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# Farm Inefficiency As Rational Equilibrium: Rethinking Agricultural Household Behavior Beyond Production Functions

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**Abstract**

Farm efficiency is commonly evaluated through frontier-based metrics, with deviations from the production frontier often interpreted as evidence of suboptimal farmer behavior. This paper challenges that interpretation by arguing that measured farm inefficiency in smallholder agriculture may reflect rational equilibrium under constrained household optimization rather than technical failure alone. Using a structured conceptual literature review, the study synthesizes literature on technical efficiency, stochastic frontier analysis, data envelopment analysis, metafrontier approaches, agricultural household models, non-separability, risk, labor allocation, and smallholder decision-making. The analysis shows that production decisions in smallholder systems are rarely separable from household consumption, labor allocation, liquidity management, and risk exposure. Under incomplete markets, endogenous shadow wages, heterogeneous technologies, and pervasive uncertainty, farmers may rationally choose conservative input use, diversification, partial technology adoption, or lower production intensity to protect household welfare. These choices may appear inefficient from a production-centered perspective, yet they can be consistent with broader household objectives such as income stability, consumption smoothing, labor feasibility, and livelihood security. The paper contributes conceptually by reframing farm inefficiency as a possible rational equilibrium outcome and by shifting the analytical benchmark from proximity to a production frontier toward coherence between household objectives, constraints, and observed choices. This reinterpretation has implications for future research and policy, suggesting that frontier estimates should be complemented with household-level variables and used as diagnostic tools rather than final judgments of farmer performance.

Keywords: Agricultural Household Model, Farm Inefficiency, Non-Separability, Rational Equilibrium, Smallholder Agriculture

## 1. Introduction

Farm efficiency has long occupied a central position in agricultural economics as a benchmark for evaluating farm performance, productivity, and policy effectiveness. A large body of empirical research relies on frontier-based approaches, particularly stochastic frontier analysis and data envelopment analysis, to estimate technical efficiency as the distance between observed production and an estimated best-practice frontier (Abate et al., 2014; Binam et al., 2008; Liu et al., 2020). Within this tradition, farms that operate below the frontier are commonly interpreted as inefficient, and such inefficiency is often attributed to managerial limitations, technological gaps, inadequate input use, weak institutions, or limited access to productive resources (Mwalupaso et al., 2019; Ngango & Hong, 2021; Zhao & Barry, 2014). This approach has generated valuable insights into agricultural productivity and has informed policies aimed at closing efficiency gaps, improving input use, and enhancing farm-level performance.

However, the dominant interpretation of farm efficiency rests on assumptions that are rarely examined with sufficient conceptual scrutiny. Frontier-based models often treat the farm as a production unit whose primary objective is to maximize output or minimize cost under a given technology set. Such an interpretation implicitly assumes that production decisions can be separated from household consumption, labor allocation, and risk management. Under complete markets, this assumption may be defensible because labor can be valued at market wages, capital can move freely, credit is accessible, and production choices can be analyzed independently from household needs. Yet these conditions are seldom observed in smallholder agriculture, where markets are incomplete, family labor is often imperfectly tradable, liquidity constraints are binding, and production risks are pervasive (Gourlay & Kilic, 2023; Seymour, 2017; Zhao & Barry, 2014). In such contexts, production cannot be meaningfully understood apart from the household that organizes, finances, and bears the consequences of farming decisions.

This creates a conceptual tension in the interpretation of measured inefficiency. When smallholders operate below an estimated production frontier, the deviation is often treated as evidence of suboptimal behavior. Yet the frontier itself may not represent a relevant or attainable benchmark for households facing binding constraints, heterogeneous technologies, and multiple objectives. Efficiency estimates may therefore conflate true technical inefficiency with rational responses to risk, labor scarcity, liquidity limitations, and institutional barriers (Ngango & Hong, 2021; Seymour, 2017). In this sense, what is measured as inefficiency may partly reflect the distance between observed behavior and an idealized production model, rather than the distance between observed behavior and household-level optimality. The problem is therefore not merely empirical, but fundamentally conceptual: efficiency is often evaluated within a framework that misrepresents the objective function and constraint set faced by smallholder households.

The agricultural household framework provides a more appropriate lens for addressing this limitation. Unlike production-centered models that isolate input-output relationships, agricultural household models recognize that production, consumption, and labor allocation decisions are jointly determined under imperfect markets. Foundational and contemporary studies show that when credit markets are incomplete, labor markets are missing or imperfect, and risks cannot be fully insured, households must allocate labor, capital, and consumption within a unified decision-making system (Christopoulos et al., 2021; Deininger et al., 2008; Petrick, 2005; Roumasset, 2006). Under these conditions, the opportunity cost of family labor is not simply given by an external wage rate, but emerges endogenously as a shadow price shaped by household needs, risk exposure, and competing uses of time. Consequently, observed input choices and production intensity may reflect rational household optimization rather than technical failure.

Empirical evidence supports this reinterpretation. Household characteristics such as demographic structure, access to off-farm income, gendered labor roles, and intra-household bargaining have been shown to influence production intensity, input use, technology adoption, and measured efficiency (Mobarok et al., 2021; Tesema, 2022). Similarly, evidence from sandy coastal agricultural systems in Indonesia shows that farmers may adopt input strategies and technology choices that deviate from yield-maximizing recommendations, yet remain consistent with household-level adaptation to risk, labor constraints, and income stability needs (Fauzan, Marbudi, et al., 2025; Fauzan, Syaukat, et al., 2025b, 2025a). These findings indicate that lower measured efficiency does not automatically imply irrationality or poor management. Rather, it may reflect deliberate choices made under uncertainty, where households prioritize resilience, liquidity preservation, and labor feasibility over maximum output.

The limitations of universal efficiency benchmarks are further highlighted by the literature on technological heterogeneity and metafrontier analysis. Farms often operate under different feasible technology sets due to variation in resource endowments, environmental conditions, institutional access, and production systems (Gourlay & Kilic, 2023; Melo-Becerra & Orozco-Gallo, 2016; Wakili, 2013). Under such heterogeneity, comparing all farmers against a single frontier risks producing misleading conclusions because measured inefficiency may reflect differences in attainable frontiers rather than suboptimal behavior. Institutional factors, including access to credit, cooperatives, information systems, and extension services, further shape measured efficiency by altering the constraint set within which households operate (Abate et al., 2014; Zhao & Barry, 2014). These insights suggest that efficiency is not merely a technical attribute of production, but a relational outcome shaped by household objectives, market imperfections, institutional conditions, and risk environments.

In light of these concerns, this paper aims to reinterpret farm inefficiency through the agricultural household framework. Specifically, it argues that what is commonly labeled as farm inefficiency may, in many smallholder contexts, represent a rational equilibrium outcome of constrained household optimization rather than evidence of suboptimal farmer behavior. The paper develops this argument by critically synthesizing literature on frontier efficiency, metafrontier analysis, non-separability, risk, labor allocation, and smallholder decision-making. Its central contribution is to shift the analytical focus from the farm as a production function to the household as a decision system. By doing so, the paper reframes inefficiency not as a simple deviation from a production frontier, but as a possible expression of equilibrium behavior under incomplete markets, endogenous shadow wages, heterogeneous technologies, and pervasive uncertainty. This reinterpretation has important implications for how researchers measure efficiency and how policymakers design interventions intended to improve smallholder performance and welfare.

## 2. Research Methods

### 2.1. Research Design

This study adopts a structured conceptual literature review to reinterpret the meaning of farm inefficiency in smallholder agriculture through the lens of agricultural household economics. Rather than treating inefficiency as

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a purely technical deviation from a production frontier, the study examines whether observed deviations from frontier-based benchmarks may represent rational outcomes of household-level optimization under constraints. The research design is therefore conceptual and interpretive, but it is grounded in a systematic engagement with relevant theoretical and empirical literature.

The review is designed to synthesize three interrelated strands of literature. The first concerns farm efficiency measurement, particularly studies using stochastic frontier analysis, data envelopment analysis, and metafrontier approaches. The second focuses on agricultural household models, especially the non-separable structure of production, consumption, labor allocation, and risk management under imperfect markets. The third includes behavioral and institutional perspectives that explain how risk, credit constraints, gendered labor allocation, and household heterogeneity shape farm-level decisions. By bringing these strands together, the study develops a conceptual argument that farm inefficiency should not always be interpreted as suboptimal behavior, but may instead reflect rational equilibrium under constrained household decision-making.

This design is consistent with the objective of the paper, which is not to estimate technical efficiency or test a new econometric model, but to critically reassess the assumptions underlying conventional efficiency interpretation. In this sense, the paper follows a concept-driven approach: it uses existing literature not merely to summarize prior findings, but to identify analytical limitations, clarify conceptual tensions, and construct a more coherent interpretation of efficiency in smallholder farming systems.

### 2.2. Literature Search And Selection

The literature search focused on studies published primarily between 2000 and 2025, while also incorporating selected foundational works that remain theoretically important for understanding farm efficiency and agricultural household behavior. The review included peer-reviewed journal articles, theoretical contributions, and relevant empirical studies addressing technical efficiency, stochastic frontier analysis, data envelopment analysis, metafrontier analysis, agricultural household models, market imperfections, risk behavior, labor allocation, and smallholder decision-making.

The search was guided by combinations of keywords such as f*arm efficiency, technical efficiency, stochastic frontier analysis, data envelopment analysis, metafrontier, smallholder agriculture, agricultural household model, non-separability, farm household labor allocation, risk and uncertainty, credit constraints,* and *household optimization*. These keywords were used to capture both production-centered efficiency studies and broader household-centered approaches. In addition, backward and forward citation tracing was used to identify influential works that connect frontier-based efficiency analysis with household behavior, institutional constraints, and risk-related decision-making.

The selection of literature followed three main criteria. First, studies were included if they addressed farm efficiency, productivity, or frontier-based performance measurement in agricultural systems. Second, studies were selected if they examined the role of household-level factors, such as labor allocation, off-farm income, gender relations, demographic structure, credit access, or risk exposure, in shaping production decisions. Third, studies were included when they contributed conceptually to the reinterpretation of efficiency, especially by questioning separability assumptions, emphasizing market imperfections, or highlighting heterogeneity in feasible production frontiers. This selection strategy ensured that the reviewed literature was directly relevant to the central argument of the paper: that measured inefficiency may partly reflect rational household responses to constraints rather than technical failure alone.

### 2.3. Analytical Procedure

The analytical procedure was conducted in three stages: conceptual mapping, assumption critique, and theoretical synthesis. These stages were designed to ensure that the review moved beyond descriptive summary toward a structured reinterpretation of farm inefficiency.

The first stage, conceptual mapping, identified how farm efficiency is commonly defined, measured, and interpreted in the literature. Particular attention was given to the use of stochastic frontier analysis, data envelopment analysis, and metafrontier models as tools for estimating the distance between observed production and an assumed best-practice frontier. This stage clarified the dominant logic of production-centered efficiency analysis and identified the assumptions that support its interpretation, including separability, profit or output maximization, and the existence of a relevant production frontier.

The second stage, assumption critique, examined whether these assumptions are consistent with the realities of smallholder agriculture. The analysis focused on literature showing that farm households often operate under incomplete credit, labor, land, and insurance markets, where production decisions are jointly shaped by consumption needs, family labor availability, risk exposure, and institutional constraints. This stage also assessed

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how heterogeneity in technology, resource endowments, and environmental conditions affects the relevance of universal frontier benchmarks. Through this process, the review identified conceptual limitations in interpreting all deviations from the frontier as inefficiency.

The third stage, theoretical synthesis, integrated insights from efficiency analysis and agricultural household economics to develop the central proposition of the paper. In this synthesis, farm inefficiency is reinterpreted as a possible rational equilibrium outcome under constrained household optimization. Observed input underutilization, conservative production strategies, or lower measured technical efficiency may reflect household efforts to balance income, risk, labor allocation, liquidity, and resilience. The synthesis therefore reframes efficiency not merely as proximity to a production frontier, but as coherence between household objectives, constraints, and observed choices. This analytical procedure provides the methodological foundation for the discussion that follows, where the paper develops a household-centered reinterpretation of farm inefficiency in smallholder agriculture.

## 3. Results And Discussions

### 3.1. The Production-Centered Illusion Of Farm Efficiency

The dominant literature on farm efficiency has long relied on a production-centered interpretation of agricultural performance. Within this tradition, efficiency is commonly defined as the ability of farms to produce maximum output from a given set of inputs or to minimize input use for a given level of output. Frontier-based approaches, particularly stochastic frontier analysis and data envelopment analysis, have become standard tools for estimating this performance gap by measuring the distance between observed production and an estimated best-practice frontier (Fauzan et al., 2023; Liu et al., 2020; Saputri et al., 2024; Triyono et al., 2021). The analytical appeal of these methods lies in their ability to quantify technical inefficiency and identify potential sources of productivity loss. As a result, they have shaped both academic research and policy interventions aimed at improving farm productivity, strengthening input use, and closing efficiency gaps.

However, the production-centered interpretation of efficiency carries an implicit assumption that is often insufficiently examined: that the estimated frontier represents the relevant benchmark of optimal behavior for all farmers. In conventional efficiency analysis, deviations from this frontier are typically interpreted as evidence of managerial weakness, technological inadequacy, poor input allocation, or limited access to institutions and resources (Mwalupaso et al., 2019; Ngango & Hong, 2021; Zhao & Barry, 2014). This interpretation is useful when farmers operate under relatively complete markets, face similar technology sets, and pursue production or profit maximization as their primary objective. Yet these conditions are rarely fulfilled in smallholder agriculture, where production decisions are embedded within household constraints, incomplete markets, and pervasive uncertainty. In such contexts, the frontier may represent a technically feasible maximum, but not necessarily the welfare-relevant optimum for the household.

The core problem lies in the separability assumption that underpins much of the production-centered efficiency paradigm. By treating the farm as an independent production unit, frontier models often abstract from the household processes that govern input use, labor allocation, and risk-bearing. Under a separable framework, labor is valued at an external market wage, capital can be adjusted freely, and households are assumed to respond to input-output prices in ways that approximate profit-maximizing firms. Yet the literature on smallholder agriculture repeatedly demonstrates that these assumptions are fragile. Labor markets may be thin or incomplete, family labor may not be fully tradable, credit may be rationed, and production risks may be imperfectly insured (Fauzan, Syaukat, et al., 2025b; Gourlay & Kilic, 2023; Merfeld, 2023; Seymour, 2017). Consequently, production cannot be meaningfully interpreted apart from the household that organizes, finances, and absorbs the consequences of farming decisions.

This limitation generates what can be called the production-centered illusion of farm efficiency. Farmers who operate below an estimated frontier are classified as inefficient, even when their production choices may be rational responses to constraints that the model does not fully represent. Efficiency measures may therefore conflate technical inefficiency with risk management, liquidity preservation, labor scarcity, or institutional exclusion. As highlighted in the draft argument, what is measured in many cases is not inefficiency per se, but the distance between observed behavior and an idealized model that abstracts away from the actual decision environment faced by farmers . The issue is not simply that efficiency estimates may be empirically imperfect, but that the underlying benchmark may misrepresent the objective function and constraint set of the household.

The role of the household is central to this critique. In smallholder systems, production decisions are inherently connected to labor allocation, consumption smoothing, liquidity management, and risk exposure. Household composition, access to off-farm income, gendered labor roles, and intra-household bargaining have been shown to influence input use, production intensity, and technology adoption (Fauzan, Syaukat, et al., 2025a; Mobarok et al., 2021; Tesema, 2022). Labor, in particular, cannot always be assigned a fixed market opportunity cost. Where labor

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markets are incomplete or unreliable, the value of family labor emerges endogenously from competing household needs, seasonal demands, care responsibilities, and alternative livelihood opportunities. Thus, lower input intensity or conservative production behavior may reflect a rational allocation of scarce household resources rather than managerial failure.

This interpretation becomes even more important under conditions of technological and environmental heterogeneity. Metafrontier studies show that farmers often operate under different feasible technology sets, shaped by variations in land quality, resource endowments, agroecological conditions, institutional access, and production systems (Gourlay & Kilic, 2023; Gwebu & Matthews, 2018; Melo-Becerra & Orozco-Gallo, 2016). When farmers are compared against a single frontier, measured inefficiency may partly reflect differences in attainable frontiers rather than deviations from an achievable optimum. Institutional factors such as access to credit, cooperatives, extension services, and information systems further shape measured efficiency, indicating that technical efficiency is not purely a technical attribute but a relational outcome mediated by socio-economic structures (Abate et al., 2014; Zhao & Barry, 2014). A universal frontier may therefore simplify comparison, but it can also obscure the differentiated realities within which smallholders make decisions.

Evidence from high-risk and resource-constrained agricultural systems reinforces this reinterpretation. In sandy coastal farming systems, for example, farmers may adopt input strategies that deviate from yield-maximizing recommendations, not because they fail to understand production technology, but because they must manage climatic uncertainty, price volatility, labor constraints, and income stability. From a conventional efficiency perspective, such behavior is often interpreted as underutilization of productive potential, whereas a household-centered lens reveals it as a rational adaptation to uncertainty and constraint (Fauzan, Syaukat, et al., 2025a). Similar insights from risk-based and metafrontier studies suggest that farmers may deliberately reduce input intensity or avoid full intensification to limit exposure to production shocks, thereby prioritizing resilience over maximum output (Gwebu & Matthews, 2018; Melo-Becerra & Orozco-Gallo, 2016; Mwalupaso et al., 2019; Nkurunziza et al., 2022).

Taken together, these arguments suggest that farm efficiency should not be interpreted solely as proximity to a production frontier. The production-centered paradigm remains valuable for measuring input-output performance, but it becomes analytically incomplete when treated as a universal measure of optimality. In smallholder agriculture, observed production outcomes are shaped not only by technology and management, but also by household objectives, labor constraints, market imperfections, institutional access, and risk environments. The illusion of farm efficiency emerges when rational, constraint-consistent behavior is misclassified as inefficiency because the analytical framework ignores the household decision system behind production choices. Recognizing this illusion is the necessary first step toward reframing inefficiency not as a simple failure to reach the frontier, but as a possible equilibrium outcome of constrained household optimization.

### 3.2. Non-Separability And Household-Constrained Optimization

The critique of production-centered efficiency becomes more compelling when the non-separable nature of smallholder decision-making is explicitly recognized. In conventional efficiency analysis, production decisions are often evaluated as if they can be separated from household consumption, labor allocation, and risk management. This assumption offers analytical convenience, but it becomes problematic in smallholder systems where the household functions simultaneously as a production unit, consumption unit, labor allocator, and risk-bearing institution. Under such conditions, farming decisions cannot be reduced to input-output optimization alone because they are embedded within a broader household decision system shaped by multiple objectives and binding constraints.

The agricultural household model provides the theoretical basis for this reinterpretation. Unlike the canonical separable model, where production and consumption decisions can be analyzed independently under complete markets, non-separable models recognize that market imperfections create direct linkages among what households produce, consume, and allocate as labor. When credit markets are incomplete, labor markets are missing or imperfect, and production risk cannot be fully insured, households must make production, consumption, and labor decisions within a unified allocation framework (Christopoulos et al., 2021; Deininger et al., 2008; Petrick, 2005). In this setting, input choices are not merely technical responses to prices, but household allocation decisions shaped by the need to balance income generation, consumption stability, labor availability, liquidity, and exposure to risk.

A central implication of non-separability concerns the valuation of family labor. In a separable production model, labor has an exogenous opportunity cost, usually represented by the market wage. In smallholder agriculture, however, family labor often does not move freely between farm and non-farm activities because labor markets are seasonal, incomplete, uncertain, or socially constrained. The opportunity cost of labor therefore emerges endogenously within the household as a shadow wage that reflects internal trade-offs across farm work, off-farm employment, domestic responsibilities, care work, leisure, and risk management. This is why observed labor use

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may appear inefficient from a production frontier perspective while remaining consistent with household-level optimization.

Empirical evidence strongly supports this non-separable interpretation. Household characteristics such as demographic composition, access to off-farm income, gendered labor roles, and intra-household bargaining systematically influence input use, production intensity, technology adoption, and measured efficiency (Mobarok et al., 2021; Seymour, 2017; Tesema, 2022). These findings show that farm performance is not determined by technology and prices alone, but by how households organize labor, capital, and risk across competing needs. Evidence from coastal farming systems in Indonesia also shows that technology adoption and economic exit decisions are shaped by household-level constraints and structural conditions rather than by profitability considerations alone (Fauzan, Marbudi, et al., 2025; Fauzan, Syaukat, et al., 2025a, 2025b). Such evidence reinforces the view that production outcomes reflect the joint solution to a multi-dimensional household optimization problem rather than the maximization of a single production objective. The source manuscript also frames production decisions as embedded in labor allocation, consumption smoothing, and risk management, rather than as isolated technical choices.

Non-separability also changes the interpretation of input underutilization. From a production-centered perspective, lower-than-recommended input use is often interpreted as technical inefficiency, managerial weakness, or insufficient adoption of available technology. From a household-centered perspective, however, the same behavior may reflect a rational attempt to preserve liquidity, reduce exposure to production risk, or accommodate labor constraints. Farmers may avoid full intensification not because they fail to understand production technology, but because intensification increases cash requirements, labor demand, and vulnerability to climatic or price shocks. Under uncertainty, conservative input use can therefore be consistent with household welfare maximization even when it reduces measured technical efficiency.

Risk management is particularly important in explaining why production choices may deviate from frontier-based expectations. Smallholder households often operate in environments where weather variability, pest pressure, input price fluctuations, and output price uncertainty create substantial downside risk. In such settings, maximizing expected output is not equivalent to maximizing household welfare. A household may prefer a production strategy that yields lower average output but reduces income variability, protects consumption, and preserves flexibility. Studies on farmer behavior under risk show that input underutilization, diversification, and conservative production strategies can be deliberate choices aimed at stabilizing income and reducing vulnerability (Deininger et al., 2008; Foster & Rausser, 1991; Khan & Iqbal, 2022). This logic is consistent with the argument that crop choice and input intensity are often shaped by strategies to reduce income variability rather than to maximize expected output, particularly in high-risk environments.

The role of off-farm income further illustrates the logic of household-constrained optimization. In many rural settings, off-farm income does not necessarily replace farming. It may instead complement farming by relaxing liquidity constraints, stabilizing income, and enabling households to maintain agricultural activity while reducing exposure to farm-specific shocks. At the same time, off-farm employment can reduce the availability of family labor for farm operations, thereby affecting input use, production intensity, and crop choice. This dual effect means that off-farm income can simultaneously support and constrain agricultural production. A production frontier model that treats labor allocation as a purely technical input decision may fail to capture this household-level balancing process.

Gendered decision-making and intra-household bargaining add another layer to the non-separability of agricultural production. Studies on women's empowerment and agricultural productivity show that intra-household authority, control over resources, and gendered labor responsibilities influence production outcomes and measured efficiency (Mobarok et al., 2021; Seymour, 2017). These effects do not imply that previous household decisions were irrational or technically deficient. Rather, they reveal that efficiency outcomes depend on who controls resources, who provides labor, who bears risk, and whose preferences shape production decisions. When household objectives are plural and negotiated internally, the resulting production plan may differ from the frontier-maximizing behavior assumed in standard efficiency models.

Household-constrained optimization therefore reframes farm performance as the result of a joint decision process rather than a purely technical outcome. Production choices emerge from the allocation of labor, capital, time, liquidity, and risk-bearing capacity across multiple objectives, including output generation, consumption smoothing, resilience, labor feasibility, and long-term livelihood security. The farm is not an isolated production function, but one component of a wider household system. Efficiency analysis that ignores this structure risks mistaking rational allocation under constraint for technical failure.

If production choices are non-separable from household decisions, deviations from a production frontier cannot automatically be interpreted as suboptimal behavior. They may represent equilibrium outcomes within a

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constrained household system, where farmers choose feasible production plans that balance expected returns, labor availability, liquidity, consumption needs, and risk exposure. This interpretation provides the basis for the next subsection, which develops the central proposition that what is commonly labeled as farm inefficiency may be better understood as rational equilibrium under constraints.

### 3.3. Inefficiency As Rational Equilibrium

Once the non-separable structure of smallholder decision-making is acknowledged, the interpretation of farm inefficiency must be fundamentally reconsidered. In conventional frontier analysis, inefficiency is defined as the distance between observed production and an estimated frontier, with the frontier implicitly treated as the relevant optimum. This interpretation assumes that farmers should move as close as possible to the maximum attainable output given available inputs and technology. However, when the household rather than the farm is treated as the relevant decision-making unit, the production frontier no longer represents the only meaningful benchmark. A household may deliberately choose a production plan below the estimated frontier if doing so better satisfies its broader welfare objectives under constraints.

This leads to the central proposition of this paper: what is conventionally labeled as farm inefficiency may, in many smallholder contexts, represent a rational equilibrium outcome. Inefficiency, in this sense, is not necessarily a deviation from optimal behavior, but the observed result of optimization within a constrained household system. Households choose production strategies by balancing expected output, income stability, labor availability, liquidity, risk exposure, consumption needs, and long-term livelihood security. Under such conditions, maximizing production is not equivalent to maximizing household welfare. The relevant question is therefore not simply why farmers fail to reach the frontier, but whether the frontier itself represents the objective that households are actually trying to achieve.

The logic of rational equilibrium is particularly clear under risk and uncertainty. Smallholder farmers frequently operate in environments characterized by rainfall variability, pest pressure, volatile output prices, rising input costs, and limited access to insurance. In such environments, the pursuit of maximum output may expose households to greater downside risk. A farmer who reduces fertilizer use, diversifies crops, avoids risky technology, or limits labor-intensive intensification may appear inefficient from a production frontier perspective, but such choices can be rational when the objective is to stabilize income and protect household consumption. Studies on farmer behavior under risk have long shown that input underutilization, diversification, and conservative production strategies may reflect deliberate efforts to reduce vulnerability rather than technical failure (Deininger et al., 2008; Foster & Rausser, 1991; Huang et al., 2018; Khan & Iqbal, 2022; Zeleke et al., 2021).

This interpretation is also consistent with the broader agricultural household literature, which shows that household decisions are shaped by interlinked production, consumption, and labor allocation considerations. When markets are incomplete, the shadow price of labor, capital, and risk is internally determined rather than externally given. Households therefore do not merely compare marginal products with market prices; they evaluate production choices against the internal constraints and needs of the household. Evidence from farm and non-farm labor studies shows that labor decisions influence household efficiency, not because farmers are necessarily technically weak, but because labor allocation itself is part of the household's optimization problem (Christopoulos et al., 2021). Likewise, credit constraints can reduce measured technical efficiency by limiting farmers' ability to adopt input-intensive production plans, even when those farmers are making rational choices under liquidity restrictions (Petrick, 2005; Zhao & Barry, 2014).

Institutional conditions further strengthen the equilibrium interpretation of inefficiency. Access to credit, cooperatives, extension services, information networks, and market infrastructure can alter measured efficiency by changing the feasible choice set faced by households (Abate et al., 2014; Ngango & Hong, 2021). If a household becomes more efficient after gaining access to credit or cooperative support, this does not necessarily imply that its previous behavior was irrational. It may simply indicate that the household's constraint set has changed. The same logic applies to information access, technology availability, and market integration. Efficiency is therefore not a purely technical property of the farm, but a relational outcome shaped by the interaction between household objectives and the institutional environment.

Gender and intra-household bargaining also complicate the interpretation of inefficiency. Empirical studies show that women's empowerment, control over resources, and household decision-making structures influence agricultural productivity and efficiency outcomes (Mobarok et al., 2021; Seymour, 2017). These findings suggest that measured inefficiency can reflect internal household arrangements, labor responsibilities, and resource control rather than purely technical shortcomings. From a household equilibrium perspective, production choices emerge from negotiated priorities within the household, where different members may value income, labor burden, risk exposure, food security, and time allocation differently. A production plan that appears inefficient under a single-

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objective model may be coherent when understood as the outcome of household bargaining and resource allocation.

The concept of rational equilibrium also helps explain why smallholders may maintain diversified or conservative farming systems despite lower measured technical efficiency. Diversification is often treated as a departure from specialization and, by implication, from maximum technical performance. However, diversification can reduce income variability, secure food access, spread labor demand across seasons, and protect households from crop-specific shocks. Evidence from production diversity and dietary quality studies shows that farm diversification is linked to broader welfare outcomes beyond profit alone (Sibhatu & Qaim, 2018). Similarly, studies on livelihood diversification and off-farm employment show that households often combine farming with non-farm activities not to abandon agriculture, but to stabilize welfare under uncertainty (Barrett et al., 2001; Yitbarek & Tesfaye, 2022). In this context, lower technical efficiency in a particular enterprise may coexist with higher household-level resilience.

The same argument applies to technology adoption. Conventional efficiency analysis may interpret non-adoption or partial adoption as evidence of inefficiency, lack of information, or resistance to innovation. Yet household-level studies show that technology adoption is shaped by risk, labor requirements, capital constraints, and expected implications for household welfare (Fauzan, Marbudi, et al., 2025; Fauzan, Syaukat, et al., 2025a). A technology that increases output may also increase labor demand, cash exposure, management complexity, or vulnerability to climate and price shocks. Under these conditions, partial adoption or delayed adoption may be a rational equilibrium response rather than an inefficient deviation. The relevant analytical question is not whether farmers adopt the technically superior option, but whether adoption improves household welfare under the constraints they actually face.

This perspective resonates with the argument developed in the paper on invisible utility, which shows that farm household behavior is often guided by a multidimensional utility structure rather than by income or profit alone. In that framework, household decisions are shaped not only by monetary returns, but also by risk, autonomy, social embeddedness, land attachment, and psychological security (Ambrey et al., 2017; Rao, 2017; Terefe et al., 2024). Although the present paper focuses on efficiency rather than non-monetary utility, both arguments share a common theoretical foundation: observed farmer behavior should be interpreted through the household's objective function rather than through a narrow external benchmark. A production outcome that appears inefficient may still be consistent with the household's broader welfare calculus.

Reframing inefficiency as rational equilibrium does not imply that all measured inefficiency is desirable or that technical inefficiency is irrelevant. Some deviations from the frontier may indeed result from poor management, lack of knowledge, inadequate input use, or weak institutional support. The point is that frontier deviation should not automatically be equated with irrationality or suboptimal behavior. A more careful interpretation requires distinguishing between avoidable technical inefficiency and rational constraint-driven divergence from the frontier. This distinction is crucial because the policy response to each condition differs. If inefficiency reflects lack of knowledge, extension may be appropriate. If it reflects liquidity constraints, credit access may matter. If it reflects risk exposure, insurance and stabilization mechanisms may be more relevant. If it reflects household labor constraints, technology that saves labor may be more welfare-enhancing than technology that simply raises output.

The equilibrium interpretation therefore shifts the meaning of efficiency from proximity to a production frontier toward coherence between household objectives, constraints, and observed choices. A farm may appear technically inefficient while still representing an internally consistent allocation of household resources. In this sense, the frontier is not rejected, but relativized. It remains useful as a measure of production potential, but insufficient as a measure of household optimality. Efficiency must be interpreted in relation to the decision environment in which households operate, including incomplete markets, endogenous shadow wages, risk exposure, institutional access, and livelihood objectives.

This reinterpretation provides the conceptual core of the paper. Farm inefficiency should not be understood only as failure to reach a technical frontier, but as a possible equilibrium outcome produced by rational household choices under constraints. The real analytical task is to identify when observed inefficiency reflects technical failure and when it reflects welfare-consistent adaptation. This distinction allows agricultural economics to move beyond a purely production-centered reading of farm performance and toward a more realistic household-centered understanding of smallholder behavior.

### 3.4. Beyond Frontier Metrics: Implications For Research And Policy

The reinterpretation of farm inefficiency as rational equilibrium has important implications for how agricultural performance should be measured, explained, and translated into policy. Frontier-based metrics remain valuable for identifying gaps in observed production performance, comparing farms, and detecting potential sources of

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productivity loss. However, their interpretive power becomes limited when they are treated as complete indicators of household optimality. In smallholder agriculture, technical efficiency estimates should not be read as neutral measures of farmer competence without considering the decision environment in which production takes place. A farm may appear inefficient relative to a production frontier while still representing a coherent allocation of household labor, capital, liquidity, and risk-bearing capacity.

For research, the first implication is the need to distinguish between technical inefficiency and constraint-consistent behavior. Conventional frontier analysis often treats all deviations from the frontier as inefficiency, yet such deviations may arise from incomplete labor markets, credit rationing, risk exposure, institutional limitations, or household-level labor constraints (Christopoulos et al., 2021; Petrick, 2005; Zhao & Barry, 2014). The analytical challenge is therefore not merely to estimate the size of the efficiency gap, but to interpret its source. A low technical efficiency score may indicate poor management or technological weakness, but it may also reflect rational adaptation to binding constraints. Without this distinction, empirical research risks converting symptoms of structural limitation into judgments about farmer behavior.

This calls for a more household-sensitive approach to efficiency analysis. Technical efficiency models should be complemented by variables and frameworks that capture household composition, labor availability, off-farm income, liquidity constraints, gendered decision-making, risk exposure, and access to institutions. Studies on women's empowerment and agricultural productivity demonstrate that household bargaining and control over resources shape efficiency outcomes (Mobarok et al., 2021; Seymour, 2017). Similarly, evidence on credit constraints and cooperative participation shows that institutional access affects measured efficiency by reshaping the feasible choices available to farmers rather than simply improving technical ability (Abate et al., 2014; Zhao & Barry, 2014). In this perspective, efficiency is not only a function of production technology, but also an outcome of the household's constraint set and institutional embeddedness.

A second research implication concerns the use of metafrontier and heterogeneous frontier approaches. Metafrontier models have improved the analysis of efficiency by recognizing that farmers may operate under different technology sets due to variations in agroecology, resource endowments, infrastructure, and institutional access (Gourlay & Kilic, 2023; Melo-Becerra & Orozco-Gallo, 2016; Taramuel-Taramuel et al., 2023). This is an important advance because it challenges the assumption that all farmers should be compared against a single universal frontier. However, even metafrontier approaches remain insufficient if heterogeneity is interpreted only as technological difference. Smallholders may face different feasible frontiers not only because of technology or environment, but also because household labor, liquidity, gender relations, risk tolerance, and livelihood priorities differ across households. Frontier heterogeneity must therefore be understood as both technical and behavioral.

Future research should also place greater attention on shadow prices and implicit constraints. In smallholder systems, the market wage may not accurately represent the opportunity cost of family labor, and observed input prices may not reflect the true cost of liquidity-constrained input use. The shadow price of labor, capital, and risk is often internally determined by household conditions. Empirical models that ignore these endogenous valuations may overstate inefficiency by assuming that farmers face the same prices, constraints, and adjustment capacities. Integrating shadow wage estimation, labor allocation models, risk preference measures, and household decision variables into efficiency analysis would improve the ability to distinguish avoidable inefficiency from rational constraint-driven divergence from the frontier (Christopoulos et al., 2021; Deininger et al., 2008; Petrick, 2005).

The implication extends beyond econometric specification. Research on farm efficiency should increasingly adopt a multidimensional interpretation of performance. Output maximization and cost minimization remain important, but smallholder welfare also depends on income stability, consumption smoothing, food security, resilience, autonomy, and livelihood continuity. Evidence from production diversity and dietary quality studies shows that farming choices may generate welfare outcomes that are not captured by profit or output alone (Sibhatu & Qaim, 2018). Studies on rural welfare, resilience, and multidimensional poverty similarly indicate that household well-being cannot be reduced to monetary indicators, especially in contexts of climate variability and institutional vulnerability (Giwa-Daramola & James, 2023; Khosla, 2025; Terefe et al., 2024). This suggests that farm performance should be evaluated not only in terms of productive efficiency, but also in terms of its contribution to household stability and adaptive capacity.

The interpretation of efficiency also needs to be situated within a broader household welfare framework. Farm household decisions may reflect not only monetary returns, but also non-monetary considerations such as identity, autonomy, land attachment, psychological security, and resilience, all of which interact with income, risk, and resource constraints. From this perspective, efficiency metrics become analytically incomplete when they ignore the wider welfare space within which household decisions are made. A farmer who maintains a less intensive or less specialized production system may not be technically maximizing output, but may be preserving flexibility, food access, labor control, autonomy, or livelihood stability. This does not reject efficiency analysis; rather, it

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strengthens its interpretation by locating production performance within the broader objectives and constraints of the farm household.

For policy, the implications are substantial. Many agricultural interventions are designed around the objective of closing efficiency gaps. Such interventions often promote input intensification, improved seed adoption, mechanization, credit expansion, or extension services with the expectation that farmers will move closer to the production frontier. These policies can be highly valuable when inefficiency reflects lack of access, weak information, or technological barriers. However, if measured inefficiency reflects rational responses to risk, liquidity constraints, labor scarcity, or household priorities, then policies that push farmers toward the frontier may fail to improve welfare. They may even increase vulnerability if they raise cash exposure, labor burden, or dependence on uncertain markets.

A household-centered policy approach should therefore begin by diagnosing why farmers appear inefficient. If the main constraint is liquidity, credit and savings instruments may be appropriate. If the constraint is risk, insurance, price stabilization, climate services, or risk-reducing technologies may matter more than input intensification. If the constraint is labor scarcity, labor-saving technologies may generate greater welfare benefits than yield-increasing technologies that require more labor. If inefficiency reflects gendered constraints or unequal control over resources, interventions must address intra-household decision-making and empowerment rather than assuming that technical training alone will solve the problem (Arora & Rada, 2020; Bryan & Garner, 2022; Malapit et al., 2019; Mobarok et al., 2021).

This perspective also changes how technology adoption policies should be evaluated. Non-adoption or partial adoption should not automatically be interpreted as backwardness, resistance, or inefficiency. Technologies that increase output may also increase risk, labor requirements, input dependence, or management complexity. Household-level studies in coastal farming systems show that adoption, labor allocation, and economic exit decisions are shaped by structural and behavioral conditions embedded within the household, not merely by profitability considerations (Fauzan, Marbudi, et al., 2025; Fauzan, Syaukat, et al., 2025b). A technology is not truly efficient for a smallholder household unless it improves performance within the household's actual constraint set and welfare objectives.

Policy evaluation frameworks should therefore move beyond technical efficiency scores as standalone indicators of success. Conventional impact assessments that focus on yield, productivity, or efficiency gains may overlook whether interventions improve household resilience, reduce downside risk, preserve consumption, or ease labor constraints. Indicators such as income stability, vulnerability reduction, labor burden, food security, subjective well-being, and perceived security can complement frontier-based metrics and provide a more complete picture of policy outcomes (Ambrey et al., 2014; Terefe et al., 2024; Welsch & Kühling, 2009). Such an approach is especially important in marginal, climate-exposed, and resource-constrained farming systems where maximum output is not always the most welfare-enhancing objective.

The policy message is not that productivity and efficiency should be abandoned. Smallholder agriculture still requires productivity improvement, better technology, stronger institutions, and more efficient resource use. The point is that efficiency-enhancing interventions must be designed around household realities rather than abstract production frontiers. Policy should expand the feasible choice set of households by reducing constraints, lowering risk, improving market access, strengthening institutional support, and enabling farmers to choose production strategies that are both technically feasible and welfare-enhancing. The objective is not simply to push farmers toward a predefined frontier, but to create conditions under which higher productivity becomes compatible with household resilience and well-being.

This reframing opens a more careful agenda for future research and policy. Frontier metrics should be used as diagnostic tools, not final judgments. They can reveal where performance gaps exist, but they cannot fully explain why those gaps emerge or whether closing them would improve household welfare. Agricultural economics needs efficiency analysis that is technically rigorous, institutionally grounded, and behaviorally realistic. In smallholder systems, the question is no longer only how far farmers are from the frontier, but whether the frontier represents the decision problem they actually face.

## 4. Conclusion

This paper has argued that farm inefficiency in smallholder agriculture cannot be adequately understood through frontier-based metrics alone. While stochastic frontier analysis, data envelopment analysis, and related approaches remain valuable for measuring production performance, their interpretation becomes incomplete when deviations from the frontier are automatically treated as evidence of suboptimal farmer behavior. In smallholder systems, production decisions are embedded within household processes involving labor allocation, consumption smoothing, liquidity management, risk exposure, and institutional constraints. Under such conditions, lower

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measured technical efficiency may reflect not managerial failure, but a rational response to the actual decision environment faced by farm households. The central contribution of this paper is the reinterpretation of farm inefficiency as a possible rational equilibrium outcome of constrained household optimization. When production, consumption, and labor allocation are non-separable, the relevant benchmark is not merely proximity to a production frontier, but coherence between household objectives, constraints, and observed choices. Conservative input use, diversification, partial technology adoption, or lower production intensity may be consistent with welfare-maximizing behavior when households must balance expected returns against risk, labor availability, liquidity constraints, and livelihood security. This perspective does not deny the existence of technical inefficiency, but it cautions against treating all frontier deviations as irrational or avoidable. This reinterpretation has important implications for future research and policy. Empirical studies should complement frontier estimates with household-level variables, including shadow wages, risk preferences, labor constraints, credit access, gendered decision-making, and livelihood objectives. Policy interventions should likewise move beyond the narrow objective of closing efficiency gaps and instead focus on expanding the feasible choice set of smallholder households. Productivity improvement remains important, but it must be pursued in ways that reduce risk, relax binding constraints, and strengthen household welfare. In this sense, the real analytical challenge is not only to identify how far farmers are from the frontier, but to understand whether that frontier represents the decision problem they actually face.

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