CURBING CROP STUBBLE BURNING IN INDIA: A STRATEGIC POLICY INTERACTION

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Abstract

This paper aims to study government policy interventions for tackling the issue of crop stubble burning (CSB), a major contributor to air pollution in North India. This paper formalises farmer-government interactions around CSB, to comprehensively evaluation of different government policies' impacts on farmer behaviour. These interactions have been modelled as an extensive-form game, wherein n number of farmer-agents and the government react to the beliefs and actions of one another. This model demonstrates the unsustainability of monetary compensation as a long-run solution, and contrasts this with the persistence of the impacts of behavioural interventions.

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1. INTRODUCTION

Crop stubble-burning (CSB) is a serious policy problem faced by the North Indian states of Delhi, Haryana, Punjab, and Uttar Pradesh. In the months of October-November, farmers in these regions burn large quantities of rice paddy stubble, leftover on their fields post-harvesting. In Punjab alone, an estimated 15 million tonnes of rice stubble are burnt in a year.

The issue of CSB has plagued North India since the Green Revolution of the 1980s. Technological advancements allowed India to achieve self-sufficiency in foodgrain production. However, among other negative ecological fallouts, the Green Revolution led to the phenomenon of CSB.

Firstly, the Green Revolution promoted the adoption of modern implements like the combined harvester for harvesting the paddy crop. At present, in Punjab, around 80% of paddy is harvested using this implement (Kumar, Kumar & Joshi, 2015). However, the use of the combined harvester leaves large amounts of stubble as residue on the fields, as compared to manual harvesting. Secondly, whereas farmers in the region used to harvest a single crop, either wheat or rice, in an agricultural year, technological advancements allowed them to harvest their crops in shorter time-spans, allowing them to pursue two-crop yields in a year. In the short period before farmers can sow their wheat seeds for the rabi (winter) season, farmers find it most efficient—in terms of time and money—to simply burn the residue on their fields.

CSB is now a routine activity that farmers in this region perform yearly before the onset of winters. The main polluting effect caused by this practice is in the form of emissions of greenhouse gases and particulate matter. This has serious implications for air quality in North India. The poor state of affairs with respect to North India's air quality is reflected by New Delhi's pollution levels—with an AQI of 483, Delhi was the single-most polluted city in the world as of November 2023 (Kulkarni, 2023). It has been observed that the annual peak of Delhi's pollution levels coincides with the peak of CSB incidences, in October-November (Dahiya, 2022). Further, the particulate matter in Delhi generated by CSB is 17 times greater than that of other sources (Bhuvaneshwari, Hettiarachchi & Meegoda, 2019).

CSB lies at the intersection of various issues of sustainability, including good health, climate change, and life on land. At the core of the issue is the sustainability of agriculture as a livelihood, making it a pressing public policy question.

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The following section of this paper will review existing literature in academia and the news media. The third section will assess the policy responses adopted by the government. The fourth section will then formalise farmer-government interactions under a dynamic strategic model. The purpose of creating such a model is to descriptively frame the CSB issue, including the policy basket available to the government, and farmer responses to these.

Such a framing of the CSB issue does not exist in the literature on the subject, though experimental and behavioural analyses of different policy responses come close. Such a model would allow us to better comprehend the failure of governments in altering farmer behaviour. After deriving some key policy implications of this model in the fifth section, this paper will conclude with an overview of salient features of the model, and how it can contribute to public policy.

2. LITERATURE REVIEW

The most prolific literature about CSB is in the form of news media reports. Given the severity of air pollution in North India in the winter months, the issue predictably gains traction in the media in these months. Debates about the efficacy of policies, exploration of alternatives, and the harms caused by pollution, are among the myriad themes covered by the media. As such, they form a vast base of knowledge which collates official statements and important data qualifying the problem, and are essential to any study of CSB in India.

Within academia, a significant portion of the literature is scientific-technological. Papers such as Porichha et al. (2021), Singh et al. (2017), and Abdurrahman, Chaki, and Saini (2020) are examples of papers which deal with technological alternatives, and environmental and health costs of CSB. Several papers within this group specifically evaluate the contribution of CSB on pollution.

Then, there are papers that take a public policy focus on the issue, including Barman and Mukhopadhyay (2020) and Kumar, Kumar, and Joshi (2015). This category of literature discusses socio-economic and technological aspects and solutions to the problem. A third, and smaller, portion of the CSB-themed literature is dedicated to experimental studies testing interventions for influencing farmer behaviour. Extensively used in this paper as well, these include Lopes, Viriyavipart and Tasneem (2020) and Jack et al. (2023), which respectively test policies such as behavioural interventions and cash transfers.

Apart from the CSB-themed literature, of interest to this study is literature in the realm of behavioural science. Particularly, two works referred to in the construction of this paper's model are Sunstein and Thaler's Nudge (2008) and Kahneman's Thinking, Fast and Slow (2011). These are among the leading voices of contemporary behavioural theory, and provide valuable concepts—including nudge theory and loss aversion—which are of use in this study.

Finally, anthropologist Karl Polanyi's work on economic sociology forms the cornerstone of the approach used in the construction of the model in this paper. His "embeddedness" idea postulated that economic activities are all embedded in, and constrained by, social institutions. This will be made clear in this model's use of beliefs and farmer resistance against harsh government policies.

An important gap in the literature is the lack of sufficient investigation into the behavioural factors motivating stubble burning. Apart from Lopes, Viriyavipart and Tasneem (2020) and Jack et al. (2023), there are few studies looking into these factors. Consequently, academic, policy, and political discussions on the issue fail to take into account the constraints and beliefs driving farmer behaviour. This paper highlights the need to look at farmers as bounded-rational agents like any other, to identify the root causes of the stubble burning problem. Only by understanding farmer behaviour can policymakers design effective policy for mitigating stubble burning.

3. POLICY RESPONSES AND LIMITATIONS

Before delving into the model itself, it would be useful to look at the various levers employed by the government to influence farmer behaviour with respect to crop residue management. Government policies to tackle stubble burning can be encompassed under the following broad categories:

- Subsidies: To make technological solutions accessible.
- Positive incentives: Monetary compensation for farmers who cease stubble burning.
- Negative incentives: Fines, imprisonment against farmers who perform stubble burning.
- Information dissemination: Educating farmers about the harms of stubble burning and alternatives.
- Behavioural Interventions: Marketing campaigns, selective affirmation/shaming of farmers, nudges, and other behavioural interventions to shape collective farmer behaviour and influence the social acceptability of stubble burning.

This section will go over some of these schemes, highlighting their objectives and assessing their implementation. Subsequently, there shall be a brief discussion of the results of two experimental papers and their findings.

3.1. Making machinery accessible: Availability and subsidies

Specific machinery, such as Happy Seeders, Balers etc. among others, are necessary to facilitate in-situ (in-field) and ex-situ (outside-field) solutions for crop residue management. For instance, the Happy Seeder allows for in-situ management by simultaneously clearing residue and sowing seeds in the cleared space (Singh et al., 2017).

Any alternative to stubble burning necessitates access to such essential machinery. However, two main obstacles are: (a) insufficient supply and (b) unaffordable costs. The state and central governments have intervened to try and fill these gaps. For instance, Punjab's state government has provided over 90,000 pieces of subsidised machinery in the 2018-22 period (Punjab Pollution and Control Board, 2022). The Central Government's scheme for "Promotion of Agricultural Mechanisation for In-Situ Management of Crop Residue" outlines the multi-pronged strategy for promoting access to machinery through farm machinery banks, and providing financial assistance to make these more affordable (Ministry of Agriculture and Farmers Welfare, 2018).

However, despite these efforts, successes in promoting uptake of this machinery by farmers have been limited.

At present around 90% of these machines remain unutilised. The most prominent factors are the high rental and running costs of such machinery. Despite having purchased machines at substantial subsidies of 50-80%, these machines are often abandoned in successive years as farmers 'lapse' back to their original stubble burning behaviour, owing to the fuel and time costs of using these machines. Even studies demonstrating the profitability of adopting alternatives to CSB report that "The relative profitability of the Happy Seeder option suggests that farmers could transition away from burning while improving their bottom line, but variation in returns may contribute to low adoption" (Shyamsundar et al., 2019).

3.2. Positive Incentives: Monetary Compensation to Farmers

Monetary compensation has been much-touted by governments and the judiciary as essential to wean farmers away from CSB. This has been demonstrated in Haryana, where the state government in 2022 provided an incentive of Rs. 1000 per acre[1] to those farmers not burning residue (Mann, 2022).

A working paper published by the MIT Centre for Energy and Environmental Policy Research demonstrates the effectiveness of upfront cash transfers in reducing CSB (Jack et al, 2023). Through a randomised control trial conducted across two Punjab districts, they find that upfront, unconditional cash transfers reduce CSB by 8-11.5 percentage points relative to the control group (no payments). They reason that an upfront payment indicates a costly signal on behalf of the government, increasing farmer trust in subsequent payments being made.

There is also the alternative claim that such an incentive has a perverse effect. In 2020, a representative of the Environmental Pollution (Preservation and Control) Authority (EPCA) stated to the Supreme Court that "an incentive for not burning stubble is a perverse incentive" (Mann, 2022). This is a mechanism that will be further explored in the model described in this paper.

[1] In PPP terms, $1 is roughly equal to Rs. 24.059, as of 2022 (OECD Data, Conversion rates - purchasing power parities (PPP)

3.3. Negative Incentives

These include prohibitions, fines, and imprisonment. For instance, many districts in Punjab imposed bans on stubble burning, and the Haryana government has imposed stringent fines on farmers observed to be burning stubble (Times of India, 2023). As of November 2023, the Haryana government had imposed 939 fines amounting to over Rs. 25 lakhs (Livemint, 2023). These punitive measures serve as the proverbial 'stick' accompanying 'carrots' that discourage stubble burning. However, an unintended consequence is farmers' collective mobilisation, usually through unions, in defiance of government directives. Farmer unions have organised protests in opposition to these measures, and there have been instances of farmers resisting officials sent to monitor stubble burning. While these instances may be statistically not significant, they are symptomatic of farmer attitudes with respect to these punitive measures, and of the wider limitations of relying on negative incentives to change farmer behaviour in the context of residue management.

3.4. Information dissemination and nudges

Information dissemination is another important policy tool used to influence farmer behaviour. Awareness campaigns surrounding the polluting harms generated by CSB are less significant, given that farmer testimonials indicate that they are well-aware of these harms already (Rathore, 2022). More significant are efforts to reduce informational frictions around sustainable alternatives to CSB.

Apart from direct informational campaigns, it is important to note the role of social behaviour in influencing the decision to burn stubble. Another experimental paper discusses the role of social influence in this decision, finding that "social influence and herd behaviour is a significant determinant of CSB in...Northern India—the perception that it is a common practice increases the probability of burning paddy residue by as much as 12%" (Lopes, Viriyavipart & Tasneem, 2020). Inspired by this approach, the model described below will also take into account collective farmer behaviour rather than just a single-farmer focused approach.

4. MODELLING STUBBLE BURNING POLICY INTERACTIONS

In this section, the strategic interaction model will be laid out, with a purpose to formalise and describe interactions between the government and farmers on the issue of CSB. This formalisation will serve to derive key mechanisms by which farmer perceptions and government actions influence farmer behaviour with respect to residue management, and to finally arrive at salient conclusions around public policy regarding stubble burning.

4.1. Assumptions and Layout

This interaction has been modelled as an extensive-form n-player game. In Year 1, the government first observes the state of the world (assumed for our purposes to be one where all farmers burn stubble) and chooses its policies. Next, n-number of farmers observe government policies, and evaluating their individual payoffs and their beliefs about other farmers, decide whether or not to burn stubble. Their actions determine the state of the world in the beginning of Year 2, where the same sequence of actions is iterated.

The simplifying assumptions followed thus far are:

1. Homogeneity of farmer preferences: Implying that all farmers have uniform utility functions, and are undifferentiated by class, landholding size etc.
2. Absence of market frictions: Implying that all government policies are perfectly implemented, with zero corruption, implementation failures etc.
3. Common Knowledge: Farmers and the government are aware of one another's preferences.

These assumptions will be further modified as the model is developed, to reflect these interactions more realistically.

4.2. Farmer Preferences

Farmers have two main strategies to choose from in this model:

- To burn stubble (SB)
- Not to burn stubble (NSB)

To begin with, a typical farmer in our model has certain baseline preferences guiding their decisions. The payoffs obtained from stubble burning are as follows:

$$u(SB) = \frac{1}{4}(-H_i - H_e - P_G - S(1 - p^{n-1})) \quad (1)$$

where,

- H_i represents the farmer's perception of internal harms (or harms faced by own household) caused due to air pollution generated by CSB.
- H_e represents the farmer's perception of external harms, i.e., those faced by surrounding households, caused due to air pollution generated by CSB. The inclusion of this variable is based on the assumption that the typical farmer is altruistic, meaning that they also care about the harms caused to others by pollution.
- S represents the perceived social costs of stubble burning. In Year 1 of our model, this value is exogenously determined.
- p represents the farmer's belief about the probability of another typical farmer burning stubble. Therefore, p^{n-1} represents the farmer's belief about the likelihood of all other farmers burning stubble. The variable S is weighted by (1- p^{n-1}) to account for the impact of farmer beliefs on their accounting of social costs. Here, as the farmer's believed likelihood of others burning stubble increases, the impact of social costs on their overall utility decreases. As this belief tends to 1, the impact of social costs tends to 0. This expression reflects the idea of herd behaviour: the acceptability of burning stubble increases as other farmers are seen to be increasingly likely to do the same, and vice-versa. This is in line with Lopes, Viriyavipart and Tasneem (2020), who used experimental evidence to demonstrate the role of herd behaviour in influencing farmer decisions to burn stubble.
- P_G represents the farmer's costs incurred by the risk of penalisation by the government for burning stubble. This penalisation is typically in the form of fines, imprisonment, confiscation of licenses etc.

Except for p, all other variables in the above function are represented as a proportion of the farmer's annual consumption expenditure. Therefore, each variable here belongs to the range [0,1]. The entire summation of costs has been divided by 4 in order to normalise utility to the [0,1] range.

The payoffs from not burning stubble are as follows:

$$u(NSB) = \frac{1}{3}(-C - H_i \cdot p^{n-1} - H_e \cdot p^{n-1}) \quad (2)$$

where,

- C represents the costs of adopting alternative solutions for crop residue management. These could include costs for renting machinery, running costs (fuel, maintenance etc.), decomposer sprays, labour costs etc. Like in Equation 1, C is also represented as a proportion of annual farmer consumption expenditure, and thus belongs to the range [0,1].
- H_i and H_e have the same interpretations as in Equation (1). Each of these have been weighted by p^{n-1} to reflect that these harms arise from others' stubble burning. Whereas in Equation 1, both harms arose from the farmer's own decision to burn stubble, here these harms arise from others' decisions. Consequently, these are weighed according to the farmer's belief of others farmers' likelihood of burning stubble. As this probability tends to 0, the impact of these harms also tends to 0 in the farmer's payoffs from not burning stubble, and vice-versa. The implication here is again that of herd behaviour: as farmers increasingly believe others will burn stubble, they are less incentivised to pursue alternative solutions themselves. The intuitive logic here is that if these harms from pollution exist anyway, choosing to not burn stubble makes less and less of a difference.

4.3. Introducing government policy's impact on farmer decisions

Based on earlier discussions, government policies regarding CSB can be classified as follows:

- Monetary compensation
- Subsidies
- Penalisation
- Nudges and Information

We first incorporate the impact of subsidies and the compensation on farmer preferences. Thus, the modified farmer payoff function from not burning stubble is as follows:

$$u(NSB) = \frac{1}{3}(C \cdot Sub - H \cdot p^{n-1}) + Cmp \tag{3}$$

where,

- *H* is simply the sum of internal and external harms
- *Sub* is the subsidy provided by the government. This can be interpreted as the percentage of machinery costs (C) that have to be paid by the farmer themselves. For instance, a subsidy of 40% means that only 40% of the cost is borne by the farmer, with the rest being subsidised by the state.
- *Cmp* represents the monetary compensation given to the farmer by the government, as an incentive to not burn stubble. This is again represented as a proportion of the farmer's annual consumption, belonging to the [0,1] range.

The major changes to the baseline payoffs from not burning stubble are the inclusion of subsidies and compensation. While subsidies lower the costs of alternative solutions, the compensation positively adds to the payoff from not burning stubble.

Next is the question of penalisation. There are some limitations to P_G as a policy instrument. We observed earlier that penalisation, in some cases, leads to counter-moves by farmers in defiance of the government. While this model does not account for the impact of protests and other actions taken by farmers, it does focus on the act of disobedience by farmers in response to penalisation. Here, this interaction is modelled by describing a certain threshold of punitive measures, beyond which any increase will counterproductively increase farmer incentives to burn stubble. Mathematically, this is represented as:

$$P_G = y - ay^2 \tag{4}$$

Where y represents the probability of a farmer being penalised when they burn stubble. a is an exogenous measure of sensitivity, such that $1/a$ is the threshold of y beyond which P_G becomes negative. For example, if a = 2, then the highest value of P_G is obtained at y=1/4, and P_G becomes negative as y exceeds 1/2. Recall Equation (1), and it observed that as P_G becomes increasingly negative, the incentive to burn stubble also increases. This is reflective of farmers' observed socio-political tendency to mobilise and defy government actions perceived as hostile to them (The Hindu Bureau, 2023).

Finally, it remains to model the impact of behavioural interventions. The idea of a nudge, as defined by Thaler and Sunstein (2008), is "...any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives."

In our case, government nudges come in the form of awareness campaigns, advertisements, and publicly praising farmers for not stubble burning, among others. None of these significantly alter incentives for farmers: they do not necessarily provide farmers with new information, especially when it comes to awareness of pollution harms, nor do farmers economically benefit from public commendation. What does matter here is that all farmers observe these interventions, and accordingly modify their beliefs about other farmers' probability of burning stubble. Functionally, this is expressed as:

$$p^{n-1} = B - N^{\frac{1}{2}} \tag{5}$$

Here, B is simply the farmer's prior belief, determined exogenously in Year 1. We see that nudges serve to moderate farmer beliefs, in an attempt to bring about collective behavioural change among n farmers. As nudges decrease farmer beliefs about others' probability of burning stubble, we see that their consequent incentive to burn stubble decreases (see Equation 1) and to not burn stubble increases (see Equation 3).

N is a representation of government expenditure on behavioural interventions, and is expressed in terms of proportion of a farmer's annual consumption expenditure, in the range of [0,1].

The usage $N^{\frac{1}{2}}$ of reflects the limited effectiveness of nudges. We assume that behavioural interventions as a whole, and nudges in particular, have a significant, yet limited, impact on farmer behaviour. Behavioural solutions alone are, in the real world, not sufficient to alter farmer decisions of burning stubble. For instance, in Lopes, Viriyavipart and Tasneem (2020), an increase in the belief of CSB being a "common practice" leads to a 12 percentage point increase in the likelihood of a farmer deciding to burn stubble—

which is statistically significant, but limited in magnitude. As a policy tool, we cannot imagine nudges as being a be-all solution which can infinitely and solely alter farmer choices. This limitation is represented in the functional expression of farmer beliefs being a concave function of *N*, which will later establish itself as a constraint on government spending on the policy. While this model has used the form $N^{\frac{1}{2}}$ for simplification, any other concave function would communicate the same idea.

Having accounted for all government policies and their impacts on farmer's incentives to burn [or not] stubble, we come to the final expressions of farmer utilities in Year 1:

$$u(SB) = \frac{1}{4}(-H_i - H_e - S \cdot (1 - B + N^{\frac{1}{2}}) - y + 2y^2) \quad (6)$$

$$u(NSB) = \frac{1}{3}(-C \cdot Sub - H \cdot p^{n-1}) + Cmp \quad (7)$$

4.4. Government Preferences

Having refined farmer preferences in a world with policy interventions, we now turn to the incentives which drive government policy. Very simply, we can say that:

u_g = Welfare gains - Policy costs

Policy costs can be very simply derived from the discussion in the preceding section, as follows:

- *C(Cmp)* = *n* · *Cmp*, where *Cmp* ∈ [0,1]. *Cmp* represents the compensation awarded to an individual farmer, and the total cost is given by multiplying this amount with the total population of farmers.
- *C(Sub)* = *n*·*(1–Sub)C*, where, as discussed, *Sub*·*C* represents the actual amount a farmer has to pay for machinery post-subsidy. Thus, the remainder is included in government expenditure.
- *C(N)* = *nN*, representing the cost of nudges. Here also, *N* is a percentage of one farmer's annual consumption expenditure.
- *C(Penalisation)* = *ny*. We assume, for simplicity, that government expenditure, as a share of annual farmer consumption, directly translates into the probability of being penalised for a farmer who burns stubble.

Thus, total policy cost is simply a summation of the above costs:

$$PC(per\ farmer) = Cmp + (1 - Sub)C + N + y \quad (8)$$

Next is the question of quantifying welfare gains. There exists a precedent for representing the economic costs of harms generated by air pollution, most notably with the WTP (Willingness to Pay) approach. The WTP encompasses welfare losses from pollution, including not only forgone income and capital formation, but other measures of welfare including quality of life, health, leisure etc. The WTP has been defined as "the marginal trade-offs that individuals are willing to make to reduce their chances of dying [prematurely due to pollution]" (Institute for Health Metrics and Evaluation, 2016, p.48). Derived from the WTP is the VSL (Value of Statistical Life), which sums up many individuals' WTPs for reducing risks of premature death from pollution (Institute for Health Metrics and Evaluation, 2016). These measures are based on survey data, and vary according to demographic characteristics.

The main takeaway from alluding to these measures is the use of quantitative measures to define economic costs of an intangible phenomenon like air pollution. Such values of welfare can also be used in further refinements of this model. For simplification, however, welfare gains will have a much simpler definition in this model, but this does not preclude the applicability of a WTP or VSL-based approach. Welfare gains are defined here as:

$$W = \Delta(\text{percentage of farmers not burning stubble}), \in [0,1] \quad (9)$$

Thus, the change in the percentage of farmers not burning stubble, compared to the past time period, captures the welfare gains the government achieves. If we assume an initial state of the world as being one where 100% of farmers burn stubble, then Year 1's *W* is simply equal to the absolute percentage of farmers that do not burn stubble in Year 1.

Having defined both costs and gains for the government, our final government payoff function is as follows:

$$u_g = W - (Cmp + (1 - Sub)C + N + y) \quad (10)$$

A further note on *W* is important here. So far, we have assumed complete homogeneity in the preferences of *n* farmers, and the complete absence of market frictions. However, this would imply that welfare gains are always binary: either 0 or 1. If all farmers have the same preferences and are equally affected by government policy, then we will have an outcome where either all or zero farmers burn stubble. This does not seem like a very useful outcome.

Thus, we now relax the initial assumptions of homogenous preferences and a frictionless market. To account for both heterogeneity and market frictions, we can express the percentage of farmers not burning stubble as a random variable distributed normally. The mean of this distribution, μ, may be functionally expressed as:

$$\mu = f(u_f(NSB) - u_f(SB))$$

Where f is increasing in $(u_f(NSB) - u_f(SB))$ .The implication here is that as this difference becomes positive and increases, the mean value of the share of non-burners accordingly rises, and vice-versa. Thus, as the model farmer prefers *NSB* over *SB*, we see an increasing proportion of farmers choose to not burn stubble, and vice-versa.

The normal distribution of non-burner proportion is a simplifying choice made for this model, and any other appropriate random distribution may also be applied in further refinements. What it achieves for our purposes is a continuous value for *W*, while moving our model closer to the real world.

This further helps in the formulation of farmer priors *B* in Year 2. While B is defined exogenously in Year 1, in Year 2 it is defined as:

$$B_{year2} = \text{percentage of farmers burning stubble} \quad (11)$$

Therefore, Year 2 priors are simply based on the observed state of the world at the end of Year 1. Thanks to our introduction of frictions and heterogenous outcomes, the Year 2 *B* is also a continuous variable.

5. POLICY IMPLICATIONS

Having now derived a simple set of payoffs for the government and farmers in the CSB policy environment, we can now try to implement our model of interactions and derive some salient policy implications, particularly with regard to monetary compensation as a tool.

Compensation is a popular and important tool available to the government to incentivise farmers away from CSB. This approach stems from the idea that farmers are compelled by circumstance to burn stubble, and it is the state's prerogative to provide them with the necessary financial assistance to move towards more sustainable practices.

However, this does not change the fact that compensation is a costly tool, especially for financially over-extended state governments. For instance, Punjab sought to implement a programme for compensating farmers at a rate of Rs. 2500 per acre, with the centre contributing Rs. 1500 per acre. This came out to be a centre-state division of Rs. 1125 crore and Rs. 750 crore (for both Punjab and Delhi), respectively. However, this propoal was turned down by the central government (Nibber, 2022).

This incident reflects the inherently limited sustainability of financial compensation. Therefore, while it is an effective short-term measure, as also demonstrated by Jack et al. (2023), it needs to be phased out eventually. Further, using our model, we observe challenges in the withdrawal of these subsidies leading to farmers to increasingly lapse to their original stubble burning behaviour.

From our earlier derived preferences, when we impose the condition *u(NSB)* >= *u(SB)*, i.e., that the typical farmer prefers to not burn stubble, we obtain a minimum value for *Cmp* as follows:

$$Cmp >= \frac{1}{12}(4C \cdot Sub - 3S(1 - p^{n-1}) + (4p^{n-1} - 3)H - 3P_G) \quad (12)$$

Observations:

1. Higher costs of alternatives ⇒ higher compensation demand
2. Higher social costs of burning ⇒ lower compensation demand
3. (a) When $p^{n-1} > 0.75$ → higher harms from pollution ⇒ higher compensation demand
   (b) When $p^{n-1} < 0.75$ → higher harms from pollution ⇒ lower compensation demand

The first two observations are quite intuitive. What is more interesting here is the role of farmer beliefs. While the impact of social costs of burning is decreasing in beliefs, this is not the case for the harms caused by pollution. Recall that when we were constructing Equation 2, we attached p^{n-1} as a weight on harms caused by pollution. This was to reflect the idea that when not burning stubble themselves, the farmer still considers the potential harms generated by the likelihood of others still doing so.

Therefore, in our formulation of *Cmp*, we see that when the belief crosses a certain threshold (in this case, 75%), the farmer demands increased compensation for not burning stubble. Intuitively: if enough farmers are burning stubble, the typical farmer has less incentive to not burn stubble to avoid the harms caused by pollution—they are still breathing the same air. However, if the belief is below that threshold, i.e., the farmer believes that too few among the other farmers are burning stubble, then the harms caused by pollution decrease their demand for burning stubble. In other words, the incentive ex-compensation to not burn stubble increases in pollution harms. But why?

Simply, the logic here is that a farmer will not want to act as an outlier. If they perceive that not enough farmers are burning stubble, they will not want to generate pollution harms through their own decision to burn stubble. If fewer other farmers around them are burning stubble, then the farmer in question will be more likely to avoid the harms (internal and external) of pollution by not burning stubble themselves. Consequently, they demand less compensation.

Further, this model can also tell us about the effects on farmer preferences in Year 2 from a Year 1 provision of compensation.

Year 2 starts with a state of the world wherein the government provides some $Cmp \in [0,1]$ in Year 1, such that *uf(NSB)* > *uf(SB)*. Let us take a case where the payoffs from burning stubble remain unchanged, and the government chooses to withdraw an amount $X \in [0,Cmp]$ from the Year 1 compensation (meaning Year 2 compensation = $Cmp - X$). The farmer payoffs from not burning stubble in this period can be written as:

$$u(NSB) = \frac{1}{3}(-C \cdot Sub - H \cdot p^{n-1}) + Cmp - lX \qquad (13)$$

Here, $l > 1$ is a factor of loss-aversion. Loss aversion is a behavioural concept which postulates that "the response to losses is stronger than the response to corresponding gains" (Kahneman, 2011, pp. 282-83). Functionally, this means that $|v(-x)| > |v(x)|$, where v is some value function.

Here, we observe that a full withdrawal of compensation ($X = Cmp$) does not return farmer preferences to the pre-compensation status quo, but rather to an even lower level of utility, since $Cmp - lX < 0$. The implication is that the decision to provide an incentive in Year 1 increases the farmer's frame of reference determining their utility. This means that a Year 2 farmer whose compensation has been withdrawn is even less incentivised to not burn stubble than a Year 1 farmer who never received compensation. Herein lies the perverse nature of the monetary incentive, as argued by the Environmental Pollution (Preservation and Control) Authority in 2020 (Mann, 2022).

This fact outlines the need for a decreased reliance on compensation as a tool for mitigating CSB, despite its proven effectiveness in changing farmer behaviour. Lasting changes can only come through sustained market and behavioural shifts, which respectively increase affordability of sustainable solutions and decrease the collective acceptability of CSB among farmers.

Further, in contrast to the unsustainability of compensation as a long-run policy solution, we can observe that belief shifts are far more persistent. The Lopes, Viriyavipart and Tasneem (2020) paper demonstrates the immediate-run effectiveness of behavioural interventions, specifically the impact of herd behaviour (modelled as beliefs in this paper). Our model goes a step further and creates a mechanism by which these beliefs, influenced in Year 1, are further translated into Year 2 beliefs.

Recall Equation (5), where we defined B as being the exogenously defined prior beliefs held by a farmer about others' likelihood of burning stubble. Behavioural interventions, such as nudges, serve to moderate these beliefs and collectively reduce farmers' expectations of each others' likelihood of burning stubble. From our payoff functions, we know that this ultimately pushes farmers towards not burning stubble.

As discussed earlier, B in Year 2 is not exogenously determined, but is equal to the percentage of n farmers who burn stubble by the end of Year 1. Among the factors influencing the number of nonburning farmers are the nudges deployed by the government. As nudges reduce farmer beliefs about beliefs about others' likelihood of stubble burning, they influence an increasing number of farmers to move away from CSB. This reduced percentage of farmers burning stubble translates into reduced prior beliefs, defined as B, in Year 2. Thus, through this mechanism, the reduced expectations from Year 1 translate into reduced expectations in Year 2. Consequently, we see that in the long-run, the required investments in nudges, as well as in other policy tools, come down. Inexpensive nudges turn out to be a powerful long-run tool, despite their immediate-run limitations. While the other policy tools have a similar effect, they are subject to other constraints as well: subsidies face the same loss-aversion problem as compensation, and penalisation of farmers is seen to have the peculiar constraint that has the counterproductive potential to induce farmers to burn stubble.

6. CONCLUSION

The above model is an attempt to theorize in some detail the public policy conundrum of CSB, in the context of the persistence of the phenomenon, despite years of government efforts. While a lack of empirical analysis may be a limitation of this paper, this formalisation of the problem creates a base not only for future refinements of the problem, but also for future empirical explorations of specific levers influencing farmer behaviour regarding residue management. The strength of this model lies in its detailed identification of these levers and their constraints, and the nature of farmer and government preferences in the long and short runs. This paper integrates these various components into a functioning model, which creates a unique formalisation of a prominent sustainability issue in India.

Summing up the above discussions, some salient points emerging from the formalisation of these interactions are:

1. Farmer beliefs about other farmers' behaviour are a key determinant of their decision of whether or not to burn stubble.
2. Owing to loss-aversion tendencies, compensation and subsidies are likely to be unsustainable in the long run, as withdrawing them increasingly incentivises farmers to lapse back to burning stubble. This necessitates the diversification of government policies for creating persistent change in farmer behaviour.
3. By translating existing expectation changes into reality, which informs future farmer expectations of others' decisions to burn stubble, nudges cause low-magnitude, but persistent behavioural change in farmers.

Public policy with respect to stubble burning must necessarily be multi-pronged and cohesive, with a focus on both immediate and long-run solutions. Further, while fixing market failures is central to ending CSB, equally important is entrenching behavioural influences towards changing a decades-long social and cultural norm of crop residue management. The issue of CSB is in equal parts financial, economic, and social-behavioural, and it is the role of public policy to sustainably and cohesively address each of these aspects in turn.

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