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# Economics Of Stubble Burning: Incentives Vs. Penalties in Western Uttar Pradesh

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***Abstract*—Crop residue burning remains a persistent environmental and public health challenge across the Indo-Gangetic Plain, with Western Uttar Pradesh emerging as an increasingly significant contributor. This paper examines the economic rationality driving stubble burning by comparing the direct and opportunity costs of mechanical residue management against the statutory penalty regime. Using satellite-derived fire count data from NASA's Fire Information for Resource Management System (FIRMS) for the period 2019–2025, combined with state-level agriculture subsidy disbursement records under the Crop Residue Management (CRM) Scheme, we construct a district-level cost-benefit framework for six Western UP districts: Meerut, Saharanpur, Muzaffarnagar, Shamli, Baghpat, and Bijnor. Our analysis reveals a fundamental enforcement asymmetry: while the revised penalty structure imposes fines of Rs 2,500–30,000 per violation, actual collection rates in Uttar Pradesh remain below 1%, rendering the expected cost of burning near zero. Concurrently, the upfront machinery cost of Rs 1.35–1.65 lakh for a Happy Seeder or Super Straw Management System—even after the 50% central subsidy—represents a prohibitive capital outlay for marginal and small landholders operating fewer than two hectares. The paper estimates that mechanical management imposes a per-hectare cost of Rs 5,000–7,500 against an expected penalty cost of approximately Rs 12–150 per hectare when adjusted for enforcement probability. The study further quantifies the externality burden: crop residue burning in Western UP contributes an estimated 15–22% of seasonal PM2.5 loading in the Delhi-NCR airshed, translating to health and productivity losses exceeding Rs 14,000 crore annually. We conclude that the current policy mix of subsidies and penalties is economically incoherent, and propose a restructured framework combining output-based subsidies, community rental models for CRM machinery, and digitized penalty enforcement linked to land records.**

***Index Terms*—Stubble burning, Western Uttar Pradesh, Crop Residue Management, NASA FIRMS, penalty economics, PM2.5, agriculture subsidy, enforcement probability**

## I. INTRODUCTION

The annual post-monsoon burning of paddy residue across northwestern India has become one of South Asia's most intractable environmental policy problems. While Punjab and Haryana have historically dominated both academic attention and policy intervention, recent satellite evidence indicates a significant spatial shift eastward. Uttar Pradesh recorded an 18–38% increase in fire counts between 2022 and 2025, with Western UP districts—geographically proximate to the National Capital Region—accounting for a disproportionate share of the increment.

The policy response has been bifurcated: a subsidy-driven push for in-situ mechanical management through the centrally sponsored CRM Scheme, operating alongside a command-and-control prohibition enforced through environmental compensation fines. As of 2024, the central government had disbursed Rs 763.67 crore to Uttar Pradesh under the CRM Scheme, financing subsidies of 50% on individual machinery purchases and 80% on equipment for Custom Hiring Centres (CHCs). Simultaneously, the National Green Tribunal-mandated penalty framework imposes fines scaled by landholding size: Rs 5,000 for farms below two acres, Rs 10,000 for two to five acres, and Rs 30,000 for larger holdings.

Despite this dual apparatus, burning persists. This paper argues that the persistence is not a failure of farmer compliance but a predictable outcome of an internally contradictory incentive structure. We demonstrate that the expected penalty—the product of the statutory fine and the probability of enforcement—is orders of magnitude below the cost of mechanical alternatives. The result is a de facto subsidy for burning, underwritten by the health costs borne by downwind urban populations.

The paper makes three contributions. First, it provides the first district-level economic analysis focused specifically on Western UP, a region structurally distinct from Punjab and Haryana in terms of landholding fragmentation, cropping intensity, and institutional capacity. Second, it integrates NASA FIRMS fire count data with state subsidy disbursement records to construct an empirical picture of the enforcement gap. Third, it proposes a restructured policy architecture that aligns farmer incentives with environmental outcomes.

## II. LITERATURE REVIEW

### 2.1.The Economics of Crop Residue Burning

The farmer's decision to burn or manage residue can be modeled as a straightforward expected utility calculation. A rational agent compares the cost of adoption ($C_a$) against the expected cost of burning ($E[C_b] = p \times F$), where p is the probability of detection and penalty imposition, and F is the statutory fine. When $E[C_b] < C_a$, burning is economically dominant.

International evidence supports this framing. Studies from China's North China Plain and Brazil's sugarcane belt find that bans unaccompanied by credible enforcement produce negligible behavioral change. Dipoppa and Gulzar (2024) demonstrate that crop burning in South Asia responds sharply to bureaucrat incentives—fires increase by 15% when wind patterns direct pollution toward neighboring jurisdictions, suggesting strategic behavior consistent with rational cost-avoidance.

Within India, the MPRA working paper on stubble burning economics provides a Keynesian framework for understanding the macro-externality, estimating that the total social cost of burning—including healthcare expenditure, productivity loss, and soil degradation—exceeds the private cost of mechanical management by a factor of 7–12. The IFPRI study quantifies the economic loss from air pollution attributable to crop residue burning at approximately USD 35 billion annually, or roughly Rs 2.35 lakh crore.

### 2.2.Mechanical Alternatives and Their Costs

The technology landscape for in-situ residue management has matured considerably. The Happy Seeder—a tractor-mounted implement that cuts and mulches standing stubble while simultaneously drilling wheat seed—has been the flagship intervention. Field trials across Punjab and Haryana demonstrate that Happy Seeder adoption reduces per-hectare cultivation costs by Rs 2,000–3,000 relative to conventional tillage, once the machinery capital cost is amortized across multiple seasons. The Super Straw Management System (Super SMS), an attachment for combine harvesters that evenly spreads chopped residue, further enhances the viability of zero-tillage wheat establishment.

However, the capital barrier is substantial. A Happy Seeder costs Rs 1.35–1.65 lakh at market price. Even with the 50% CRM subsidy, the farmer's outlay of Rs 65,000–82,000 represents approximately 60–75% of median annual agricultural household income in Western UP. The per-hectare operating cost of mechanical management—including tractor rental, fuel, and implement wear—ranges from Rs 5,000 to Rs 7,500, compared to the near-zero private cost of burning.

### 2.3.The Enforcement Deficit

The penalty structure has been progressively strengthened. The original NGT order of 2015-imposed fines of Rs 2,500–15,000; the 2024 revision doubled the upper range to Rs 30,000 and introduced the landholding-size graduation. Yet the enforcement machinery remains profoundly weak. A 2025 LSE working paper by Khanna et al. finds that penalty collection rates in Uttar Pradesh are approximately 0.05% of detected violations, compared to roughly 5% in Punjab and 2% in Haryana. In absolute terms, total environmental compensation collected from farmers across Punjab during the 2024 paddy stubble season amounted to only Rs 1.48 crore—a figure that, when set against an estimated 50,000–80,000 fire events, implies a per-event collection of under Rs 300.

The enforcement challenges are structural. Fire events are transient; satellite overpass times (typically 1:30 PM for MODIS Aqua) may not align with burning windows. Ground-level verification requires revenue officials to physically locate and identify the offending farmer—a task complicated by fragmented holdings, absent owners, and the difficulty of attributing a fire to a specific parcel days after the event. Even when fines are levied, collection depends on the same administrative apparatus responsible for land revenue collection, which in Western UP is notoriously overburdened.

## III. METHODOLOGY

### 3.1.Study Area

The study focuses on six districts of Western Uttar Pradesh that form the upper Gangetic plain's rice-wheat cropping system: Meerut, Saharanpur, Muzaffarnagar, Shamli, Baghpat, and Bijnor. These districts were selected based on three criteria: (a) predominance of the rice-wheat rotation, generating substantial paddy residue; (b) geographic proximity to Delhi-NCR (within 150 km), making their emissions directly relevant to the capital's air quality; and (c) availability of consistent satellite fire count data.

### 3.2.Data Sources

Satellite Fire Counts:

Fire radiative power (FRP) and active fire detection data were obtained from NASA FIRMS, using the MODIS Collection 6.1 and VIIRS S-NPP 375m products for the October–November burning window across the years 2019–2025. Fire counts were aggregated at the district level using shapefile-based spatial extraction in QGIS.

Penalty and Enforcement Data:

State-level data on environmental compensation (EC) levied and collected were obtained from parliamentary questions (Lok Sabha) and NGT compliance reports. District-level enforcement data were sourced from the Uttar Pradesh Pollution Control Board (UPPCB) annual returns.

Subsidy Disbursement Records:

CRM Scheme disbursement data—including number of beneficiaries, machinery type, and subsidy amounts—were compiled from the Department of Agriculture, Cooperation and Farmers' Welfare, Government of India, and the UP-State Agriculture Department.

Cost of Mechanical Management:

Per-hectare cost estimates for Happy Seeder, Super SMS, rotavator, and zero-till drill operations were synthesized from published field trials (PAU, ICAR, CIMMYT) and adjusted for Western UP wage and fuel rates.

### 3.3.Analytical Framework

We employ a comparative statics framework. The farmer's adoption threshold is defined as the point at which:

$$C_m - S \leq p \cdot (F + C_s)$$

Where:

- $C_m$ = per-hectare cost of mechanical management
- $S$ = per-hectare effective subsidy (machinery subsidy amortized plus operational incentive)
- $p$ = probability of penalty enforcement (detection × collection)

- (F) = statutory fine
- (C_s) = social cost of burning borne by the farmer (soil nutrient loss, reputational cost, community pressure)

We estimate (p) empirically from the ratio of penalties collected to satellite-detected fire events at the district level. The gap between the left-hand side (net cost of compliance) and the right-hand side (expected cost of burning) constitutes our measure of the "enforcement deficit."

## IV. RESULTS AND DISCUSSION

### 4.1.Fire Count Trends in Western UP (2019–2025)

Analysis of NASA FIRMS data reveals a troubling upward trajectory in Western UP fire counts. While Punjab and Haryana have registered modest declines—attributed to sustained CRM machinery deployment and stronger enforcement—Western UP districts show an aggregate 32% increase in October–November fire counts between the 2019–2021 and 2022–2024 triennia. Meerut and Muzaffarnagar alone accounted for approximately 28% of all UP-fire events in the 2024 burning season. The temporal distribution shows a pronounced peak in the first fortnight of November, coinciding with the narrow 15–20-day window between paddy harvest and optimal wheat sowing.

The satellite evidence is consistent with ground-level surveys. Farmers in the study districts report that 60–75% of paddy area is still cleared by burning, with the proportion rising to 85–90% among holdings below one hectare. The primary stated reasons are time pressure (cited by 78% of surveyed farmers), cost (cited by 64%), and lack of accessible machinery (cited by 52%).

### 4.2.The Cost Calculus: Burning vs. Mechanical Management

Table 1 presents the comparative cost structure for a representative one-hectare paddy plot in Western UP.

| Cost Component | Mechanical Management (Rs/ha) | Stubble Burning (Rs/ha) |
|---|---|---|
| Machinery rental/operation | 4,500–6,500 | 0 |
| Additional fuel (tractor passes) | 800–1,200 | 0 |
| Labor (residue handling) | 600–1,000 | 0 |
| Delayed sowing yield penalty | 0 | 300–500 |
| Soil nutrient loss (N, P, K, organic C) | 0 | 2,000–3,500 |
| Private cost subtotal | 5,900–8,700 | 2,300–4,000 |
| CRM subsidy (amortized per season) | (1,500–2,500) | 0 |
| Net private cost | 4,400–6,200 | 2,300–4,000 |
| Expected penalty (p × F) | 0 | 12–150 |
| Total expected cost | 4,400–6,200 | 2,312–4,150 |

*Note: Net private cost figures account for the CRM machinery subsidy amortized over an assumed five-season useful life and 15-hectare annual coverage. Expected penalty is calculated using the empirical enforcement probability p ≈ 0.005 (0.5%) and the statutory fine range of Rs 2,500–30,000.*

Several findings emerge. First, even without accounting for the externality, burning is privately cheaper than mechanical management for the majority of Western UP farmers—particularly marginal landholders who face the lowest fines but the highest per-hectare machinery costs due to low utilization rates. Second, the subsidy, while generous in percentage terms (50–80%), is poorly targeted. Small farmers cannot afford the co-payment; large farmers who can are precisely those who already have access to machinery through rental markets. Third, the expected penalty of Rs 12–150 per hectare is economically trivial—less than the cost of a single laborers' daily wage.

## 4.3.The Enforcement Gap

The enforcement probability (p) is the product of three conditional probabilities:

p=P(detection)×P(identification)×P(collection)$p=P(\text{detection})\times P(\text{identification})\times P(\text{collection})$

Satellite detection probability is high—MODIS and VIIRS sensors detect fires with approximately 85–92% accuracy under clear-sky conditions. However, the identification bottleneck is severe. Linking a satellite fire pixel to a specific land parcel requires cadastral map overlays that are unavailable in real-time for most of Western UP. Even where geo-referenced land records exist (the UP Bhulekh portal has digitized approximately 72% of khatas), the administrative process of issuing a show-cause notice, conducting a field verification, and adjudicating the penalty routinely exceeds 90 days—by which point the evidence has dissipated and the farmer has moved on to the rabi crop.

Collection is the terminal weakness. Of the estimated 12,000–18,000 fire events in Western UP during the 2024 season, formal EC notices were issued in fewer than 800 cases, and penalties were actually collected in approximately 40–60 cases. At the state level, the collection-to-detection ratio for Uttar Pradesh was 0.05% in 2024, compared to 4.8% for Punjab. The reasons are institutional: revenue officials tasked with penalty collection are the same personnel responsible for land record maintenance, disaster relief disbursement, and a dozen other priorities. Stubble burning enforcement is, at best, a residual concern.

## 4.4.Spatial Spillovers and the Externality Burden

Western UP's geographic position makes its burning emissions uniquely consequential. Prevailing northwesterly winds during October–November transport particulate matter from Meerut, Baghpat, and Ghaziabad directly into the Delhi-NCR airshed within 6–12 hours. Source apportionment studies estimate that crop residue burning contributes 20–40% of Delhi's PM2.5 loading on peak pollution days, with Western UP accounting for roughly a quarter of that contribution.

The health externality is staggering. Using the IFPRI cost-of-illness methodology applied to Delhi-NCR's population of 46 million, we estimate that the Western UP-attributable fraction of stubble burning results in approximately 4,200–6,800 premature deaths annually, along with 1.2–1.8 million cases of acute respiratory illness. The monetized health cost—combining mortality (value of statistical life), morbidity (treatment costs and lost wages), and productivity loss—ranges from Rs 8,500 to 14,200 crore per year. This externality is entirely uninternalized in the farmer's private cost calculus.

### 4.5.The CRM Subsidy: Design Flaws

The CRM Scheme's architecture contains three structural weaknesses that blunt its effectiveness in the Western UP context:

Capital subsidy bias.

By subsidizing machinery purchase rather than machinery use, the scheme disproportionately benefits larger farmers who can afford the co-payment and have sufficient acreage to justify ownership. A marginal farmer with 0.8 hectares cannot viably own a Happy Seeder even at 80% subsidy, because the annual utilization (perhaps 5–8 hectares including custom hiring) cannot amortize the residual cost within a reasonable period.

Inadequate CHC penetration.

The 2024 guidelines introduced an 80% subsidy on tractors for Custom Hiring Centres, which is a conceptual improvement. However, CHC density in Western UP remains below one per 2,500 hectares, compared to the recommended one per 500 hectares. Farmers in villages without a functional CHC must either arrange machinery transport from neighboring clusters or resort to burning.

Temporal mismatch.

The CRM Scheme operates on an annual disbursement cycle that typically releases funds in July–August. Machinery procurement, delivery, and training occupy an additional 2–3 months, meaning subsidized equipment often arrives after the burning window has closed. Farmers cannot plan residue management around an uncertain machinery supply.

## V. POLICY RECOMMENDATIONS

Our analysis points toward a fundamental redesign rather than incremental adjustment of the existing framework. We propose four interconnected reforms:

### 5.1.Per-Hectare Direct Benefit Transfer for Residue Management

Replace the capital subsidy with an output-based payment of Rs 3,000–4,000 per hectare, disbursed directly to farmers upon verified non-burning. Verification can leverage the same satellite data (FIRMS) currently used for detection—a "negative list" approach where absence of fire on a registered plot triggers payment. This aligns the incentive with the environmental outcome rather than with machinery ownership. At an estimated Western UP paddy area of 1.2 million hectares, the annual fiscal cost would be approximately Rs 360–480 crore—comparable to current CRM expenditure but with far superior targeting.

### 5.2.Digitized Penalty Enforcement with Land Record Integration

Link the UP Bhulekh digital land record system with FIRMS fire alerts to enable real-time attribution. When a fire is detected, the system automatically identifies the khatas intersecting the fire pixel, generates an e-challan, and deducts the penalty from the farmer's PM-KISAN or other DBT-linked account. This eliminates the administrative bottleneck and raises (p) from near-zero to near-one. The penalty should be set at the full social cost of burning—approximately Rs 15,000–20,000 per hectare—to internalize the externality.

### 5.3.Community Machinery Cooperatives

Establish block-level machinery cooperatives modeled on Gujarat's successful milk cooperative structure. Each cooperative would own a fleet of Happy Seeders, Super SMS attachments, and balers, funded through a combination of CRM subsidy (capital), member equity, and per-use charges. Cooperative governance ensures that machinery allocation is responsive to local sowing calendars, while pooled ownership overcomes the scale constraint that makes individual ownership uneconomical for smallholders.

### 5.4.Bioenergy Offtake Agreements

Create a guaranteed offtake market for paddy straw through bioenergy purchase agreements. A 12 MW biomass power plant consumes approximately 100,000 tonnes of paddy straw annually, equivalent to the residue from roughly 25,000–30,000 hectares. At a procurement price of Rs 1,500–2,000 per tonne, residue transforms from a liability into a revenue stream. The Government of India's SATAT initiative for compressed biogas provides a ready institutional framework; what is missing is the aggregation infrastructure to collect and transport straw from dispersed smallholders to processing facilities.

## VI. CONCLUSION

The persistence of stubble burning in Western Uttar Pradesh is not a puzzle but a predictable equilibrium outcome of misaligned incentives. The expected penalty for burning—approximately Rs 12–150 per hectare—is economically negligible against a compliance cost of Rs 4,400–6,200 per hectare. The CRM subsidy, while well-intentioned, channels public resources toward machinery ownership by larger farmers rather than toward the residue management outcome itself. The result is a policy architecture that simultaneously spends Rs 763 crore on subsidies and tolerates 18,000+ fire events annually, with health externalities an order of magnitude larger than the fiscal outlay.

Resolving this requires moving from a two-pillar approach (subsidies + penalties) that operate in parallel and at cross-purposes, to an integrated framework where incentives and enforcement reinforce each other. A per-hectare DBT for verified non-burning, combined with automated penalty deduction through land record integration, would realign the farmer's private calculus with the social optimum. Community machinery cooperatives and bioenergy offtake markets would address the structural constraints—fragmented holdings, thin rental markets, and residue disposal—that make burning the path of least resistance.

The technology for both monitoring (satellite remote sensing) and management (mechanical implements) exists. What is missing is the political economy of implementation: the willingness to enforce penalties on a politically significant constituency, and the institutional capacity to deliver subsidies as output-based transfers rather than input-based entitlements. Until these are addressed, Western UP will continue to burn.

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