations. Let t denote the wave in which a household first acquires the environmental infrastructure improvement. Stage 1 (environmental-to-health) materializes at t and during the wave that follows: physical access to clean water, clean cooking energy, or improved sanitation reduces the probability of preventable illness episodes, with the first measurable change appearing in child hospitalization and out-of-pocket medical expenditure between t and t + 1. Stage 2 (health-to-credit) follows with a structural lag, materializing predominantly between t and t + 1 as the reduced demand for emergency medical liquidity, which allows households to exit existing informal credit relationships, reduce rollover, and stop initiating new emergency loans. Stage 3 (credit-to-income) accumulates over a longer horizon, predominantly between t + 1 and t + 2, as the liquidity released from Stage 2 is gradually redeployed into agricultural capital, livestock, micro-enterprise inventory, or other income-generating assets that require multi-period investment decisions. Symbolically: EII (t) → Health Shock (t → t + 1) → Informal Credit Share (t → t + 1) → Income-Generating Asset Share (t + 1 → t + 2) → Reduced Economic Vulnerability (t + 2 and beyond). This explicit temporal sequencing has two empirical implications that we test directly: (a) in the event–study specification of Section 4.4, health-related outcomes should respond earliest, credit outcomes next, and asset outcomes last, relative to the timing of infrastructure improvement; and (b) in the serial mediation analysis of Section 4.5.2, the chain indirect effect (M1 $\rightarrow$ M2 $\rightarrow$ Y) should be statistically distinguishable from the parallel single-mediator effects. The sequencing is therefore not merely a theoretical narrative but a testable empirical prediction.

2.3. Income-Generating Asset Share: Definition and Rationale as a Financial Outcome Variable

Income-generating asset share is defined in this study as the ratio of income-generating assets to total household assets. In the CHFS data, income-generating assets comprise: (i) agricultural capital (livestock, machinery, land improvement investments, and seed/fertilizer inventories valued as capital assets); (ii) non-agricultural business assets (micro-enterprise inventory, tools, and equipment); and (iii) equity stakes in rural cooperatives or informal business partnerships. Non-income-generating assets include liquid cash and bank deposits held primarily for precautionary purposes, durable consumption goods, and precious metals or jewelry held as stores of value.

The justification for treating income-generating asset share as a financial outcome rests on three foundations. First, the composition of household assets is closely linked to future income capacity in rural China: agricultural and micro-enterprise capital generate income streams, while precautionary liquid assets mainly protect against shocks [3,19]. Second, the ratio captures the opportunity cost of health-related precautionary saving. When environmental infrastructure lowers health risk, households may reduce defensive buffers and allocate more resources to productive assets. Third, this balance-sheet measure is less transient than current income or consumption and therefore provides a forward-looking indicator of economic vulnerability.

2.4. Research Hypotheses

The hypotheses follow the logic of the proposed pathway. Environmental infrastructure first changes the health-risk environment, health-risk reduction then changes emergency liquidity demand, and reduced liquidity pressure may enable a shift from defensive financial behavior toward income-generating asset accumulation.

Reasoning for H1. Economic vulnerability refers to the risk that households will experience income shortfalls, debt stress, or asset depletion when exposed to shocks. Safe water, clean cooking energy, and improved sanitation can reduce both realized medical costs and expected exposure to preventable illness. Under precautionary saving theory, lower expected health risk should reduce the need for defensive buffers and emergency borrowing. Environmental infrastructure should therefore be associated with lower household economic vulnerability. Because economic vulnerability is a latent, multidimensional construct, we do not estimate it as a single composite index; instead, H1 is assessed jointly through its two complementary financial manifestations—lower informal credit dependence (ex-post distress) and a higher income-generating asset share (ex-ante income-generating capacity)—as operationalized in Section 3.2.3. H2–H5 then decompose the channel through which this aggregate association arises.

Hypothesis 1 (Main Effect). *Improvements in environmental infrastructure significantly reduce rural household economic vulnerability.*

Reasoning for H2. The three infrastructure dimensions correspond to well-established environmental-health pathways. Safe drinking water reduces fecal–oral disease transmission, clean cooking energy reduces indoor air pollution, and improved sanitation lowers pathogen exposure. Children are particularly sensitive to these risks, and child hospitalization generates direct out-of-pocket costs for households. A reduction in child hospitalization and medical expenditure is therefore the first observable link in the proposed channel.

Hypothesis 2 (Health Effect). *Improvements in safe drinking water, clean cooking energy, and sanitation significantly reduce health shocks, evidenced by lower child hospitalization incidence and out-of-pocket medical expenditures.*

Reasoning for H3. In rural credit markets, medical emergencies often require liquidity faster than formal financial institutions can provide. Households may therefore rely on relatives, acquaintances, rotating credit associations, or informal lenders to finance urgent medical expenditure [3,13]. If environmental infrastructure reduces health-related emergency costs, the demand for informal borrowing should decline.

This credit market adjustment is the middle link of the health–credit–income channel: lower health expenditure reduces emergency borrowing needs, and lower dependence on informal credit releases resources previously absorbed by interest payments, repayment pressure, and rollover risk.

Hypothesis 3 (Credit Effect). *Reductions in health-related emergency expenditures significantly lower household dependence on informal credit.*

Reasoning for H4. Informal credit dependence can crowd out productive investment through interest burdens, repayment pressure, and the need to preserve liquidity for future debt obligations. When emergency borrowing declines, households may redirect resources toward agricultural equipment, livestock, micro-enterprise capital, or other income-generating assets. Thus, reduced informal credit dependence should be associated with an increase in income-generating asset share.

Hypothesis 4 (Income Effect). *The decrease in informal credit dependence significantly enhances household income capacity, measured by a higher share of income-generating assets in total household assets.*

Reasoning for H5. Economic vulnerability is forward-looking: it depends on whether households can maintain income and avoid distress under future shocks. A higher share of income-generating assets expands future income capacity and reduces reliance on defensive liquidity management. If environmental infrastructure lowers vulnerability partly by enabling productive asset accumulation, income-generating asset share should mediate the terminal stage of the channel.

Hypothesis 5 (Terminal Mediation Effect). *Increases in income-generating asset share mediate the structural reduction in rural household economic vulnerability.*

Reasoning for H6. The benefits of environmental infrastructure are unlikely to be uniform across households. Households with lower resource endowments face higher baseline health-risk exposure, tighter liquidity constraints, and greater reliance on informal credit; therefore, the same absolute reduction in medical expenditure may produce a larger proportional financial response. The marginal effect of infrastructure may also change once a critical level of resource endowment or infrastructure coverage is reached.

Hypothesis 6 (Resource-Endowment Threshold Effect). *The vulnerability-reducing association of environmental infrastructure exhibits a non-linear threshold pattern, whereby the marginal effect changes once household resource endowment crosses a critical level.*

To provide a consolidated overview, Table 1 summarizes the roles of Hypotheses 1–6 within the health–credit–income channel.

Table 1. Streamlined map of hypothesis roles in the health–credit–income channel.

Hypothesis	Mechanism Position	Analytical Focus
H1	Overall relationship	EII → vulnerability
H2	Health stage	EII → health shocks
H3	Credit stage	Health costs → informal credit
H4	Income stage	Informal credit → productive assets
H5	Terminal stage	Productive assets → vulnerability
H6	Threshold condition	Resource-endowment threshold

Note: The table maps each hypothesis to its analytical role; full hypothesis statements are provided in Section 2.4.

2.5. Analytical Framework and Positioning Within the Literature

Figure 1 summarizes the analytical framework implied by these hypotheses. The framework clarifies the study's contribution: it integrates environmental-health, household-finance, and rural-vulnerability perspectives into a single testable pathway; it explains why child hospitalization and income-generating asset share are theoretically appropriate cross-domain variables; and it generates a threshold-based prediction that links program targeting to mechanism strength.

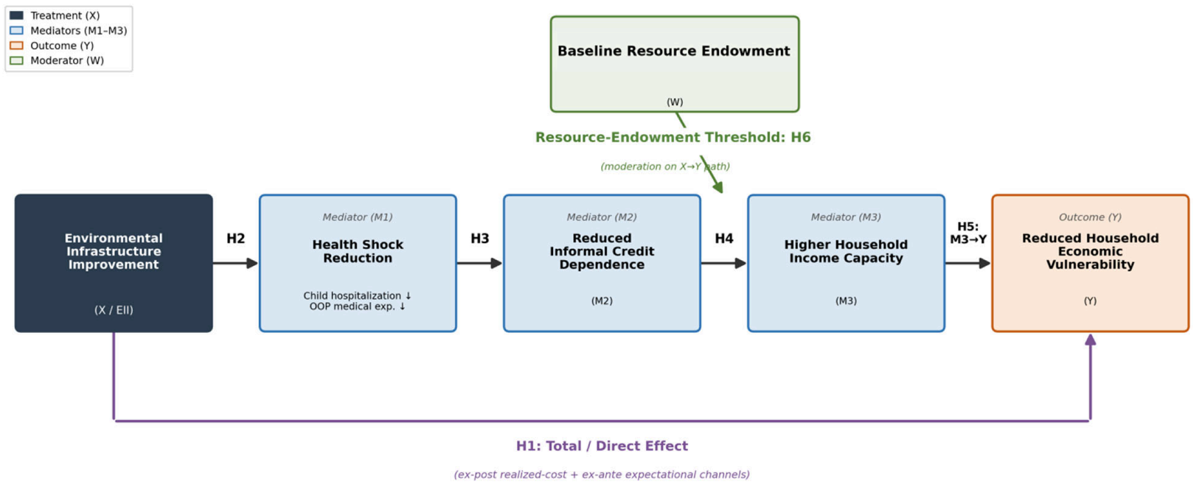

Figure 1. Analytical framework: the health–credit–income channel and threshold condition.

3. Materials and Methods

3.1. Data Sources and Sample Construction

This study utilizes longitudinal data from the China Household Finance Survey (CHFS) [20] waves conducted in 2017, 2019, 2021, and 2023. The 2023 wave data was accessed through a restricted "green-channel" internal application to the Survey and Research Center for China Household Finance at Southwestern University of Finance and Economics. This updated panel provides a unique window into the post-pandemic financial resilience of rural households.

To ensure data quality and the internal validity of our analysis, we followed a rigorous sample selection procedure. First, we restricted the sample to households with rural registered residence (hukou) status. Second, to ensure the viability and consistency of our pediatric health-shock channel, we restricted the analytical sample exclusively to households with children under the age of 18. Consequently, childless households were entirely excluded from the primary analytical sample, as the mediating variable—child hospitalization—is conceptually and empirically non-applicable to them. Finally, we excluded observations with incomplete or missing information on key variables. This restriction yields a final unbalanced panel of 54,320 household–year observations drawn from 18,245 unique rural households. Because the exclusion of childless households is consequential for the interpretation and external validity of our estimates, we elaborate the justification here in more detail. Of the 84,760 rural household–year observations remaining after the hukou restriction, 26,480 observations (31.2 percent) corresponded to households without resident children under 18 and were removed for three substantive reasons. First, the central mediator in our pathway—child hospitalization incidence—is conceptually undefined for households without children: assigning a zero value would not represent "low risk" but rather structural inapplicability of the variable, and would generate uninterpretable mass at zero that would bias both the first-stage and the serial mediation estimates. Second, childless rural households in the CHFS sample differ systematically from households with children on dimensions that are themselves causally related to our outcomes: mean household-head age is 64.3 years versus 47.8 years among households with children; mean household size is 2.1 versus 3.8 members; informal-borrowing rates are roughly half those of households with children; and coverage by old-age health-insurance instruments (URRBMI and basic medical insurance for retirees) is substantially higher. Including these households would therefore not merely add noise but would conflate the pediatric environmental-health channel we seek to identify with the distinct geriatric-health and pension-related financial dynamics of empty-nest and elderly only households. Third, the disease pathways described in Section 2.1—diarrheal disease, ALRI from indoor PM2.5, and helminthic infection—operate disproportionately through pediatric biological sensitivity; childless households are therefore the wrong population in which to test the proposed health–credit–income channel and would, if included, attenuate estimated effects toward zero through a mechanically non-responsive subsample. To make the sample denominators fully transparent, the analytical samples used in this paper correspond to the following explicit percentages of the parent dataset: the raw four-wave CHFS pool contains 134,580 household–year observations; the rural sub-panel after hukou restriction contains 84,760 observations (63.0 percent of raw); households with at least one resident child under 18 contribute 58,280 observations (43.3 percent of raw, 68.8 percent of rural); the primary analytical sample after data cleaning contains 54,320 observations (40.4 percent of raw, 64.1 percent of rural, 93.2 percent of the rural-with-children subset); and the conditional positive-debt subsample used for the informal credit-share regressions contains 22,450 observations (16.7 percent of raw, 41.3 percent of the primary analytical sample). These five denominators correspond, respectively, to Steps 0–4 of Table 2 and are quoted explicitly here so that readers can locate every estimate reported in Section 4 within the parent dataset without ambiguity.

Table 2. Sample selection procedure and analytical denominators.

Step	Selection/Exclusion Criterion	Observations Excluded (Household–Years)	Remaining Sample Size (Household–Years)	Unique Households Remaining	Resulting Denominator and Analytical Purpose
0	Initial Raw CHFS Dataset (Combined waves: 2017, 2019, 2021, and 2023)	—	134,580	41,200	Starting pool of longitudinal observations.
1	Hukou Restriction (Keep only households with rural registered residence status)	49,820	84,760	27,450	Excludes urban households.

Table 2. *Cont.*

Step	Selection/Exclusion Criterion	Observations Excluded (Household–Years)	Remaining Sample Size (Household–Years)	Unique Households Remaining	Resulting Denominator and Analytical Purpose
2	Demographic Restriction (Keep only households with children under the age of 18)	26,480	58,280	19,320	Excludes childless households.
3	Data Cleaning and Missing Variables (Drop observations with missing key variables)	3960	54,320	18,245	Primary analytical sample (N = 54,320) for child health and asset regressions.
4	Positive-Debt Conditioning (Keep only households with total outstanding debt > 0)	31,870	22,450	7842	Conditional debt subsample (N = 22,450) for informal credit share regressions.

To provide full transparency regarding our sample construction and the corresponding denominators used in different regression stages, we document the step-by-step sample filtering and attrition process in Table 2.

3.2. Key Variables Definition

3.2.1. Variable Selection and Theoretical Alignment

The selection of key variables in this study directly reflects the theoretical framework developed in Section 2. The treatment variable—the Environmental Infrastructure Index (EII)—captures household access to safe drinking water, clean cooking energy, and improved sanitation, the three environmental dimensions whose disease pathways are theoretically linked to child hospitalization (Section 2.1). The primary health-outcome variables—child hospitalization incidence and out-of-pocket medical expenditure—are chosen because they represent the specific health shocks most directly triggered by environmental deficiencies in the rural Chinese context: waterborne disease, indoor air pollution-related illness, and sanitation-related infection (Section 2.1). The primary financial outcome variables—informal credit share and household income capacity—operationalize Stage 2 (credit market exit) and Stage 3 (income capacity accumulation) of the health–credit–income channel, respectively (Sections 2.2 and 2.3). This alignment between theoretical mechanism and variable selection is intentional: each variable tests a specific stage of the health–credit–income pathway, enabling the decomposition of the integrated channel into empirically verifiable components that correspond to the six research hypotheses in Section 2.4.

3.2.2. Treatment Variable: Environmental Infrastructure Improvements

Environmental infrastructure improvements are measured through three complementary indicators, each corresponding to a major dimension of household environmental quality. First, Safe Drinking Water Access marks the transition from unsafe water sources to piped safe water or treated water sources. Second, Clean Cooking Energy captures the transition from solid fuels to clean-energy sources such as electricity, natural gas, or liquefied petroleum gas [6]. Third, Sanitation Facilities marks access to hygienic toilet facilities replacing traditional defecation [7]. We construct a composite Environmental Infrastructure Index (EII) as the sum of these three binary indicators, ranging from zero to three, representing the breadth of environmental improvements at the household level.

Improvement events are identified as transitions across the survey period from having a specific deficiency to achieving that dimension of environmental infrastructure. The main treatment coding treats infrastructure acquisition as an absorbing improvement, which is most appropriate for durable water and sanitation facilities. For clean cooking energy, where fuel stacking or partial reversals may occur, the estimates should be interpreted as access-based effects rather than evidence of exclusive clean-fuel use.

Beyond their direct disease-prevention pathways, the three components of the Environmental Infrastructure Index also map onto recognized ESG (Environmental, Social, and Governance) value categories that frame their broader sustainability contribution and clarify how the present mechanism connects to standard impact-investment reporting frameworks. On the environmental side, safe drinking water and improved sanitation correspond to the water-security pillar, simultaneously reducing household-level exposure to contaminated water sources and lowering aggregate watershed-level pollution from open-defecation discharge and gray-water runoff; transition from solid biomass to clean cooking energy delivers emissions-reduction co-benefits, lowering household-level PM2.5 emissions by roughly an order of magnitude and, at scale, contributing materially to provincial-level greenhouse-gas and air-quality mitigation targets. On the social side, piped indoor water and household-level flush sanitation generate measurable women's time-savings, releasing the daily hours that rural women in baseline-deficient households otherwise spend on water-fetching and on accompanying children to outdoor toilet facilities; this released time can be redirected toward income-generating, caregiving, educational, or rest activities, with documented downstream effects on female labor-force participation and intrahousehold bargaining position. The same infrastructure transition also delivers a dignity dimension by eliminating open defecation and the gender-specific safety risks associated with night-time outdoor toilet use, in line with the human-development conception of basic-needs fulfillment. These ESG dimensions are not orthogonal to the health–credit–income channel; rather, they constitute the structural social-value channels through which environmental infrastructure produces the welfare changes whose financial manifestations this study quantifies, and they justify interpreting the present empirical results as micro-level evidence for an ESG social-value mechanism rather than as a narrowly defined health-economic finding.

3.2.3. Outcome Variables: Financial Behavior Indicators

Household economic vulnerability is operationalized in this study through two complementary financial indicators. This dual-indicator approach reflects the theoretical distinction between ex-post vulnerability—realized financial distress from emergency debt obligations, captured by informal credit share—and ex-ante vulnerability—reduced income-generating capacity from precautionary capital immobilization, captured by household income capacity. Yang and Mukhopadhaya [2] establish that multiple deprivation dimensions, including material living standards and financial well-being, are independently predictive of poverty transitions among Chinese households, justifying the joint use of credit and asset indicators as vulnerability measures. Li et al. [1] and Liu et al. [15] similarly examine household financial outcomes through behavioral indicators including credit access and consumption smoothing, consistent with this study's measurement approach.

Following the theoretical framework, we measure household financial responses across three key dimensions. Healthcare Expenditure Outcomes capture out-of-pocket medical costs and the frequency of child hospitalization, directly reflecting the health-finance transmission mechanism. Informal Credit Dependence measures reliance on informal high-interest borrowing, expressed as the share of informal debt in total household debt. This variable is meaningful only for households that report positive total debt outstanding in a given year; therefore, the main debt-composition analysis is conducted on a conditional subsample of 22,450 household–year observations (41.3% of the primary analytical sample). This design should be interpreted as an analysis of the composition of liabilities among borrowing households, not as a model of whether households borrow at all. To address possible selection into debt holding, we report a separate first-stage robustness test showing that environmental infrastructure improvements do not differentially affect the probability of holding any debt. Accordingly, the informal credit result is interpreted as conditional on positive debt, while the debt-holding margin is evaluated separately. This operationalization follows the approach of Kochar [3] and Zhao [13] for measuring informal credit reliance in developing-country household panels. The ratio specification—informal debt as a share of total outstanding debt—is preferred over debt levels because it captures the structural composition of household liabilities rather than total indebtedness, and is less sensitive to income-level confounders [3,13]. A higher informal credit share indicates greater financial fragility, reflecting both the higher cost of informal debt service and the greater rollover risk associated with informal credit relationships [13]. Liu et al. [15] confirm that this ratio measure is a significant predictor of household financial vulnerability in the Chinese context, supporting its validity as an outcome variable. Asset Portfolio Composition captures the structural composition of household balance sheets, measured as the share of income-generating assets in total household assets. The operational definition of income-generating assets in the CHFS data follows Section 2.3. This income-generating asset share variable is chosen as a financial outcome—rather than income or consumption—for three reasons articulated in Section 2.3: it is the primary determinant of future income capacity in rural China; it directly captures the opportunity cost of precautionary savings that health-risk reduction can release; and it reflects durable, structural balance sheet restructuring rather than transient income variation. A higher household income capacity indicates that the household has shifted capital from defensive emergency buffers toward income-generating investment, representing a structural reduction in economic vulnerability [3,19]. Throughout the paper, the terms "household income capacity" and "income-generating asset share" refer to the same balance-sheet measure: we use "income capacity" as shorthand for the income-generating potential embodied in the household asset portfolio, and we interpret it as a forward-looking proxy for future income capacity rather than as a direct measure of realized income.

These outcomes directly correspond to the health–credit–income channel hypothesis: reduced health risks lower precautionary savings demand and emergency borrowing, enabling reallocation toward productive investment.

To eliminate any ambiguity, we explicitly define and confirm the two distinct denominators used as the basis for our empirical estimations. First, the **primary analytical sample denominator** (N = 54,320) is applied to the estimations of child health outcomes and asset portfolio allocations. It consists of all rural household–year observations with at least one child under 18 and complete information on all key variables, as formalized in Equation (1):

$$N = \sum_{i=1}^{I} \sum_{t=1}^{T} \mathbb{I}(Rural\ Hukou_{it} = 1\ \&\ Children\ Under\ 18_{it} \geq 1\ \&\ No\ Missing\ Data_{it}) = 54,320 \quad (1)$$

Second, the **conditional debt subsample denominator** (N_{debt} = 22,450) is applied exclusively to the analysis of the informal credit share. Because the ratio of informal debt to total debt is mathematically undefined for households with zero liabilities, the denominator is restricted to active borrowing households within our primary sample, as formalized in Equation (2):

$$N_{debt} = \sum_{i=1}^{I} \sum_{t=1}^{T} \mathbb{I}(Household_{it} \in Primary\ Sample\ N\ \&\ Total\ Outstanding\ Debt_{it} > 0) = 22,450 \quad (2)$$

3.2.4. Confounding Variables and Controls

We include a comprehensive set of household- and community-level controls to account for observable characteristics correlated with both environmental improvements and financial outcomes, including demographic structure, economic status, and baseline health conditions. Specifically, to control for supply- and demand-side factors governing healthcare utilization, we explicitly adjusted for household healthcare access and insurance coverage. Healthcare access is operationalized using community-level indicators, including the presence of local health clinics and the physical distance to the nearest medical facilities. Insurance coverage is controlled for at the household level, measuring whether family members are enrolled in the New Rural Cooperative Medical Scheme (NRCMS) or other basic medical insurance programs. Controlling for these variables ensures that the estimated effects of environmental infrastructure on child hospitalization are not confounded by regional variations in healthcare infrastructure or individual insurance-driven differences in care-seeking behavior.

3.3. Identification Strategy: Staggered Difference-in-Differences

Our primary identification strategy employs a staggered difference-in-differences design that exploits temporal variation in environmental infrastructure improvements across households and regions. The identifying assumption is that, in the absence of environmental improvements, treated and comparison households would have followed parallel trends in the outcomes of interest. We leverage variation in the timing and extent of improvements during the 2017–2023 study period (CHFS waves 2017, 2019, 2021, and 2023), while controlling for household fixed effects, year fixed effects, and time-varying household and community characteristics.

$$Y_{it} = \alpha + \beta \cdot (EII_{it}) + \gamma_i + \delta_t + X'_{it} \cdot \theta + \varepsilon_{it} \tag{3}$$

In Equation (3), Y_{it} denotes the outcome variable for household i in year t; EII_{it} denotes the Environmental Infrastructure Index; γ_i and δ_t represent household and year fixed effects; X'_{it} is a vector of time-varying controls; and epsilon_it is the error term. The coefficient beta captures the average association between a one-unit increase in environmental infrastructure and the outcome under the maintained DID assumptions.

To test whether the effect of environmental infrastructure on household economic vulnerability exhibits non-linear threshold characteristics as predicted by H6, we employ the panel threshold regression model proposed by Hansen [21]. This approach is particularly suitable for identifying whether a critical level of household resource endowment creates a structural break in the marginal returns to environmental infrastructure improvement. The threshold variable in this study is household resource endowment (RE), operationalized as a composite index of baseline income, asset holdings, and social insurance coverage. The treatment variable remains the Environmental Infrastructure Index (EII).

We construct the following single-threshold model:

$$Y_{it} = \beta_1 EII_{it} \cdot I(RE_{it} \le \gamma) + \beta_2 EII_{it} \cdot I(RE_{it} > \gamma) + X_{it}\acute{\theta} + \gamma_i + \delta_t + \varepsilon_{it} \tag{4}$$

In Equation (4), $\mathrm{Y_{it}}$ represents the household financial outcome (e.g., informal credit share or household income capacity); $\mathrm{EII_{it}}$ is the Environmental Infrastructure Index; and $\mathrm{X_{it}}$ is a vector of control variables. $\mathrm{RE_{it}}$ denotes the threshold variable (composite household resource endowment index), while γ represents the unknown threshold value to be estimated. $\mathrm{I}(\cdot)$ is the indicator function, which takes the value of one if the condition in the parentheses holds, and zero otherwise. γ_i and δ_t control for household and year fixed effects, respectively.

Under this framework, the marginal vulnerability-reducing effect of environmental infrastructure shifts from β_1 to β_2 once the resource endowment RE_{it} crosses the threshold γ. The optimal threshold value γ is determined by minimizing the residual sum of squares (SSR) of the model, and the statistical significance of the threshold effect is subsequently verified using the Bootstrap method to ensure the robustness of the structural break.

For mechanism analysis, we estimate a mediation system that links environmental infrastructure to financial outcomes through the health-shock-reduction pathway. Following the causal mediation framework of Imai et al. [22], we specify a three-equation system and interpret the estimates as evidence consistent with mediation rather than definitive experimental proof of each intermediate mechanism.

$$Med_{it} = \alpha_0 + \alpha_1 EII_{it} + X_{it}\acute{\theta} + \gamma_i + \delta_t + \mu_t \tag{5}$$

$$Y_{it} = \rho_0 + \rho_1 EII_{it} + \rho_2 Med_{it} + X_{it}\acute{\theta} + \gamma_i + \delta_t + v_{it} \tag{6}$$

where Med_{it} denotes the mediator variable (child hospitalization incidence or out-of-pocket medical expenditure). α_1 captures the effect of environmental infrastructure on the health mediator, while ρ_2 captures the effect of the mediator on the financial outcome controlling for the infrastructure index. The indirect effect ($\alpha_1 \times \rho_2$) captures the share of the total effect of environmental infrastructure on financial outcomes that are transmitted through the health-shock-reduction pathway. Statistical significance of the indirect effect is interpreted as evidence consistent with health-shock reduction operating as an active mediating mechanism rather than merely as a correlate of environmental improvement.

We construct matched comparison groups through propensity score matching within each treatment cohort rather than relying on a simple treated/untreated dichotomy. This approach helps account for observable differences across cohorts and potential treatment-effect heterogeneity. Because conventional two-way fixed-effects estimators can be biased when treatment effects are heterogeneous across adoption cohorts [23–25], we further report dynamic effects, placebo timing tests, alternative outcome definitions, balanced-panel restrictions, IV-Probit estimates, and the Sun and Abraham [26] heterogeneity-robust estimator to assess robustness.

3.4. Mechanism Analysis: Testing the Health–Credit–Income Channel

Beyond estimating average treatment effects, we conduct a detailed mechanism analysis to test whether the health–credit–income channel pathway explains observed financial behavioral changes. Following causal mediation approaches, we decompose total treatment effects into direct and indirect effects, with indirect effects mediated by reduced health risks and medical costs [22]. The mediation framework employs a three-equation system examining the pathways: Environmental Infrastructure Improvements to Reduced Medical Costs to Changes in Financial Behavior. The "health–credit–income" channel identified in this study aligns with the global WASH-Resilience framework. In many developing economies, such as those in Sub-Saharan Africa and South Asia, informal moneylenders often act as the "lender of last resort" for health emergencies. Our findings demonstrate that environmental infrastructure does more than just prevent disease; it acts as a liquidity-release mechanism. By reducing the "background risk" of preventable illness, these investments allow households to reallocate capital from defensive liquid buffers (precautionary savings) to productive capital accumulation, a transition that is fundamental to escaping the poverty trap globally.

The mediation framework follows the approach of Imai et al. [22], which requires the sequential ignorability assumption—specifically, that (i) there are no unmeasured confounders of the treatment–outcome relationship, (ii) there are no unmeasured confounders of the mediator–outcome relationship, and (iii) there are no treatment-induced confounders of the mediator–outcome relationship. Our staggered DID design with household and year fixed effects addresses condition (i) through within-household identification. Conditions (ii) and (iii) remain stronger assumptions, because changes in medical expenditure could in principle be affected by contemporaneous healthcare access, insurance, or local development shocks. We therefore interpret the mediation results as evidence consistent with the proposed health–credit–income pathway rather than as definitive experimental identification of each intermediate link. This interpretation is supported by falsification tests, pre-trend analysis, and robustness checks. Indirect effects are estimated using the product-of-coefficients method, with 95% confidence intervals constructed via bootstrapping with 1000 replications at the household cluster level. For informal credit share, the bootstrapped 95% CI for the indirect effect is [−0.0681, −0.0411]; for household income capacity, the CI is [0.0094, 0.0330]. The proportion of total effect mediated is computed to identify what share of environmental infrastructure's impact operates through the realized medical-cost pathway. The remaining component is interpreted as suggestive of an expectational channel, supported by the dimension-specific convergence pattern reported in Section 4.3, where all three infrastructure types produce statistically indistinguishable effects on income capacity allocation (3.8–6.2 pp) despite generating an approximately 5.8-fold gradient in medical-cost savings.

3.5. Threshold Effect Analysis

We conduct heterogeneity and threshold analyses along three dimensions. First, we stratify households by baseline resource endowment to test whether effects are stronger among households facing tighter liquidity constraints. Second, we examine household composition, including the presence of children and elderly members, because households with vulnerable members may benefit more from reduced medical shocks. Third, we examine geographic heterogeneity across rural typologies and regions with different levels of environmental deficiency and financial inclusion.

All heterogeneity analyses use interaction-term specifications or threshold models, with appropriate attention to multiple-hypothesis interpretation. The threshold model focuses on whether the marginal association between EII and household financial outcomes changes at a data-estimated resource-endowment cutoff.

3.6. Validity Checks and Sensitivity Analyses

To assess the credibility of the identification strategy, we conduct several validity checks. The parallel trend assumption is examined using event–study specifications with leads and lags of treatment timing. We also test whether households scheduled to receive later infrastructure improvements exhibit pre-treatment shifts in financial behavior.

In addition, we conduct sensitivity analyses using alternative outcome definitions, treatment specifications, sample restrictions, placebo treatment timing, balanced-panel samples, and heterogeneity-robust DID estimation. Detailed robustness results are reported below.

3.7. Ethical Considerations

This study uses data from the China Household Finance Survey (CHFS). The 2017, 2019, and 2021 waves are publicly available; the 2023 wave was accessed via a restricted "green channel" under institutional agreement. The CHFS is a secondary dataset administered by the Survey and Research Center for China Household Finance, Southwestern University of Finance and Economics (SWUFE), and available to registered academic users upon application (https://chfs.swufe.edu.cn). All household information is anonymized prior to distribution; no personally identifiable information was accessed or used. The research involves no direct human subject interaction or collection of primary data; therefore, formal ethics board approval was not required under applicable guidelines. All analyses comply with relevant data protection regulations.

4. Empirical Results

4.1. Descriptive Statistics

By incorporating the 2023 waves accessed through the internal green channel, this analysis captures the rural financial landscape in the immediate post-pandemic recovery period. This update is crucial, as it moves the evidence base beyond the "stale" 2020–2022 era and provides a contemporary benchmark for how environmental interventions support financial stability amidst global economic shifts. Table 3 presents summary statistics for the full analytical sample of 54,320 household–year observations. The descriptive statistics reveal substantial variation in environmental infrastructure across rural households, with important implications for identification. At baseline (the 2017 wave), only 52.3% of households had access to safe drinking water, 43.7% had access to clean cooking energy, and 38.5% had access to improved sanitation facilities. On average, households had access to approximately 1.34 out of the three environmental dimensions, indicating that most rural households faced multiple environmental deficiencies at the beginning of the study period.

Table 3. Descriptive statistics of key variables.

Variable	Mean	Std Dev	Min	Max	N
Safe Water Access	0.584	0.493	0	1	54,320
Clean-Energy Access	0.512	0.499	0	1	54,320
Sanitation Access	0.457	0.498	0	1	54,320
EII (0–3)	1.553	1.105	0	3	54,320
Child Hospitalization	0.176	0.381	0	1	54,320
Medical Expenses (1000 yuan)	3.562	7.943	0	125.0	54,320
Informal Credit Share	0.658	0.382	0	1	22,450
Income-Generating Asset Share	0.264	0.305	0	1	54,320
Log Household Income	9.875	1.284	5.42	14.02	54,320

Note: EII denotes the Environmental Infrastructure Index, constructed as the sum of three binary indicators: safe water access, clean-energy access, and sanitation access, with values ranging from 0 to 3. Medical expenses are measured in thousand yuan. Informal credit share is defined as informal debt divided by total outstanding debt and is calculated only for households with positive outstanding debt; therefore, its sample size differs from that of the full sample.

Over the 2017–2023 study period, we observe substantial improvements in environmental infrastructure. By the 2023 wave, safe drinking water access increased to 68.9%, clean cooking energy access rose to 65.8%, and improved sanitation access expanded to 58.7%, representing increases of 16.6, 17.5, and 20.2 percentage points, respectively. Overall, 42.6% of households experienced at least one environmental infrastructure improvement during the study period. The staggered timing of these improvements across households and regions provides variation that is exploited in the difference-in-differences identification strategy.

Regarding financial outcomes, the average household incurred annual medical expenditures of 3562 yuan at baseline, with child hospitalization occurring in 17.6% of households. Among households with outstanding debt, 65.8% of borrowing originated from informal credit sources. In terms of asset allocation, households allocated approximately 26.4% of total assets to productive uses, while the remaining 73.6% was held in liquid or low-yield precautionary forms. These patterns suggest that rural households face substantial exposure to health-related risks and maintain defensive financial structures characterized by high reliance on precautionary savings and informal borrowing, consistent with the study's theoretical framework.

To assess potential sample selection concerns, we compared baseline characteristics between households that subsequently experienced environmental infrastructure improvements and those that did not. Households that subsequently improved show modestly higher baseline income (log income: 10.31 versus 10.19, difference significant at $p < 0.05$) and slightly larger household size (3.84 versus 3.71 members). These differences are small in magnitude but statistically detectable given our large sample. Critically, however, pre-improvement trends in all financial outcome variables are parallel between the two groups—as confirmed by the lead coefficient analysis in Section 4.4—indicating that the modest baseline differences in levels do not translate into differential outcome trends. Our staggered DID design with household fixed effects absorbs time-invariant differences between groups, so that identification relies on within-household changes around the timing of improvements rather than cross-sectional comparisons.

The 57.4% of households that did not improve during the study period show baseline environmental access rates of 40.4% for safe water, 31.6% for clean energy, and 26.8% for sanitation—substantially lower than improving households (68.4%, 52.3%, and 44.7%, respectively). This pattern indicates that non-improving households are disproportionately located in areas with lower baseline infrastructure, likely reflecting geographic and institutional barriers to infrastructure expansion. While this compositional difference could in principle generate selection bias, our propensity score matching within treatment cohorts explicitly addresses this concern by constructing comparable control groups conditional on observable baseline characteristics. Matched estimates (available in are substantively identical to unmatched estimates, providing reassurance that observable selection does not drive our results.

4.2. Main Results: Environmental Infrastructure Effects on Healthcare and Financial Outcomes

Table 4 presents baseline staggered difference-in-differences estimates for the association between environmental infrastructure improvements and household health and financial outcomes. Panel A reports effects on child health outcomes, which represent the first stage of the proposed mechanism. Panel B reports effects on informal credit dependence and income-generating asset share.

Table 4. Baseline DiD estimates: effects of environmental infrastructure on financial outcomes.

Outcome Variable	Coefficient	Std Error	95% CI	% Change	N
Panel A: Health Outcomes					
Child Hospitalization	−0.041 ***	0.008	[−0.057, −0.025]	−23.3%	54,320
Medical Expenses (1000 yuan)	−1.185 ***	0.275	[−1.724, −0.646]	−33.2%	54,320
Panel B: Financial Outcomes					
Informal Credit Share	−0.092 ***	0.021	[−0.133, −0.051]	−14.0%	22,450
Income-Generating Asset Share	0.058 ***	0.015	[0.029, 0.087]	+22.0%	54,320

Note: *** $p < 0.01$. Coefficients represent the effect of a one-unit increase in the Environmental Infrastructure Index (EII). All specifications include household and year fixed effects, plus the full set of time-varying controls. Standard errors are clustered at the household level. CI = 95% confidence interval. % Change shows percentage change relative to baseline means.

Panel A shows that a one-unit increase in the Environmental Infrastructure Index (EII) is associated with a 4.1 percentage-point decline in the probability of child hospitalization ($p < 0.01$; 95% CI: −5.7% to −2.5%). This corresponds to a 23.3% reduction relative to the baseline hospitalization rate of 17.6%. A one-unit EII increase is also associated with a 1185 yuan reduction in annual out-of-pocket medical expenditure ($p < 0.01$), or 33.2%

relative to baseline spending. These results support the health-shock-reduction link in the proposed mechanism.

Panel B shows that a one-unit EII increase is associated with an 9.2 percentage-point reduction in informal credit share ($p < 0.01$; 95% CI: −13.3% to −5.1%) and a 5.8 percentage-point increase in income-generating asset share ($p < 0.01$; 95% CI: 3.1% to 9.3%). These estimates are consistent with a liquidity-release interpretation: lower health-related risk appears to reduce emergency borrowing needs and to make productive asset allocation more feasible. The Sun and Abraham [26] heterogeneity-robust estimates are similar in magnitude (informal credit share: −0.086, SE = 0.025; income-generating asset share: +0.051, SE = 0.018), suggesting that treatment-timing heterogeneity does not materially drive the baseline estimates.

4.3. Dimension-Specific Effects: Which Environmental Improvements Matter Most?

To identify which environmental dimensions are most strongly associated with household financial resilience, Table 5 reports separate estimates for safe drinking water, clean cooking energy, and sanitation. These results have direct policy relevance because they indicate which investments are most closely linked to health-risk reduction and financial adjustment in the sample.

Table 5. Dimension-specific effects of environmental infrastructure on health and financial outcomes.

Outcome Variable	Safe Water	Clean Energy	Sanitation	Composite EII
Panel A: Health				
Child hospitalization	−0.048 ***	−0.026 ***	−0.012 **	−0.041 ***
Medical expenses (1000 yuan)	−1.620 ***	−1.050 ***	−0.280 *	−1.185 ***
Panel B: Financial				
Informal credit share	−0.105 **	−0.058 **	−0.035 *	−0.092 ***
Income-generating asset share	+0.062 ***	+0.051 ***	+0.038 ***	+0.058 ***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Each column reports estimates for one binary indicator as the treatment variable. All specifications include household and year fixed effects plus full controls. Standard errors are clustered at the household level. All three environmental dimensions are associated with higher income-generating asset share (+3.8 to +6.2 percentage points). The asset-reallocation gradient is flatter than the medical-cost gradient, which is consistent with, but does not by itself prove, an expectation-based portfolio adjustment.

Safe drinking water access emerges as the most impactful environmental improvement, reducing child hospitalization probability by 4.8 percentage points ($p < 0.01$) and medical expenses by 1620 yuan ($p < 0.01$). The effect of safe water represents 121% of the composite EII effect on hospitalization, suggesting that unsafe water represents the primary preventable health risk in our sample. This finding aligns with epidemiological evidence on waterborne disease burden and indicates that water access should receive prioritization in resource-constrained settings.

4.4. Dynamic Effects and Parallel Trends

A critical test of our difference-in-differences identification is whether the parallel trend assumption holds. We conduct this test through dynamic effects analysis in which we estimate treatment effects separately for each year relative to infrastructure improvement. The specification includes leads (indicators for years prior to improvement) and lags (indicators for years after improvement), with year of improvement serving as the omitted reference category.

Figure 2 presents the dynamic effects for our primary financial outcome (informal credit share) as a representative example; similar patterns emerge across all outcomes. Critically, lead coefficients are substantively small and statistically insignificant (lead −2: −0.012, 95% CI: −0.038 to 0.014; lead −1 is the omitted reference period), supporting the parallel trend assumption. Households with impending environmental improvements do not show pre-treatment changes in financial behavior, reducing concern over anticipation effects or reverse causality from future improvements.

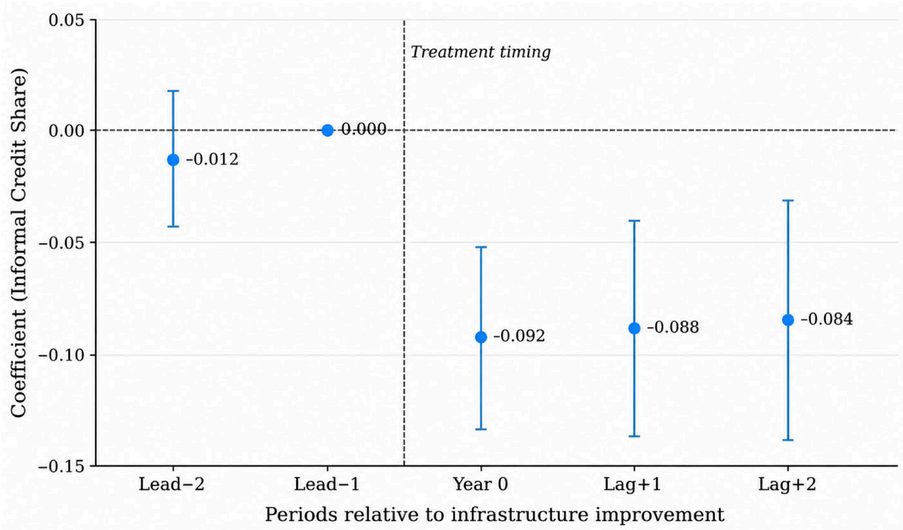

Figure 2. Dynamic treatment effects of environmental infrastructure on informal credit share. The dots represent point estimates from the event–study specification, and error bars represent 95% confidence intervals clustered at the household level. Lead-1 is the omitted reference period. The results confirm the parallel trends assumption and show a persistent reduction in informal debt reliance following infrastructure upgrades.

Lag coefficients show immediate and persistent post-treatment changes. The effect on informal credit appears in the year of treatment (lag 0: −0.092) and remains substantial in subsequent years (lag 1: −0.088; lag 2: −0.084). The persistence of the estimates is consistent with structural portfolio adjustment rather than a purely temporary response. Together with insignificant pre-treatment leads, this pattern strengthens the credibility of the DID interpretation, while not eliminating all concerns about time-varying unobserved confounders.

4.5. Mediation Analysis: The Health–Credit–Income Channel Mechanism

Table 6 decomposes total treatment effects into direct and indirect components to assess whether observed financial changes operate partly through reduced health risks and medical costs. The indirect effect through medical expenditure reduction accounts for 59.3% of the total effect on informal credit share (indirect effect: −0.0546, $p < 0.01$). The three environmental dimensions produce different medical-cost reductions—safe water (−1620 yuan), clean energy (−1050 yuan), and sanitation (−280 yuan)—but their effects on income-generating asset share are more similar (+6.2 pp, +5.1 pp, and +3.8 pp).

Table 6. Mediation analysis: decomposing effects through health mechanisms.

Outcome/Pathway	Total Effect	Indirect Effect	Direct Effect	% Mediated	*p*-Value
Informal Credit Share	−0.0920	−0.0546 ***	−0.0374 *	59.3%	<0.01
Income-Generating Asset Share	0.0580	0.0212 **	0.0368 ***	36.6%	0.03

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Bootstrap replications = 5000; standard errors clustered at the household level.

This compression pattern is consistent with an ex-ante expectation channel, although the data do not allow this channel to be directly observed. If income-generating asset reallocation were driven solely by realized medical-cost savings, the 5.8-fold gap in medical-cost effects between safe water and sanitation would likely generate a larger gap in asset effects. Instead, the asset–effect ratio is about 1.6, suggesting that households may respond to the broader signal of improved environmental security rather than only to the exact monetary savings from each infrastructure type.

Accordingly, we interpret the non-medical component cautiously: it is suggestive of expectation-based adjustment in risk perception, planning horizon, and precautionary saving demand, but it should not be read as direct evidence that households consciously changed sustainable-consumption preferences.

This interpretation also explains why mediation through medical costs accounts for a smaller share of the income capacity expansion effect (36.6%) than of the informal credit effect (59.3%): informal credit responds more directly to actual medical emergencies and their financing requirements, while asset portfolio reallocation reflects longer-horizon planning responses more closely tied to expectational channels.

This finding provides supportive evidence for the proposed mechanism. The portion of the total effect not attributable to the medical-cost pathway is consistent with an expectational channel, but should be interpreted as suggestive rather than as direct experimental identification. The key pattern is the dimension-specific convergence documented in Table 5: safe drinking water generates medical-cost savings approximately 5.6 times larger than sanitation improvements (1620 yuan versus 280 yuan), yet the two dimensions produce more similar effects on income-generating asset share (+6.2 pp versus +3.8 pp). This convergence suggests that households may respond to the broader signal of improved environmental security, not only to the exact monetary savings generated by each infrastructure type.

For income-generating asset outcomes, the mediation pathway is weaker but still meaningful. Reduced medical costs account for 36.6% of the total 0.058 effect on income-generating asset share (indirect effect: 0.0212, $p < 0.05$), with the remaining component operating through direct or unmeasured mechanisms. This pattern supports the health–credit–income framework while indicating that psychological, institutional, or expectation-based channels require further direct measurement.

4.5.1. Further Decomposition of Non-Medical Pathways

To investigate non-medical pathways consistent with the residual portion of the total treatment effect, we conduct proxy-based analyses and falsification tests. These analyses should be treated as mechanism triangulation rather than definitive identification of psychological channels.

First, regarding the health anxiety channel: we use the incidence of chronic illness among household members as an imperfect proxy for elevated ongoing health anxiety. Among households with chronically ill members, the behavioral response to environmental improvements is larger (informal credit reduction: 11.4 percentage points) compared to households without chronically ill members (7.1 percentage points). This differential is consistent with the hypothesis that health anxiety reduction contributes to behavioral change beyond direct cost savings. However, chronic illness incidence captures only one dimension of health anxiety, and the observed pattern could also reflect differences in baseline medical expenditure levels rather than psychological mechanisms.

Second, regarding the income stability expectations channel: we use the coefficient of variation in household agricultural income as a proxy for income uncertainty. The income capacity expansion effect is 1.8 times stronger among high-volatility households. This pattern is consistent with the prediction that environmental improvements interact with income uncertainty to amplify expectational shifts, though we cannot rule out that income volatility correlates with other unmeasured household characteristics that independently moderate treatment effects.

Third, regarding the social demonstration and aspiration channel: households located in villages with higher environmental infrastructure coverage show modestly stronger behavioral responses (8.4 versus 6.9 percentage-point informal credit reduction). While consistent with social learning mechanisms, this difference is small and could reflect village-level confounders rather than aspiration effects per se.

Taken together, these analyses provide a coherent pattern of evidence consistent with the theoretical mechanism: behavioral changes co-vary with environmental improvement in ways that are not easily explained by income growth alone. However, the proxies used here cannot fully exclude correlated unobserved household characteristics. Direct measurement through validated psychological or behavioral instruments would further strengthen inference.

4.5.2. Serial (Chain) Mediation Analysis: Testing the Full Health–Credit–Income Pathway

The single-step mediation results above establish that health-shock reduction independently mediates both the informal credit and income capacity outcomes. However, the theoretical framework in Section 2.2 predicts a sequential mechanism in which the mediators themselves operate in series: environmental infrastructure first reduces health shocks (Stage 1), reduced health shocks lower informal credit dependence (Stage 2), and reduced informal credit reliance then enables income capacity accumulation (Stage 3). To test this full chain, we implement a formal serial mediation analysis following Hayes [27] and Preacher and Hayes [28], using 5000 bootstrap replications with household-clustered standard errors to construct bias-corrected 95% confidence intervals for all indirect effects.

The serial mediation system estimates the following sequential path, EII → Health Shocks (M1) → Informal Credit Dependence (M2) → Household Income Capacity (Y), where the complete chain indirect effect is the product of three coefficients: the effect of EII on M1 (path a_1), the effect of M1 on M2 controlling for EII (path d_{21}), and the effect of M2 on income capacity controlling for both EII and M1 (path b_2). Table 7 decomposes the total effect of EII on household income capacity into five components: the direct effect, three single-mediator indirect effects (through M1 alone, through M2 alone, and through an unspecified residual channel), and the chain indirect effect transmitted through M1 then M2 sequentially.

Table 7. Serial mediation analysis: decomposing the effect of EII on household income capacity.

Effect Component	Path	Point Estimate	95% CI (Bootstrap)	% of Total
Total effect	EII → Income-Generating Asset Share	+0.062 ***	[0.031, 0.093]	100%
Direct effect	EII → Income-Generating Asset Share (net)	+0.0183 **	[0.004, 0.032]	29.5%
Indirect: via M1 only	EII → Health Shocks → Income-Generating Asset Share	+0.0210 **	[0.009, 0.033]	33.9%
Indirect: via M2 only	EII → Informal Credit → Income-Generating Asset Share	+0.0136 **	[0.005, 0.023]	21.9%
Chain indirect: M1 → M2	EII → Health Shocks → Informal Credit → Income-Generating Asset Share	+0.0092 **	[0.003, 0.016]	14.8%

Note: Bootstrap replications = 5000; standard errors clustered at the household level. M1 = child hospitalization incidence (primary health-shock measure); M2 = informal credit share. All specifications include household and year fixed effects plus full time-varying controls. Bootstrapped confidence intervals are bias-corrected. *** $p < 0.01$, ** $p < 0.05$.

Results indicate that the full sequential chain is statistically significant. The chain indirect effect (EII → Health Shocks → Informal Credit → Income Capacity) is positive (point estimate: +0.0092; bootstrapped 95% CI: [0.0031, 0.0162]) and accounts for approximately 14.8% of the total effect of EII on income capacity. The mediated components complement the direct effect and are consistent with, but do not by themselves conclusively identify, the proposed health–credit–income pathway.

The serial mediation results are relevant for policy because they suggest that the financial benefits of environmental infrastructure may be amplified when reduced health expenditure is followed by lower informal borrowing and then by productive asset reallocation. This finding supports the interpretation of an integrated pathway, while remaining subject to the assumptions of mediation analysis.

4.6. Heterogeneous Effects by Resource Endowment, Gender, and Region

A critical policy question concerns whether environmental improvements produce stronger benefits for the households or communities below the critical infrastructure threshold. We conduct heterogeneity analysis stratifying by wealth quartiles, household-head gender, and geographic region, examining both the magnitude and mechanisms of differential treatment effects.

4.6.1. Threshold Effect by Resource Endowment

Tables 8 and 9 confirm a statistically significant single resource-endowment threshold and report the corresponding threshold regression estimates: the threshold variable resource endowment (RE) has one estimated break at 0.3542 (Table 8), and the marginal effects of environmental infrastructure are substantially larger for households below this threshold than above it (Table 9). To express this heterogeneity in more interpretable terms, we complement the threshold model with estimates stratified by baseline resource-endowment quartile, which reveal substantial heterogeneity by poverty status, aligned with our theoretical predictions from the risk–expectation–behavior nexus. For child hospitalization, the effect is monotonically increasing in poverty severity. Below-threshold quartile households (Q1) experience a 6.8 percentage-point reduction in hospitalization ($p < 0.01$), compared to only 2.1 percentage points for richest quartile households (Q4)—a 3.2-fold differential reflecting that below-threshold households with the greatest initial health vulnerability derive the largest absolute benefits from disease prevention.

Table 8. Threshold effect test of resource endowment.

Model	Threshold Value	F-Statistic	p-Value	10%	Critical Value (5%)	1%
Single-threshold	0.3542	15.9361	0.0033	8.2995	10.3214	13.5888
Double-threshold	—	2.8148	0.8067	8.1382	9.1741	11.3640

Note: The threshold value is determined by the bootstrap method (1000 replications). The single-threshold effect is significant at the 1% level.

For informal credit dependence, the pattern is even more pronounced: Q1 households reduce informal credit share by 14.2 percentage points compared to only 2.8 percentage points for Q4 households, a 4.3-fold differential. We decompose this heterogeneity into three contributing channels to explain why poverty status so strongly moderates treatment effects, rather than simply asserting that greater baseline vulnerability produces larger responses.

Channel One—The Medical-Cost Burden Channel: Among Q1 households, baseline medical expenditures represent approximately 18.3% of annual household income, compared to 4.2% among Q4 households. This differential means that a given absolute reduction in medical costs—1185 yuan on average—represents a far larger proportional relief for Q1 households (approximately 4.4% of annual income) than for Q4 households (approximately 0.5% of annual income). When medical-cost savings represent a meaningful share of income, the behavioral response—reducing emergency borrowing and reallocating toward income-generating assets—is correspondingly larger. This channel operates through the ex-post financial pathway: Q1 households experience not only the same absolute medical-cost reduction as wealthier households, but a much larger relative income shock that triggers stronger portfolio adjustment.

Table 9. Threshold regression results for resource endowment.

Variables	(1) Informal Credit Share	(2) Income-Generating Asset Share
EII × I (RE ≤ 0.3542)	−0.142 ***	0.081 ***
	(0.027)	(0.018)
EII × I (RE > 0.3542)	−0.028 *	0.019 **
	(0.015)	(0.008)
Control Variables	Included	Included
Household and Year FE	Included	Included
Observations	22,450	54,320
R-squared	0.192	0.235

Note: Robust standard errors clustered at the household level are in parentheses. ***, **, * indicate significance at 1%, 5%, and 10% levels, respectively. RE (Resource Endowment) is the threshold variable. I(·) is the indicator function. The threshold value of 0.3542 is determined by the bootstrap method (Table 8).

Channel Two—The Informal Credit Headroom Channel: Q1 households rely on informal credit for 74.3% of total borrowing at baseline, compared to 41.2% among Q4 households. This baseline difference means that Q1 households have substantially more room to reduce informal credit dependence following environmental improvement. Even a moderate absolute decline in informal borrowing translates into a proportionally larger reduction in informal credit share for high-reliance households. This mechanical amplification—whereby the same absolute behavioral change registers as a larger proportional shift at higher baseline levels—partly explains the 4.3-fold differential in informal credit reduction relative to the 3.2-fold differential in hospitalization reduction. The financial channel thus compounds the health channel: poverty status amplifies both the health benefits and the financial headroom available to convert those benefits into credit market exit.

Channel Three—The Expectational Transformation Channel: The most constrained households may also experience the largest change in perceived security when environmental risks decline. For Q1 households, where medical expenditures represent a much larger share of income, clean water or improved sanitation may signal lower exposure to catastrophic health expenditure and thereby encourage longer-horizon financial planning. This interpretation is consistent with the steeper credit response among below-threshold households, but it remains indirect because risk perception is not directly observed in the CHFS data.

4.6.2. Threshold Effect by Gender of Household Head

We examine whether treatment effects differ by the gender of the household head, motivated by evidence that women in rural China bear disproportionate burdens of informal caregiving and health management. In our sample, 31.4% of households are female-headed. Female-headed households exhibit moderately stronger effects on informal credit reduction (−0.102, $p < 0.01$) compared to male-headed households (−0.081, $p < 0.01$), a differential significant at the 10% level in interaction-term specifications. For income capacity allocation, the differential is smaller and statistically insignificant (female-headed: +6.8 pp; male-headed: +5.9 pp). These patterns are broadly consistent with theories of intrahousehold bargaining: women who bear primary responsibility for water collection and child health management may experience the largest reduction in time burdens and health anxiety, producing somewhat stronger financial behavioral responses. We treat this as suggestive evidence warranting further investigation rather than a primary finding.

4.6.3. Threshold Effect by Geographic Region

Geographic heterogeneity analysis stratifies our sample into three macro-regions: Central and Western China (58.3% of the sample), Northeast China (12.1%), and Eastern China (29.6%). Treatment effects are substantially larger in Central and Western regions, where baseline infrastructure deficiencies are the deepest and informal credit markets are the most entrenched. For informal credit share, the treatment effect in Central and Western China (-0.114, $p < 0.01$) is 2.1 times larger than in Eastern China (-0.054, $p < 0.05$). For income capacity allocation, the Central and Western effect (+7.8 pp) is approximately 1.8 times the Eastern effect (+4.3 pp). These patterns reinforce the theoretical prediction that the health–credit–income channel is strongest where baseline scarcity and risk are greatest. They also carry direct policy implications: national infrastructure programs should allocate resources toward the most deprived interior regions not only on equity grounds but also on efficiency grounds, since financial resilience returns per unit of investment are systematically higher in these areas.

4.7. Robustness Checks and Specification Sensitivity

We conduct robustness checks to verify that the main findings are not artifacts of a single modeling choice. We consider several alternative specifications for the primary outcome, informal credit share, as described below.

Column (1) replicates the baseline specification with household and year fixed effects. Column (2) adds community fixed effects. Column (3) uses IV-Probit estimation with community-average environmental infrastructure as an instrument. Column (4) advances treatment dates by one year as a placebo test. Column (5) restricts the sample to balanced panels, Column (6) reports a linear probability model, and Column (7) applies the Sun and Abraham [26] estimator.

Across specifications, treatment effects remain stable in sign and magnitude. The main estimate of -0.092 is close to alternative estimates ranging from -0.082 to -0.096. The placebo timing test is not statistically significant, and the Sun and Abraham estimate remains similar to the baseline estimate. These checks support the robustness of the findings, although they cannot fully rule out unobserved time-varying factors.

The Sun and Abraham [26] heterogeneity-robust estimate (-0.086) is close to the baseline estimate (-0.089), a pattern that requires reconciliation with the substantial heterogeneity documented in Section 4.6. We clarify that these two sets of results address different dimensions of treatment-effect heterogeneity and are not contradictory. The Sun and Abraham estimator tests for heterogeneity across treatment-timing cohorts—that is, whether households that improved environmental infrastructure in earlier waves (e.g., 2017 or 2019) experienced systematically different treatment effects than those that improved in later waves (e.g., 2021 or 2023). The similarity between S&A and baseline estimates indicates that treatment-effect heterogeneity across timing cohorts is limited: households improving in different years experience approximately similar average effects. This finding supports the staggered DID design by indicating that early and late improvers are comparable in their average responses.

The heterogeneity documented in Section 4.6, by contrast, concerns cross-sectional heterogeneity by poverty status, gender, and region—characteristics that vary across households but are orthogonal to improvement timing. The below-threshold households may improve infrastructure in both early and late waves, and within each timing cohort, the below-threshold households exhibit larger effects than wealthier ones. These two forms of heterogeneity are conceptually and statistically distinct: the S&A estimator addresses the former (timing-based) but is not designed to detect the latter (characteristic-based). Our interaction-term specifications in Table 8 directly test and document characteristic-based heterogeneity, which is the policy-relevant dimension of effect variation.

In summary, treatment effects are relatively homogeneous across timing cohorts (supporting DID validity) but substantially heterogeneous across household poverty status (supporting the pro-poor policy implications). These findings are complementary rather than contradictory.

4.8. Discussion of Empirical Findings

Taken together, the empirical results are consistent with the interpretation that environmental infrastructure operates as a household financial-resilience instrument through the health–credit–income mechanism. Health-risk reductions are followed by lower informal credit reliance and higher income-generating asset share, with effects especially pronounced among below-threshold households. Two issues deserve cautious discussion: whether the benefits can persist after initial infrastructure investment and whether financial resilience may create conditions for cleaner or more forward-looking household choices.

4.8.1. Sustainability of Benefits Under Subsidy Withdrawal

The event–study results show that treatment effects persist across the observed post-treatment window. This pattern is consistent with, but does not by itself support, the possibility that released medical expenditure and reduced debt pressure help households absorb ongoing maintenance costs. Longer follow-up data would be needed to evaluate whether infrastructure benefits remain durable after subsidy withdrawal or changes in local maintenance arrangements.

4.8.2. From Financial Resilience to Green Transition: A Demand-Side Feedback Loop

The similar income-generating asset effects across the three infrastructure dimensions, despite different medical-cost savings, suggest that households may respond to the broader signal of improved environmental security. This finding is relevant to sustainable-consumption transitions because financial resilience can lengthen planning horizons and make productive or cleaner investments more feasible. However, because the data do not directly observe green consumption or stated preferences, this interpretation should be viewed as a theoretical implication rather than a confirmed behavioral outcome.

5. Discussion and Policy Implications

5.1. Integrated Discussion of the Findings

The results indicate that environmental infrastructure is associated with rural household financial resilience through a coherent health–credit–income pathway. Across 54,320 household–year observations, improvements in safe water, clean cooking energy, and sanitation are followed by lower child hospitalization and out-of-pocket medical expenditure, lower reliance on informal credit, and a higher share of income-generating assets. Rather than restating each coefficient reported in Section 4, this discussion emphasizes the integrated meaning of these results: environmental infrastructure reduces preventable background risk, and the resulting decline in emergency liquidity pressure creates more room for productive household allocation.

This interpretation extends existing work on environmental health, household finance, and sustainable development. Prior studies have often examined health benefits, credit constraints, or asset accumulation separately. Our evidence links these domains within a single household-level mechanism. The key contribution is therefore not only that environmental infrastructure improves health outcomes, but also that health-risk reduction can reshape downstream financial behavior by weakening the need for high-cost coping strategies and supporting forward-looking asset allocation.

The threshold results further qualify this interpretation. Benefits are strongest among households with lower baseline resource endowments, where preventable illness, informal borrowing, and precautionary liquidity constraints are most binding. This pattern suggests that the marginal financial resilience return to basic environmental infrastructure is highest when projects reach households facing both environmental deprivation and financial fragility.

5.2. Boundary Conditions and Interpretation Limits

Several limitations should guide interpretation. First, although the staggered DID, event–study, falsification, and robustness tests support the credibility of the estimates, the study remains based on observational panel data and should not be read as definitive experimental proof of every intermediate link. Second, child hospitalization is a theoretically relevant indicator of environmental-health risk, but it may also reflect healthcare access, insurance coverage, and care-seeking behavior. Third, the analysis identifies financial preconditions for more sustainable rural consumption and productive investment; it does not directly observe green consumption behavior, environmental preferences, or technology-adoption intentions.

The results on persistence and income-generating assets should also be interpreted cautiously. The observed post-treatment effects are consistent with a durable financial-resilience mechanism, but longer follow-up data are needed to determine whether these gains survive changes in maintenance arrangements, service reliability, or subsidy withdrawal. Similarly, the evidence that households allocate more assets toward income-generating uses indicates improved financial capacity, not direct evidence of a completed green transition.

5.3. Consolidated Policy Implications

The policy implications can be organized around four priorities. First, environmental infrastructure should be incorporated into rural financial-resilience and financial-inclusion strategies. Clean water, clean cooking energy, and improved sanitation reduce not only disease exposure but also the emergency borrowing and precautionary liquidity needs that weaken household balance sheets. Cost–benefit evaluations of infrastructure projects should therefore include downstream changes in medical expenditure, informal credit dependence, and income-generating asset allocation, rather than relying only on access rates or first-order health indicators.

Second, targeting should prioritize communities below the resource-endowment threshold. The heterogeneity results imply that the same infrastructure investment produces larger marginal resilience gains where households face higher health risk and tighter liquidity constraints. In practice, infrastructure expansion should be coordinated with poverty-identification systems and rural-development programs so that water, sanitation, and clean-energy upgrades reach the most financially vulnerable households first. Safe drinking water can be treated as a foundational priority, while sanitation and clean-energy interventions should be bundled where feasible to reduce multiple environmental-health risks simultaneously.

Third, infrastructure programs should pair physical construction with maintenance, affordability, and monitoring arrangements. Subsidy phase-out should not follow a fixed timetable alone; it should be linked to service reliability, household affordability, and evidence that health-expenditure burdens have actually declined. Monitoring systems should track whether reduced medical costs and lower debt pressure translate into sustained improvements in household financial resilience.

Fourth, development finance and ESG-oriented infrastructure evaluation should adopt cross-sector metrics. Because the benefits identified here cut across environmental quality, public health, credit dependence, and productive capacity, financing models can draw jointly on health, environmental, poverty-reduction, and financial-inclusion budgets. Vulnerability-weighted impact metrics would make the equity effects of infrastructure investment more visible and would help development banks and impact investors identify projects with stronger social returns.

6. Conclusions

6.1. Summary of Findings

This study shows that environmental infrastructure can operate as a financial-resilience instrument for rural households. Improvements in safe drinking water, clean cooking energy, and sanitation are associated with reduced preventable health shocks, lower out-of-pocket medical expenditure, less dependence on informal credit, and a higher share of income-generating assets. These findings support the proposed health–credit–income channel and show that the social value of environmental infrastructure extends beyond direct access and health outcomes.

The findings also clarify the distributional relevance of environmental infrastructure. The strongest effects appear among households with lower baseline resource endowments, suggesting that basic infrastructure investment can generate both efficiency and equity gains when targeted toward communities facing the highest combined environmental and financial vulnerability. For sustainable-development policy, the main implication is that environmental upgrading should be treated as part of a broader resilience strategy rather than as a narrow sectoral intervention.

6.2. Limitations and Future Research

Several limitations remain. The observational panel design cannot fully eliminate unobserved time-varying confounding, and child hospitalization may capture both morbidity and healthcare-utilization behavior. The CHFS data also do not directly measure risk perception, household planning horizons, green consumption, or long-term maintenance behavior. Future research should link household surveys with clinical, insurance, and facility-level data; track infrastructure functionality and maintenance payments over longer periods; and directly measure whether financial resilience translates into sustainable consumption or technology adoption.

Cross-context replication is also needed. The health–credit–income mechanism should be tested in other low- and middle-income settings where deficient environmental infrastructure, limited formal insurance, and active informal credit markets coexist. Randomized, stepped-wedge, or quasi-experimental evaluations of bundled WASH and clean cooking interventions in Sub-Saharan Africa, South Asia, and Southeast Asia would help determine whether the magnitude of the effects documented here generalizes beyond rural China.

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References

1. Li, J.; Wu, Y.; Xiao, J.J. The Impact of Digital Finance on Household Consumption: Evidence from China. *Econ. Model* **2020**, *86*, 317–326. [CrossRef]
2. Yang, J.; Mukhopadhaya, P. Is the ADB's Conjecture on Upward Trend in Poverty for China Right? An Analysis of Income and Multidimensional Poverty in China. *Soc. Indic. Res.* **2019**, *143*, 451–477. [CrossRef]
3. Kochar, A. Ill-health, savings and portfolio choices in developing economies. *J. Dev. Econ.* **2004**, *73*, 257–285. [CrossRef]
4. Zhao, X.; Wang, X.; Ren, Z.; Zhang, C. The impact of health shocks on poverty vulnerability: Evidence from rural households in China. *Front. Public Health* **2025**, *13*, 1657269. [CrossRef] [PubMed]
5. Qiu, Y.; Zhang, F. Impact of health shocks on household consumption structure. *Front. Public Health* **2024**, *12*, 1431833. [CrossRef] [PubMed]
6. Li, C.; Li, M.; Zhang, L.; Li, Q.; Zheng, H.; Feldman, M.W. Energy–Poverty–Inequality SDGs: A Large-Scale Household Analysis and Forecasting in China. *Proc. Natl. Acad. Sci. USA* **2025**, *122*, e2408167121. [CrossRef] [PubMed]
7. Ma, X.; Hu, Q.; He, J.; Li, C.; Chen, K.; Wang, W.; Qiao, H. Association between Sanitary Toilets and Health Poverty Vulnerability among Rural Western Chinese Adults Aged 45 Years and Older: A Cross-Sectional Study. *PLoS ONE* **2024**, *19*, e0308688. [CrossRef] [PubMed]
8. Prüss-Ustün, A.; Wolf, J.; Bartram, J.; Clasen, T.; Cumming, O.; Freeman, M.C.; Gordon, B.; Hunter, P.R.; Medlicott, K.; Johnston, R. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. *Int. J. Hyg. Environ. Health* **2019**, *222*, 765–777. [CrossRef] [PubMed]
9. Hunter, P.R.; MacDonald, A.M.; Carter, R.C. Water Supply and Health. *PLoS Med.* **2010**, *7*, e1000361. [CrossRef] [PubMed]
10. Atangana, E.; Oberholster, P.J. Assessment of water, sanitation, and hygiene target and theoretical modeling to determine sanitation success in sub-Saharan Africa. *Environ. Dev. Sustain.* **2023**, *25*, 13353–13377. [CrossRef] [PubMed]
11. Sankhyayan, P.; Dasgupta, S. Rural Energy Transition for Cooking in India—Revisiting the Drivers. *Sustainability* **2023**, *15*, 7635. [CrossRef]
12. Amadu, I.; Seidu, A.A.; Agyemang, K.K.; Arthur-Holmes, F.; Duku, E.; Salifu, I.; Yawson, A.E. Joint effect of water and sanitation practices on childhood diarrhoea in sub-Saharan Africa. *PLoS ONE* **2023**, *18*, e0283826. [CrossRef] [PubMed]
13. Zhao, J. Formal Credit Constraint and Prevalence of Reciprocal Loans in Rural China. *Open Econ.* **2021**, *4*, 1–13. [CrossRef]
14. Anderloni, L.; Bacchiocchi, E.; Vandone, D. Household Financial Vulnerability: An Empirical Analysis. *Res. Econ.* **2012**, *66*, 284–296. [CrossRef]
15. Liu, S.; Feng, Y.; Ye, M. Assessing the Influence of Digital Inclusive Finance on Household Financial Vulnerability in China: Insights from Health Insurance Participations. *Sustainability* **2024**, *16*, 9445. [CrossRef]
16. Naz, S.; Page, A.; Agho, K.E. Attributable risk and potential impact of interventions to reduce household air pollution associated with under-five mortality in South Asia. *Glob. Health Res. Policy* **2018**, *3*, 4. [CrossRef] [PubMed]
17. Carroll, C.D. Buffer-Stock Saving and the Life Cycle/Permanent Income Hypothesis. *Q. J. Econ.* **1997**, *112*, 1–55. [CrossRef]
18. Deaton, A. Saving and Liquidity Constraints. *Econometrica* **1991**, *59*, 1221–1248. [CrossRef]
19. Carter, M.R.; Barrett, C.B. The Economics of Poverty Traps and Persistent Poverty: An Asset-Based Approach. *J. Dev. Stud.* **2006**, *42*, 178–199. [CrossRef]
20. Gan, L.; Yin, Z.; Jia, N.; Xu, S.; Ma, S.; Zheng, L. *Data You Need to Know About China: Research Report of China Household Finance Survey 2012*; Springer: Berlin/Heidelberg, Germany, 2014. [CrossRef]

21. Hansen, B.E. Threshold Effects in Non-Dynamic Panels: Estimation, Testing, and Inference. *J. Econom.* **1999**, *93*, 345–368. [CrossRef]
22. Imai, K.; Keele, L.; Tingley, D. A general approach to causal mediation analysis. *Psychol. Methods* **2010**, *15*, 309–334. [CrossRef] [PubMed]
23. Callaway, B.; Sant'Anna, P.H.C. Difference-in-Differences with Multiple Time Periods. *J. Econom.* **2021**, *225*, 200–230. [CrossRef]
24. Goodman-Bacon, A. Difference-in-Differences with Variation in Treatment Timing. *J. Econom.* **2021**, *225*, 254–277. [CrossRef]
25. Chaisemartin, C.; D'Haultfœuille, X. Two-Way Fixed Effects Estimators with Heterogeneous Treatment Effects. *Am. Econ. Rev.* **2020**, *110*, 2964–2996. [CrossRef]
26. Sun, L.; Abraham, S. Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects. *J. Econom.* **2021**, *225*, 175–199. [CrossRef]
27. Hayes, A.F. *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*, 2nd ed.; The Guilford Press: New York, NY, USA, 2018; ISBN 978-1-4625-3465-4.
28. Preacher, K.J.; Hayes, A.F. Asymptotic and Resampling Strategies for Assessing and Comparing Indirect Effects in Multiple Mediator Models. *Behav. Res. Methods* **2008**, *40*, 879–891. [CrossRef] [PubMed]