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ARTICLE

Striving to revive pulses in India with extension, input subsidies, and output price supports†

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Abstract

Pulse production in India has stagnated relative to staple grains and cash crops, raising concerns about rural protein consumption. We experimentally evaluate an effort to increase local pulse production in Bihar. This intervention consisted of 2 years of input subsidies and extension to facilitate learning, followed by the creation of marketing organizations and a year of output price support to raise profitability. Farmers respond to price signals by expanding inputs when subsidized and increasing pulse sales under price supports. However, we see no evidence that the program shifted equilibrium production portfolios as pulses return to pre-intervention levels after the support ends. Results indicate that short-term learning by doing cannot overcome long-run barriers to local pulse production, even when farmers have a viable outlet to sell their surplus output.

KEYWORDS

agricultural extension, India, pulses, technology adoption

Travis J. Lybbert and Ashish Shenoy are the senior author names presented in random order

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JEL CLASSIFICATION
O13, O33, Q12

1 | INTRODUCTION

The Green Revolution unleashed dramatic increases in food supply around the world through improved germplasm and agronomy combined with investments in infrastructure, market development, and agricultural extension. In India, agricultural output expanded by nearly four-fold between 1950 and 2000 (Tiwari & Shivhare, 2019), which contributed to impressive declines in food insecurity and malnutrition and improvements in population health and well-being (Deaton, 2008). Given the severe food shortages of the 1950s and 1960s, increasing the availability of calories was understandably the primary objective of these efforts, which consequently focused on cereals—primarily rice and wheat in India. Although the urgency of producing cheap calories has faded, the legacy of Green Revolution cereal successes continues to shape on-farm production, agrifood systems, and nutritional outcomes.

One dimension of this legacy in India has been a decline in the prevalence of pulses and other crops that received relatively little public investment. Despite being the most prominent source of protein throughout the country, Indian pulse production grew by only 30% from 1950 to 2000, compared to over 300% increases in rice and wheat production. Pulse cultivation in India has retreated to more marginal and rainfed lands and moved further south as farmers in the Indo-Gangetic plain shifted to more productive and remunerative varieties of Green Revolution cereals (Pingali, 2012; Tiwari & Shivhare, 2019).[1] Meanwhile, protein consumption in India continues to fall short of international standards across socioeconomic strata (Sharma et al., 2020). Indeed, Deaton and Dréze (2009) show that per capita protein consumption in India actually declined in the 1990s and 2000s despite rapid economic growth. Seeing a link between cereal successes at the expense of domestic pulse production and stagnating protein consumption, the Government of India has sought to make pulses more readily available in domestic markets.

In this paper, we present results from two randomized evaluations conducted during a 3-year pilot program to expand the domestic supply of protein by encouraging pulse production among smallholder farmers using improved seeds and techniques. This pulse support program consisted of 2 years of input-focused intervention followed by a third year of output marketing support. The input side of the pilot program delivered intensive, short-term extension and support by offering certified seeds of suitable varieties available at subsidized prices along with targeted extension services—including local demonstration plots and individualized feedback. In Year 3, input support concluded and the program facilitated sales of pulse crops through local farmer producer organizations. These organizations aimed to enable greater market access and raise market returns by aggregating smallholder production to sell in bulk. All support efforts were initiated by NITI-Aayog, the strategic planning arm of the Government of India, and implemented in five districts in the northeastern state of Bihar, where farmers have followed the regional trend away from pulses toward cereal crops, with the intent to scale up if successful.

The intervention design was motivated by the possibility of path dependence in agricultural technology adoption. Following decades of extension focus on cereals, the average yield for pulses in Bihar in 2010 was only 10%–25% of the estimated potential yield, compared to 40%–55% for rice and wheat.[2] Low productivity stems in part from limited use of modern seed varieties and input-intensive farming practices that were the hallmark of Green Revolution gains. In our areas of study, pulses are largely peripheral crops grown from traditional seeds interspersed between rows of other crops, on plot borders, or on marginal land.

Farmers may be hesitant to adopt new techniques on their own if there is a costly period of learning by doing or if they are uncertain about the returns. The input package in this study was

[1]For a visualization of this spatial shift at the district level, see the maps produced by Tata-Cornell Agriculture and Nutrition Initiative (2015). This shift is also apparent at the household and village levels as the most productive plots with irrigation access are devoted to more productive and profitable nonpulse crops and pulses are pushed to the borders or to marginal, rainfed plots.
[2]As reported in the FAO's GAEZ database.

designed to alleviate these barriers by removing adoption costs and accelerating learning about best practices. In effect, it sought to provide farmers with the same level of extension support for pulse cropping as they had previously received for cereals. These production activities were supplemented with subsequent assistance to raise the returns to pulse cultivation by facilitating the marketing of output.

The primary evaluation in this study randomized village-level farmer groups into a treatment arm that received the comprehensive support package and a control arm that did not. Although the public investment in the first 2 years of this program would be unsustainable as a permanent transfer, we investigate whether experience gained during a short period of intensive investment coupled with a viable market outlet for selling surplus can shift smallholder farmers to a new equilibrium that produces more pulses.

In a second evaluation, we experimentally introduced a supplementary output price subsidy among farmer groups receiving marketing support in the third year to investigate how sensitive a new equilibrium may be to market returns. Price support took the form of either a flat per-unit subsidy or a price floor matching India's Minimum Support Price (MSP) policy, both announced ahead of the planting season so farmers could adjust accordingly. These two arms separately vary expected returns and price risk (see Donovan, 2020; Goyal, 2010) in cultivation decisions. This second evaluation tests whether the shift to a new technological equilibrium can be facilitated by the type of subsidy already in place for other crops in India.

We find input support policies initially encouraged uptake of pulse farming, with evidence that farmers experimented with modern cultivation practices. The fraction of farmers growing pulses was 50%–200% greater across three growing seasons in treatment villages relative to control in the first year when pulse seeds were fully subsidized. However, these gains dissipate over the life of the program. The difference in adoption between treatment and control fell by more than half in the second year with partial subsidies, and by the third year after subsidies expired there was no detectable treatment effect. Even those offered output price subsidies do not expand their seed demand or area cultivated. Whatever learning occurred during the subsidy period did not raise the perceived returns to pulse cultivation by enough for pulses to supplant other crops, even with an outlet for sales. If anything, experience reinforced farmers' pessimism about the return to investment in pulses, as farmers who received 2 years of input support exhibit lower demand for certified pulse seeds in an experimental auction.

Consistent with this behavior, we find no evidence that households induced to grow pulses fared differently than those in the control group across a range of indicators on production, agricultural revenue, sales, and pulse stocks despite heavy input subsidies and extension support. Although each individual measure is noisy, the estimated treatment effects are quantitatively small relative to the mean across multiple outcomes and paint a uniform picture: Pulse cultivation in Bihar, even under ideal conditions with intensive support, is not more lucrative than the alternative uses of agricultural land. Given the absence of persistent effects on pulse production, we unsurprisingly find no evidence of increased pulse or protein consumption.

In our context, lack of knowledge or experience does not appear to be the binding constraint on adoption of pulses. This conclusion contrasts with an evaluation in the nearby state of Odisha that finds a similar combination of field visits and extension using demonstration plots induced sustained uptake of a new drought-tolerant rice variety (Emerick & Dar, 2021). Although much effort in agricultural development focuses on introducing producers to new technology, our findings serve as a reminder that low technology utilization in agriculture need not always be a puzzle revealing underlying frictions. In some cases, the returns to technology are sufficiently low that agents rationally choose not to adopt.

Although we observe no equilibrium shift, this study provides some evidence for the role of price supports in market development as farmer behavior responds to price signals. On the input side, adoption is greatest in the first year when inputs are fully subsidized and dwindles as subsidies are withdrawn. Those participating in the experimental auction similarly display downward-sloping demand that responds to the seed price. On the output side, although the promise of price support does not promote cultivation, subsidies increase the fraction of output sold on the market. These results suggest that price supports can supplement other policies by adding thickness to agricultural markets.

This research broadly contributes to the literature on agricultural productivity. Raising agricultural productivity is a crucial component of economic development because 75% of the world's poor live in rural areas (Castañeda et al., 2016; World Bank, 2007). Across countries, labor productivity differences between rich and poor tend to be greater in agriculture than in other sectors (Caselli, 2005), and the productivity gap between agriculture and non-agriculture is greatest at the bottom of the income distribution (Gollin et al., 2014). Adamopoulos and Restuccia (2021) show that crop selection and input use, rather than land endowments, account for the overwhelming majority of cross-country variation in agricultural productivity. McArthur and McCord (2017) argue improved use of inputs was a fundamental driver of growth in cereals during the Green Revolution. We investigate the potential to extend these gains to pulse crops in India.

Technology adoption is an important component of agricultural development (see de Janvry et al., 2017). To this end, extension work frequently focuses on knowledge and training to promote new technologies (Waddington & White, 2014). However, experimental evidence indicates training alone is insufficient to change farm practices (Fabregas et al., 2017; Kondylis et al., 2017; Maertens et al., 2021). In contrast, programs that augment training with hands-on demonstration and experience have shown greater success (Aker & Jack, 2021; Emerick & Dar, 2021; Maertens et al., 2021), highlighting the importance of either learning by doing or learning about the returns to technology (see Magruder, 2018).

Learning frictions are one of many possible market failures that may exist in the agricultural sector (Jack, 2013). Uncertainty about input quality (Bold et al., 2017; Hasanain et al., 2023) and credit constraints (Magruder, 2018) have also proven to hamper agricultural technology adoption. Our intervention resolved the asymmetric information problem by sourcing high-quality inputs from reputable vendors and distributing locally through trusted organizations with strong community ties.[3] Furthermore, our study population consists of established farmers with existing access to agricultural credit, alleviating this barrier to adoption. Nevertheless, we present a case where knowledge is still not the binding constraint to technology adoption.

Extension and training represent supply-side initiatives to increase agricultural productivity. A complementary approach focuses on demand-side interventions that raise the returns to investment and quality (see Bold et al., 2022; Rao & Shenoy, 2023 for experimental evaluations and Bellemare & Bloem, 2018 for a comprehensive review). Related demand-side factors include contract design (Goodhue et al., 2010; Saenger et al., 2013), market competition (Bernard et al., 2017; Macchiavello & Morjaria, 2021), and quality verification (Bai, 2021; Saenger et al., 2014). A few experimental evaluations bundle supply-and demand-side interventions. Macchiavello and Miquel-Florensa (2019) and Park et al. (2023) find that training induces greater technology upgrading when farmers are connected with output markets. Our research attempts to simulate market expansion with sales support and experimental price subsidies, but we cannot guarantee subsidies in future seasons. It remains an open question whether a more sustained commitment to higher output prices could promote greater pulse cultivation in the long run.

2 | BACKGROUND

2.1 | Pulses in India

India is simultaneously the world's largest producer, consumer, and importer of pulses. The country produces around 25% and consumes around 27% of the world's pulse crop. Accordingly, pulses make up an integral part of Indian diets, and are a key ingredient in traditional cuisines around the country. Nevertheless, domestic production has lagged behind demand in recent years. From 1995

[3]This distribution network for accessing high quality pulse seeds, which was not experimentally evaluated, remained in place after the intervention period.

to 2016, consumption of pulses in India increased at an average annual rate of 2.3%, outpacing the growth in domestic production of around 1%. increased to fill the gap, the pulse sector has still seen steady price increases.

Local access to pulses is particularly important because they represent a key source of protein for Indian households. Pulses account for nearly a quarter of non-cereal protein consumption on average, and are the largest protein source outside of cereals for poor households in both rural and urban areas (Rampal, 2018). Protecting this dietary component is especially vital in a country where the protein content of diets lags well behind international standards across geographic and socioeconomic strata (Sharma et al., 2020). Pulse prices also play a role in macroeconomic and political stability, as unexpected price spikes have forced administrative resignations and induced turnover among elected officials. To stabilize the national market, the Government of India has explored policy solutions to bolster supply through both domestic production and imports. In the pulse sector, however, trade policy may be unappealing because India is a large enough buyer in the world market that demand shocks can raise prices, leading to increasingly worse terms of trade (Joshi et al., 2016). Furthermore, the gains from trade rely on domestic market integration and therefore may exclude more remote rural markets (Atkin & Donaldson, 2015), making domestic production an appealing alternative (Porteous, 2020).

In this paper, we evaluate an initiative to boost domestic pulse production through agricultural extension piloted in districts in the state of Bihar that had cultivated pulses commercially before the Green Revolution. This pilot intervention was motivated by the fact that current pulse cultivation in the region typically uses few improved inputs—indeed, few inputs at all—and traditional cropping methods. As a result, not only has the technological frontier for pulses stagnated relative to the frontier for staple grains, but realized pulse yields lag farther behind the technological frontier than for commercial staple crops. While a lack of R&D investment in pulse breeding explains some of the productivity disparity,[4] agronomists have identified Bihar as an area with the potential for productivity gains in pulses through adoption of existing technology alone (Reddy & Reddy, 2010). The interventions we study follow from the hypothesis that technological sluggishness is path-dependent, such that a one-time investment by the government could raise yields by inducing local producers to permanently shift their cropping techniques and use of inputs.

2.2 | Policy design and implementation

The pulses program in this study was piloted by four local NGOs over a three-year period, with the intent of scaling up successful components into a state- or nation-wide policy. The first two program years focused on input support. Project partners established a supply of reliable insecticide-treated, modern-variety pulse seeds, which had previously been difficult to purchase in the area of study. They offered these seeds at a subsidized cost for 2 years, and provided substantial extension support to program farmers over this period. After the second year, project partners continued to make seeds available at market price. This portion of the study tests whether an intensive, short-term investment in technological upgrading can induce enough adoption to create sustained demand for seed purchases and output sales over the longer term.

In the third year, program activities shifted to marketing output. Implementers assisted farmers that had previously received input support in forming Farmer Producer Companies (FPCs) to secure higher prices by negotiating bulk sales with traders and processors. The program also experimented in this phase with offering price supports and backstopping the sale price with a floor set to match India's national Minimum Support Price (MSP). The MSP, which had previously only been enforced for cereal crops in Bihar, represents an effort to insure agricultural households against income loss

[4]This is notable in the absence of high yielding pulse varieties that (i) offer productivity gains on par with those attainable for other crops and (ii) are highly responsive to complementary inputs such as fertilizer and irrigation.

driven by unexpected price fluctuations at the time of harvest. This portion of the study tests whether local output market development could help sustain adoption and measures the elasticity of local pulse supply to the anticipated sale price.

2.3 | Geography and crop seasons

Program evaluation takes place in five districts in the state of Bihar, depicted in the online Supplementary Appendix: Data S1. Pulses, especially pigeon peas, are a traditional staple in this region, but local production has dwindled with rapid productivity gains in other crops. Current farmers at most grow small quantities of pulses for household consumption, typically on plot borders or Nearly all farm households supplement home production with pulse purchases despite being net sellers of the other crops in their portfolio.

The region of study follows a two-season cropping cycle. In the main Kharif season, which runs from May through October, farmers typically cultivate rice for commercial sale. More than 85% of control farmers report growing rice in this season, accounting for nearly 75% of farmed land. Maize covers another 9%, while pulses comprise just 3.5% of Kharif acreage in control villages. The pulses program promoted replacing a portion of rice area with pigeon peas (*arhar*) or black gram (*urad*) during this period. It should be noted that pigeon peas are a longer duration crop, so Kharif fields devoted to pigeon peas would remain occupied through both crop seasons.

Irrigation enables a secondary Rabi season that runs from November through February. More than 98% of cultivated plots in our study areas are irrigated, and total area farmed does not decrease among study farmers from Kharif to Rabi. The main commercial crop in this season is wheat, grown by over 85% of control farmers and covering 60% of farmed land. Mustard seeds and pulses are the next most common, each accounting for another 11% of farmed acreage. The pulses program specifically promoted red lentils (*masoor*) in Rabi, but implementers also provided extension support for other pulse crops.

In a small subset of project areas, soil conditions accommodate a third Zaid season in March–April. Fields are typically left fallow in these months as this is the hottest and driest time of year. However, in low-lying fields, the soil retains enough residual moisture to enable irrigated cultivation of green gram (*moong*). This season remained a minor focus of the pulse program as it was only viable for a small fraction of project farmers and could not scale up to other parts of the state or country.

3 | RESEARCH DESIGN

We evaluate two interrelated experiments to measure the effect of input and output market support on farmers' adoption and production of pulses. Primary support activities take place over the first two project years, spanning six cropping seasons in total. The second output support experiment takes place in treated villages from the primary experiment in the year after input support expired. In this section, we describe the interventions, randomization design, and evaluation data.

3.1 | Theory of change

We first present a simplified model to motivate this evaluation. This stylized model captures the central theory behind the pulse support program that, with access to quality seeds, new varieties, improved inputs, and better agronomy, farmers can significantly enhance their productivity with pulses compared to traditional production methods. Upgrading is captured by a shift from traditional to "modern" pulse production techniques at the core of this simple model.

Consider a farmer that can produce output using either a traditional (L) or modern (H) production technology. In a cropping season, the farmer chooses a technology $T \in \{L, H\}$ and a level of inputs x, and then produces output $f_T(x)$. Under the traditional technology, let $f_L(0) = 0$, and let $f_L(x)$ be increasing and concave in inputs. The modern technology requires up-front investment (e.g., for hybrid seeds), so that $f_H(x) = 0$ when inputs fall below some threshold $x \le \underline{X}$. Let $f_H(x)$ also be increasing and concave above this threshold. Further, let there be a crossover point $\overline{X}$ below which $f_L(x) \ge f_H(x)$ and above which $f_L(x) \le f_H(x)$. That is, at low input levels, the traditional technology produces more, but with sufficiently high investment, the modern technology dominates.

Figure 1a represents the pre-intervention equilibrium. Farmers maximize profits, written as revenue minus cost $\pi(x) = pf(x) - x$, for each technology by choosing inputs so that the slope of the production function equals the (inverse of) market price.[5] Farmers choose whichever option delivers higher profits at this price, which in this case is the traditional technology.

The primary intervention lowers the required level of investment $\underline{X}$ for the modern technology by subsidizing modern inputs. This treatment, which effectively shifts the farmer's modern production function to $f_H(x+s)$ for a subsidy value s, is depicted in Figure 1b. The policy package provides enough support that adoption becomes profitable.

With intensive extension, we test the hypothesis that experience raises the return to inputs in the modern technology. This can be most directly attributed to learning-by-doing. If there are returns to experience in production, then a one-time policy that provides the impetus for initial adoption can raise profitability to sustain modern practices in the long run. This effect is described conceptually as a post-intervention production function of $f'_H(x) > f_H(x)$ in the domain $x > \underline{X}$, as depicted in Figure 1c. We test this hypothesis against the alternative that post-subsidy production returns to the equilibrium in 1a.

A related possibility is that experience resolves uncertainty about returns. If farmers are risk-averse and heterogeneous in ability, then uncertainty about their private returns to a new technology can lower the expected utility of adoption. Even if experience does not alter any individual's productivity, it can induce greater adoption on average if it gives individuals more precise information about where they fall in the population distribution. Without an independent measure of farmer ability, we cannot differentiate between these mechanisms. Nevertheless, both theories generate the prediction that a short-term intervention to promote adoption of a new technology can induce a persistent increase in utilization.

Marketing support complements the input intervention by augmenting the sale price. Raising the output price leads to flatter isoprofit curves, and if the price is sufficiently high then the modern technology becomes optimal as depicted in Figure 1d. In the first experiment, we support sales through FPCs that can negotiate in bulk, and in the second experiment, we measure the impact of an additional output subsidy. Furthermore, we explicitly test the role of risk relative to expected return in the second experiment by varying whether the subsidy is applied uniformly across the distribution of possible outcomes or selectively insures against low price realizations in the form of a price floor.

3.2 | Description of interventions

We evaluate two sets of policies intended to increase pulse production in our areas of study. The primary intervention aims to trigger permanent change in cropping practices with an input-intensive

[5]This formulation with linear isoprofit curves abstracts from the opportunity cost of cultivating pulses in lieu of competing crops. If farm-level constraints—such as in land availability, credit for inputs, or managerial capacity—lead pulses to displace other crops, this would appear in the model as convex isoprofit curves as the shadow value of the constrained factor would increase with pulse scale. The main qualitative insights of the model would remain unchanged in this alternative formulation.

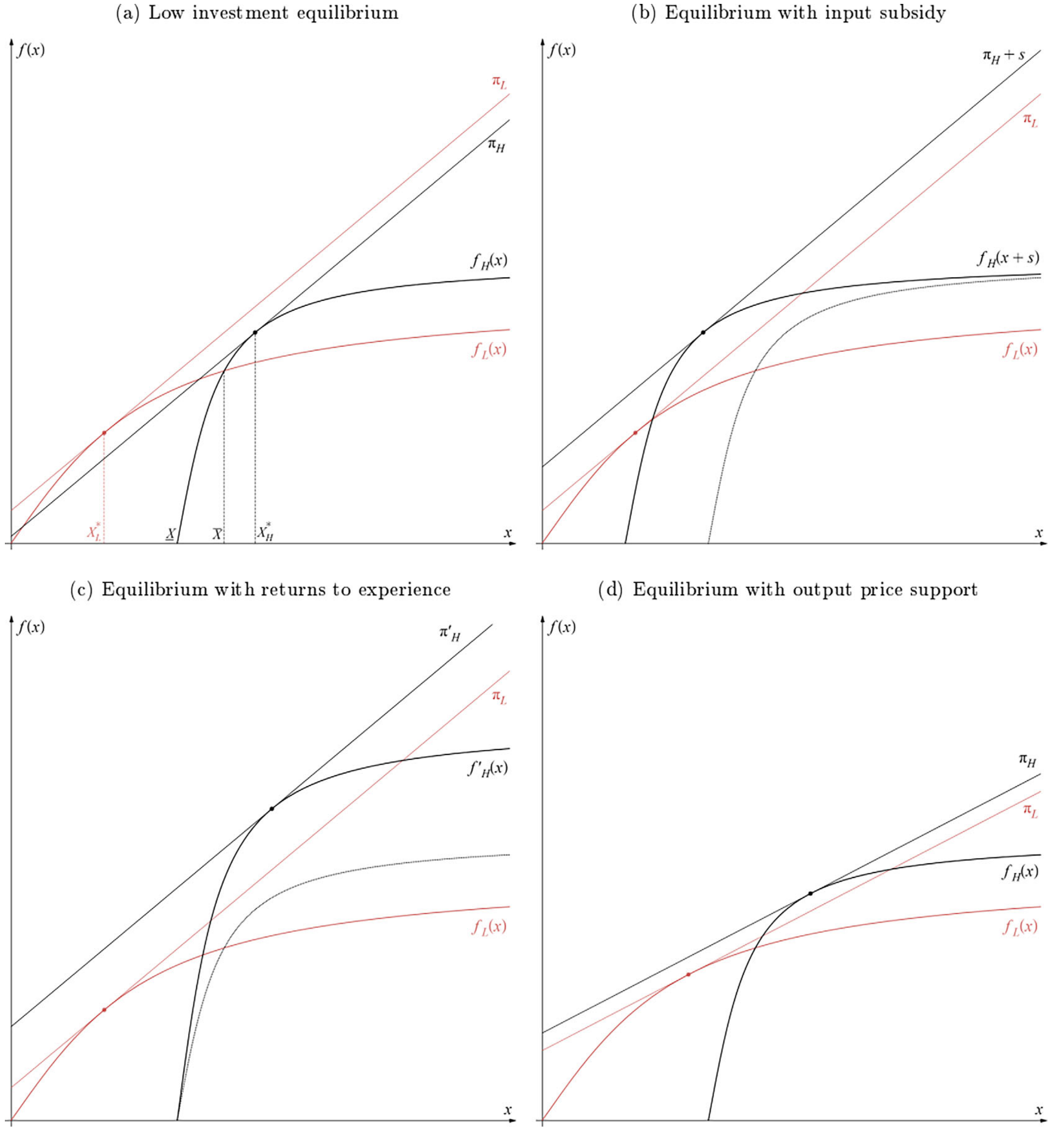

FIGURE 1 Theory of change. Production functions and isoprofit curves at the optimal level of production. $f_L(x)$ represents traditional production technology, and $f_H(x)$ represents modern technology. (a) Pre-study equilibrium with low investment and output. Profit from low investment (X_L^*) with traditional technology exceeds profit from high investment (X_H^*) with modern technology. (b) Equilibrium during input intervention with subsidy s for modern variety seeds and inputs. Subsidized profit from modern technology now exceeds profit from traditional technology. (c) Post-intervention equilibrium when there are returns to experience. Production function with modern technology grows from $f_H(x)$ to $f'_H(x)$, and is now more profitable than traditional technology. (d) Equilibrium with output price support. An increase in the output price flattens isoprofit curves, creating the possibility that modern technology dominates traditional technology even under the existing production functions without returns to experience.

package of short-term support along with an attractive outlet for sale of surplus. The secondary intervention tests whether changes in cropping practices can be sustained through subsidies to the sale of outputs.

Primary intervention: Pulse promotion and support

The input support package consists primarily of input subsidies combined with extension support for a 2-year period spanning four cropping seasons. Project implementers sourced modern-variety pulse seeds, listed in the online Supplementary Appendix: Data S1, from a seed bank for distribution to farmers. Local agronomists then provided specialized extension support for the promoted crops as well as additional guidance on other pulse crops, most commonly fava beans and green peas.

Pulse project farmers had the option to receive subsidized pulse seeds—free in the first year and at a 50% discount in the second year—under the soft conditionality that they plant what they receive and not resell. Through the life of the experiment, farmers in control villages had the option to purchase project seeds at market price as well. Therefore, the intervention tests the marginal effect of temporary subsidies and extension while holding market access to input quality constant across treatment and control arms.

Input subsidies were combined with agricultural extension. In the first study year, extension intensity in treated villages varied experimentally as well. One third of treated villages received a high-intensity extension package where agronomists managed demonstration plots to showcase best-practices and made two visits per month to provide individualized feedback and support. The remaining two thirds of treatment villages retained access to free seeds but received minimal extension, with between zero and two total visits by extension agents to conduct group training without hands-on demonstration or individualized feedback.[6] In the second year, all treatment villages received high-intensity extension, so all treated farmers had seen demonstration plots and received individualized feedback by the end of the two intervention years.[7]

At the end of the two input support years, the program established an outlet to sell surplus pulse production. Implementers created FPCs in treated areas to enable bulk sales of output. These FPCs negotiated directly with millers to secure higher prices than were available in the local market, with the gains reflected in the FPC procurement price.

In treated villages, activities were channeled through a village farmer group. Farmers planning to cultivate pulses joined the farmer group, and the group was responsible for delivering subsidized seeds, announcing extension visits by agronomists, and all other pulse-related interventions. FPC membership also drew heavily from farmer group members who wished to continue commercial pulse cultivation. No such group was formed specifically for pulses in control villages, but farmer groups for other crops and investments existed in the region throughout the duration of the experiment.

Output intervention: Price support

The output experiment tests the price elasticity of pulse supply by offering price supports to producers. Supports took the form of either a per-unit subsidy or guaranteed price floor, matching India's MSP program, to separately identify farmers' sensitivity to expected returns and to risk (see Donovan, 2020).

This intervention was implemented exclusively within treated villages from the input experiment, and took place in year three during the two cropping seasons immediately after input intervention activities had concluded. In this second experiment, villages were assigned to either control, where farmers could sell output at the market rate secured by the FPC, or to one of two treatment arms

[6]Heterogeneity in treatment intensity was initially introduced for a short-term cost–benefit analysis, and its effect on first-year pulse takeup is explored more thoroughly by Anderson et al. (2022).

[7]After the second year, implementers remained involved with project villages and may have provided informal guidance, but no funding was allocated to these activities.

where this rate was augmented by a price support. Treatment status was announced ahead of the planting season to allow participants to adjust inputs according to their anticipated returns.

Farmers in half of treated villages in this experiment received support as a price floor. The floor was set to match the MSP offered by the Government of India. While the MSP is a national policy, it was never implemented in Bihar. Therefore, it was not binding at the time of the experiment, and local wholesale prices had fallen below the MSP level multiple times in years prior. This policy effectively eliminates very low sale price realizations. As a result, it both raises the expected returns to pulse sales as well as lowers the ex ante variance of possible returns. In the other half of treated villages, farmers were offered a per-unit subsidy calibrated to match the average effective subsidy the MSP would have offered in the 10 years prior. This policy has the equivalent impact on expected returns without altering variance.

Subsidies were applied directly to FPC procurement, and FPCs did not have the opportunity to renegotiate with subsidized farmers. Therefore, this intervention can be seen as a direct shock to the farmgate sale price, and we measure the output elasticity in the context of FPC procurement. It remains an open question how comparable subsidies applied at other stages along the supply chain may pass through to farmgate prices or otherwise alter production behavior.

3.3 | Randomization and sample selection

Both experiments employ village-level randomization. The primary experiment comprised 158 villages, out of which 99 were assigned to receive input support over 2 years. Among treated villages, extension intensity experimentally varied for 1 year with 33 villages receiving the full extension package and 66 receiving only subsidized seeds with minimal extension. In the second year, all treated villages received the full support package with demonstration plots and individualized feedback. Input subsidies and extension concluded after the second year, and newly formed FPCs recruited farmers from treated villages for marketing support in the third year. The randomization design for the primary experiment is outlined in the top part of Figure 2. Village-level randomization for this experiment was stratified by block (a subdistrict administrative unit typically comprising several dozen villages) with two participating blocks in each district.

Primary outcome data come from surveys of a random sample of farmers in each study village. To ensure experimental comparability across treatment and control arms, we selected the survey sample before assigning treatment status. At the start of the study, ahead of the initial Kharif planting period, we held a kickoff meeting in each study village to identify farmers potentially interested in growing pulses. We then randomly selected around seven households per village from kickoff meetings that make up the survey sample for the life of the experiment. This strategy ensures that initial sampling is not influenced by project participation in treatment villages.

Table 1 provides baseline summary statistics for households surveyed as part of the first experiment. The first survey round took place after the initial experimental Kharif planting, so we restrict balance tests to slow-moving measures of household demographics. In each household we conducted simultaneous surveys with both the main farmer as well as the primary food preparer. The first two panels present details about survey respondents. Farm respondents, predominantly male, are typically near 50 years old, and over half have completed primary education. The primary food preparers, almost exclusively female, are typically in their mid thirties, and equally as well-educated as the farm respondents. The two respondents were frequently spouses, but father-in-law/daughter-in-law pairs were also common. The third panel of Table 1 presents household characteristics for the study sample. Notably, nearly two thirds of study households have planted pulses in some form in the past, predominantly as a border crop for home consumption.

Despite randomization, Table 1 reveals imbalance between treatment and control along several dimensions. Treated households tend to be slightly smaller on average, with slightly more educated primary farmers. Consistent with this educational gap, treatment households report owning more

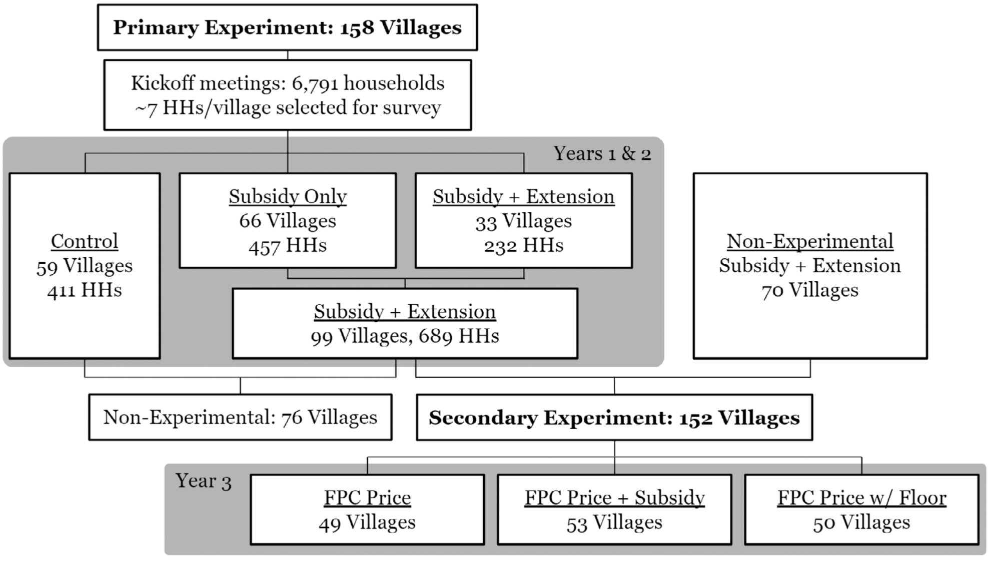

FIGURE 2 Randomization design for input and output experiments.

assets on average, though the scale of farming is consistent across study arms. Covariate imbalance may arise due to randomization error or selective attrition from surveying after treatment status was announced. To minimize its potential influence, all analysis controls for household characteristics and respondent demographics as prespecified. In the online Supplementary Appendix: Data S1 we confirm all findings are robust to using post double lasso for covariate selection (Belloni et al., 2013) and reweighting for entropy balance (Hainmueller, 2012).

The secondary output support experiment took place in the third project year, after input activities concluded. Farmer groups from 82 of the 99 treated villages were incorporated into FPCs[8] along with new 70 non-study villages that had also previously received input support. Farmers in these 152 FPC villages were randomly assigned to either receive the standard FPC price, the FPC price plus a fixed subsidy, or the FPC price with a price floor, with assignment spanning the Kharif and Rabi seasons. Figure 2 outlines the full randomization design with transitions across years.

Evaluation data for the second experiment come from newly created FPC administrative records, so no baseline exists. To test for balance in randomization, we match study villages to the 2011 Socioeconomic and Caste Census (Asher et al., 2021; Government of India, 2011) using village names and geolocations recorded by program implementers. We are able to match 98 of 152 study villages distributed evenly across treatment assignment. The majority of unmatched villages come from the West Champaran district, where implementers recorded the farmer group headquarter location rather than village details. Table 2 reports village means by treatment assignment for demographic characteristics and agricultural intensity. A joint F–test fails to reject equality across groups over all characteristics.

3.4 | Data collection and analysis

Data for the primary evaluation come from a series of household surveys asking about agricultural input, production, and consumption. In the third study year, we also conduct an incentive-compatible elicitation of demand for pulse seeds. Data for the output price evaluation come from

[8]One block was dropped due to pre-existing FPC activity.

TABLE 1 Baseline characteristics by input experiment treatment status.

Variable	(1) Total Mean/SE	(2) Control Mean/SE	(3) Treated Mean/SE	Difference (2)–(3)
Farm respondent				
Male	0.850	0.868	0.840	0.028
	(0.012)	(0.018)	(0.016)	
Age	48.952	48.264	49.371	−1.107
	(0.531)	(0.884)	(0.664)	
Primary school	0.616	0.548	0.658	−0.109***
	(0.016)	(0.027)	(0.020)	
Secondary school	0.449	0.390	0.485	−0.095***
	(0.017)	(0.026)	(0.021)	
Food respondent				
Male	0.006	0.008	0.004	0.003
	(0.002)	(0.004)	(0.003)	
Age	35.947	35.627	36.142	−0.515
	(0.397)	(0.646)	(0.505)	
Primary school	0.557	0.506	0.588	−0.082
	(0.029)	(0.050)	(0.036)	
Secondary school	0.434	0.391	0.461	−0.069
	(0.029)	(0.049)	(0.037)	
Household				
HH size	6.984	7.524	6.656	0.868***
	(0.122)	(0.217)	(0.143)	
SC/ST	0.161	0.179	0.150	0.029
	(0.012)	(0.021)	(0.015)	
Past pulses	0.656	0.642	0.665	−0.023
	(0.016)	(0.026)	(0.020)	
Asset index	−0.107	−0.253	−0.018	−0.235**
	(0.051)	(0.078)	(0.067)	
Land owned	1.570	1.383	1.684	−0.301**
	(0.060)	(0.090)	(0.080)	
Households	902	341	561	

Note: Mean values of household baseline covariates with standard errors in parentheses. Wealth and land area are censored at the 95th percentile. Column 3 reports differences in means across groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

FPC administrative records. Because all interventions are implemented experimentally, analysis follows a straightforward regression design with dummies for treatment status.

Household survey data

Data for the primary evaluation come from six rounds of surveys that took place over the three intervention years. Surveys are conducted in May/June after the Rabi (and, if applicable, Zaid) harvest and in November/December after the Kharif harvest. This timing allows us to ask about both

TABLE 2 2011 village characteristics by output experiment treatment status.

Variable	(1) Control Mean/SE	(2) Subsidy Mean/SE	(3) Floor Mean/SE	Difference (1)–(2)	(1)–(3)
Num. HHs	944.500	747.889	978.467	−196.611	33.967
	(271.256)	(119.557)	(169.755)		
HH size	6.049	5.766	5.974	−0.283	−0.076
	(0.218)	(0.166)	(0.214)		
SC/ST	0.068	0.069	0.052	0.001	−0.016
	(0.008)	(0.011)	(0.007)		
Primary school	0.440	0.400	0.465	−0.040	0.025
	(0.022)	(0.023)	(0.028)		
Secondary school	0.154	0.143	0.176	−0.011	0.022
	(0.016)	(0.014)	(0.016)		
Solid roof	0.548	0.505	0.534	−0.043	−0.014
	(0.046)	(0.043)	(0.049)		
Frac. landowners	0.370	0.379	0.401	0.009	0.031
	(0.033)	(0.027)	(0.034)		
Land owned	5.238	7.759	4.080	2.521	−1.158
	(1.522)	(1.962)	(0.894)		
Share irrigated	0.663	0.745	0.728	0.082	0.065
	(0.045)	(0.038)	(0.034)		
Ag. Empl. share	0.217	0.159	0.200	−0.058*	−0.018
	(0.027)	(0.020)	(0.023)		
Ag. primary income	0.215	0.178	0.187	−0.037	−0.028
	(0.028)	(0.019)	(0.022)		
Villages	49	53	50		
Matched to SECC	32	36	30		
F-test of joint significance				0.997	0.672

Note: Mean values of village characteristics reported in 2011 Socioeconomic and Caste Census with standard errors in parentheses. Columns 4 and 5 report differences in means across groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

the output from the previous harvest as well as planting and input decisions for the coming season. We preserve the same survey households over time to generate a panel spanning the life of the experiment.

In each survey round, we separately interview both the primary farmer and food preparer, typically a husband and wife pair. Farm respondents are asked about agricultural inputs, production, and profits. Food preparation respondents are asked about food consumption and seed stocks. This breakdown corresponds to typical domains of responsibility in our study area.

The final round was scheduled for June 2020 after the conclusion of all experimental activities. Due to the COVID-19 pandemic, this survey was pushed back to August and conducted by phone. As a result, only a subset of outcomes are available from this round. Regression analysis controls for level differences between phone and in-person responses through survey round fixed effects, so that all experimental comparisons are made between treatment and control farmers within the same survey round.

Experimental seed auction

Additional evaluation data come from two incentive-compatible seed demand elicitations. These elicitations were conducted as experimental auctions (see Lusk & Shogren, 2007) after the input intervention had concluded and prior to the third-year Kharif and Rabi planting periods.[9] We elicit input demand at multiple possible prices to provide additional evidence on the sustained effects of temporary input support.

FPC administrative records

Data for the second evaluation come from FPC administrative records on seed purchases, area planted, and sales. At the time of planting, FPCs took over the NGOs' role of sourcing and delivering certified pulse seeds, which they sold to member farmers at market price. They monitored members' area planted and anticipated output through the growing season to forecast sales volume, and then recorded the actual quantity delivered by each member farmer at harvest. These outcomes were recorded identically across payment arms and are therefore experimentally comparable.

3.5 | Methodology

We estimate the intention-to-treat (ITT) effect of the primary intervention on the panel of in-person survey outcomes using the regression specification

$$Y_{it} = \sum_{\tau} \beta_\tau T_i \times \mathbf{1}\{t=\tau\} + \alpha_t + \gamma_{b(i)} + X_i'\delta + \epsilon_{it} \tag{1}$$

where Y_{it} is an outcome of interest for household i in block $b(i)$ in year t, and T_i is a dummy indicating the treatment status of household i. The coefficients of interest β_τ represent year-specific treatment effects. α_t are year fixed effects that reflect the control mean, $\gamma_{b(i)}$ control for block-specific fixed effects, and the vector X_i controls for time-invariant household characteristics.[10]

We report the intention-to-treat effect, rather than the treatment-on-treated among farmer group members, because the intervention may have delivered indirect benefits to non-members. Those in treatment villages who did not join the pulse farmer group may have still participated in extension activities, received instructions or seeds from friends or neighbors, or otherwise altered their pulse cultivation. Therefore, we refrain from ascribing program effects exclusively to those that officially joined a farmer group.

Endline results include seed demand elicitations that do not have a panel structure, so we evaluate treatment effects using a simple cross-sectional comparison across treatment arms. Formally, this regression takes the form

$$Q_{icp} = \beta T_i + \sigma_c + \phi_p + \gamma_{b(i)} + \epsilon_{icp} \tag{2}$$

[9]Auctions were integrated into how FPCs and supporting partners elicited seed orders for the upcoming production season. Details are provided in the online supplementary appendix.

[10]For analysis of pulse production, control variables include the farmers' gender, age, and education level, caste, asset ownership at the start of the program, and a binary variable indicating whether the household had cultivated any type of pulses at least once in the two years preceding program implementation. For analysis of consumption in the food and nutrition survey, we control for the food respondent's age and education level as well as other household characteristics.

where Q_{icp} denotes the quantity demanded by individual i for seeds of crop c at price p. The coefficient of interest, β indicates how this demand differs on average for individuals originally in treatment villages, and γ again represent block fixed effects.

We evaluate the ITT effect of the secondary output price intervention using administrative data from FPCs, which allow for within-household comparisons across crops for agricultural inputs. Formally, we estimate

$$Y_{ic} = \beta^S \text{Subsidy}_{ic} + \beta^F \text{Floor}_{ic} + \phi_c + \gamma_i + \epsilon_{ic} \tag{3}$$

where Subsidy_{ic} and Floor_{ic} are indicators for whether household i was offered an output price subsidy or price floor, respectively. This was offered for only one crop per season so we are able to make within-household comparisons to measure whether households with price supports devoted relatively more resources to the supported crop compared to other pulse types.

For sales, we only observe data on the subsidized crop sold to the FPC. Because of this data limitation, we cannot distinguish whether any increase in sale to the FPC reflects displaced sales to other outlets, diminished stocks for home consumption, or, to the extent that production expands, greater marketable surplus. In practice there are few alternative pulse buyers in the market and little evidence of change in inputs, so excess sales likely come out of output saved for home consumption. For sales outcomes, we estimate

$$Y_v = \beta^S \text{Subsidy}_v + \beta^F \text{Floor}_v + \gamma_{b(v)} + \epsilon_v \tag{4}$$

For this regression we aggregate to the village level, indexed by v, to account for selection into selling to the FPC. All specifications use heteroskedasticity-robust standard errors clustered at the village level.

Given the number of survey outcomes, we apply two adjustments for multiple hypothesis testing. First, we group outcomes into families and control the false discovery rate within family following Anderson (2008). Regression tables report q-values that represent the probability of false positives (i.e., the Type I error rate) among statistically significant results using the two-stage procedure of Benjamini et al. (2006). Survey outcomes are grouped into adoption, consisting of fraction adopting and pulse area sown in each season; production, consisting of reported output in each season and total annual months of household pulses; yield, consisting of production per acre in each season; profitability, consisting of net profit, production revenue, sales revenue, production cost, and total area farmed; and pulse consumption, consisting of current household stock, per capita pulse consumption, and per capita protein consumption. Each table of results represents a separate outcome family.

Second, we combine outcomes for production, profitability, and consumption into single indices following Anderson (2008). We do not compute an index for yield because there are only 43 farmer-year observations in which a farmer grows pulses, and therefore has measured yield, in all three seasons. Principal components analysis construction details and results are presented in the online Supplementary Appendix: Data S1.

We use a balanced panel of households that participated in all survey rounds as the basis for the estimation results. We discuss attrition and verify robustness to including all survey households in the online Supplementary Appendix: Data S1.

3.6 | Timeline

Evaluation ran from 2017 to 2020. The input intervention began with the May 2017 Kharif planting and ran for 2 years through the May 2019 Zaid harvest. Output subsidies were offered in the third

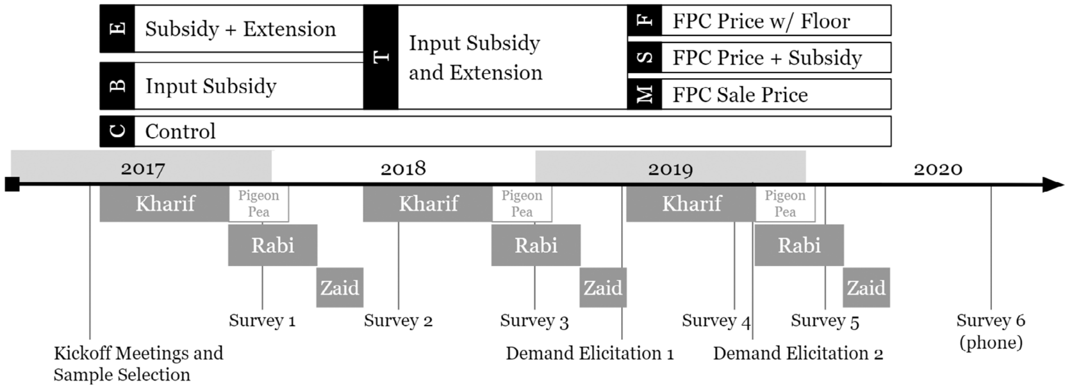

FIGURE 3 Timeline of activities.

year for November 2019 Kharif and April 2020 Rabi harvests, with seed demand elicitations during the corresponding planting periods. Data collection concluded in August 2020. We provide a full study timeline in Figure 3.

Note that the initial survey round took place during the first Rabi season of the input intervention. In this survey we ask about the prior year's production as well as household demographic characteristics. Although the survey was conducted after the intervention had begun, it is well before the pigeon pea when households would realize the majority of profits or other agricultural outcomes from decisions made in response to treatment assignment. Therefore, we use recall and demographic data from this survey as baseline covariates in regression analysis.

4 | RESULTS

In this section we present results on the impact of input subsidies, agricultural extension, and marketing support over 3 years. Additional analysis in the online Supplementary Appendix: Data S1 shows the results presented here are stable across related regression specifications and explores heterogeneity in treatment response.

4.1 | Impact of input support on pulse cultivation

Farmers expanded pulse production activities when input support was in place, but subsequently scaled back to normal. This fact is most clearly demonstrated in Figure 4. The top row shows the fraction of farmers planting pulses in each season and year of study. The input support program initially increased the fraction of farmers growing pulses by nearly double in the Kharif season, 50% in the Rabi season, and more than triple in the Zaid season. However, these differences dwindled in the second year, when subsidies were lowered. Second-year pulse adoption by treated farmers was statistically indistinguishable from control in every season except Rabi, where implementers focused the most effort. By the third year, when subsidies and extension had ended, pulse adoption among treated households was nearly identical to and statistically indistinguishable from control. Estimates are provided in the odd-numbered columns of Table 3.

Greater adoption was, for the most part, not accompanied by substantial increases in area planted. In the initial Kharif season, the fraction of area devoted to pulses was roughly three percentage points greater among treated farmers than control, with the expansion largely displacing land devoted to rice. The program effect on pulse area is statistically indistinguishable from zero in every

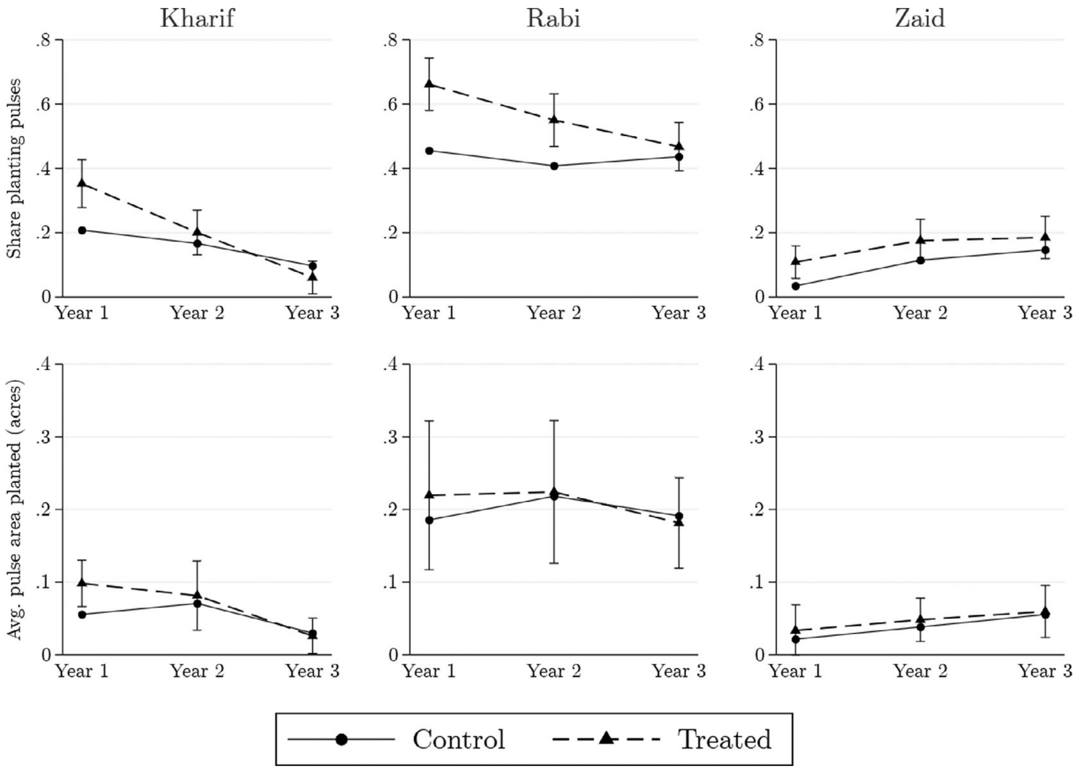

FIGURE 4 Pulse adoption and area sown. Graphical representation of regression estimates reported in Table 3.

other season, and point estimates of the difference in area planted among treated farmers are far smaller in magnitude than the rates of adoption relative to the control mean. Results are displayed in the bottom panels of Figure 4 with point estimates in the even-numbered columns of Table 3. The patterns of adoption and area planted are consistent with treated farmers experimenting with pulses on a small portion of land while subsidies and extension are available, but ultimately rejecting their viability as a major crop.

Elicitation of seed demand verifies lower desire for pulse inputs among treated farmers following 2 years of intervention. Table 4 reports results from our incentive-compatible auction. All survey farmers were invited to the seed auction, but only half elected to participate. As shown in Column 1, the difference in participation between treatment groups is negligible. In each village, survey teams recruited additional volunteers on the day of the elicitation to fill available spots in each session.

Seed auction participants reported quantity demanded over a range of prices, and one price was selected randomly for actual sale to ensure incentive compatibility. Columns 2 and 3 of Table 4 report differences in seed demand by treatment arm. Column 2 measures stated demand at the elicitation. Demand is lower for all seed types among treated farmers. To verify demand is not depressed due to saved seeds[11] from prior harvest years, in Column 3 we report the sum of stated demand and self-reported seed storage. This measure of total planned input use again reveals that post-intervention, there is lower desire to continue growing pulses among treated farmers.

We plot the full inverse demand curve for seeds by crop type in Figure 5. Demand curves are downward sloping, indicating continued subsidies could help sustain greater pulse cropping. However, seed demand is consistently lower among previously treated farmers than in control at

[11]Seeds harvested from hybrid cultivars can typically be reused for 1–2 seasons before needing replacement.

TABLE 3 Adoption and area cultivated by input treatment status.

	Kharif		Rabi		Zaid	
Variable	Adoption (1)	Area (2)	Adoption (3)	Area (4)	Adoption (5)	Area (6)
Treat Yr. 1	0.144***	0.043	0.206***	0.034	0.074*	0.012
	(0.04)	(0.02)	(0.04)	(0.05)	(0.03)	(0.02)
	[0.006]	[0.122]	[0.000]	[1.000]	[0.073]	[1.000]
Treat Yr. 2	0.034	0.011	0.142**	0.006	0.061	0.010
	(0.04)	(0.02)	(0.04)	(0.05)	(0.03)	(0.02)
	[1.000]	[1.000]	[0.017]	[1.000]	[0.758]	[1.000]
Treat Yr. 3	−0.037	−0.004	0.031	−0.010	0.038	0.004
	(0.03)	(0.01)	(0.04)	(0.03)	(0.03)	(0.02)
	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]
Year 2	−0.041	0.015	−0.047	0.033	0.080	0.017
	(0.03)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)
Year 3	−0.111	−0.026	−0.019	0.006	0.112	0.034
	(0.04)	(0.01)	(0.04)	(0.05)	(0.03)	(0.02)
Control mean	0.21	0.06	0.46	0.19	0.03	0.02
R-Squared	0.21	0.10	0.18	0.12	0.09	0.08
Observations	2511	2511	2511	2511	2004	2004

Note: Regressions according to (1). Standard errors clustered at the village level reported in parentheses and sharpened q-values in square brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level after q-value adjustment.

TABLE 4 Seed demand by input treatment status.

	Survey	Seed quantity (kg.)	
Variable	Participate (1)	Purchased (2)	Total (3)
Treat	0.0216	−0.174*	−0.712**
	(0.0336)	(0.105)	(0.323)
Price = 60		0.824***	0.824***
		(0.0519)	(0.0519)
Price = 80		0.445***	0.445***
		(0.0350)	(0.0350)
Price = 100		0.245***	0.245***
		(0.0227)	(0.0227)
Price = 120		0.0998***	0.0998***
		(0.0151)	(0.0151)
Control mean	0.46	0.94	3.04
R-Squared	0.03	0.14	0.13
Observations	3244	17,865	17,865

Note: Regressions according to (2). Control mean evaluated at price of Rs. 140. Standard errors clustered by village reported in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

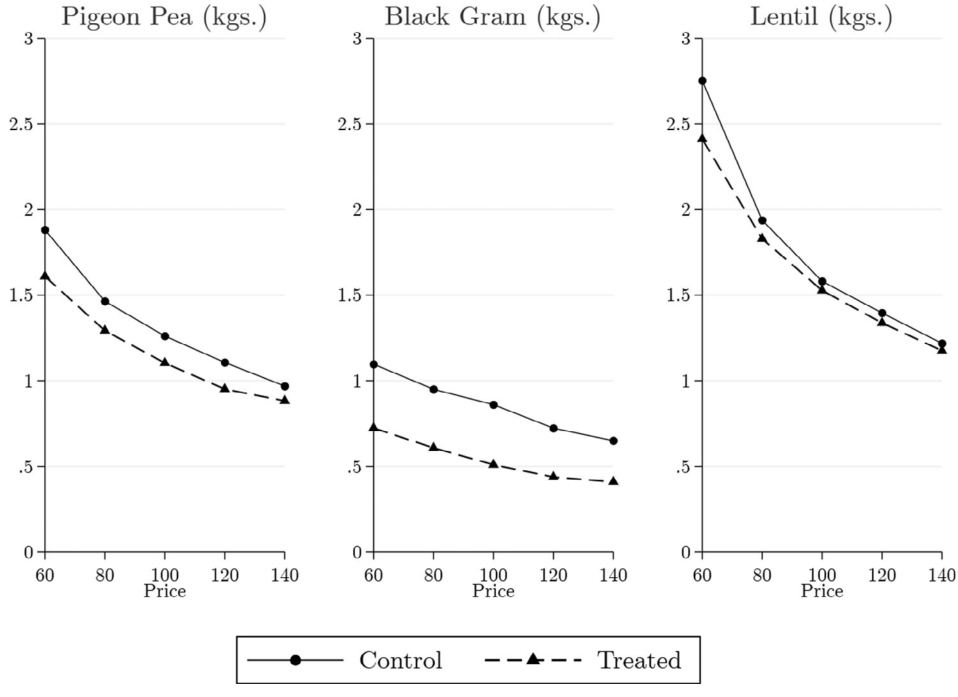

FIGURE 5 Seed demand curves. Average quantity demanded at each price in incentive-compatible elicitation of demand for coupon for certified seeds delivered by FPC.

every price. This result would suggest that, to the extent that farmers updated their beliefs about pulses during the intervention period, they inferred that the returns to pulse cropping were toward the unprofitable end of their prior expectations.

4.2 | Project participation

The lack of a sustained change in pulse practices was not a result of low interest or engagement among survey respondents. Survey households were sampled from those in attendance at the initial kickoff meeting held before treatment assignment. Kickoff meetings were advertised as forums for farm households interested in learning about modern pulse cultivation, so attendance selected for those most amenable to improving technology. Participant interest is confirmed by actual enrollment, as on average, 54% of treated respondents joined a pulse farmer group. In the online Supplementary Appendix: Data S1 we provide evidence that program engagement led to experimentation with modern cropping techniques.

Average farmer group enrollment masks heterogeneity by district. In particular, only 31% of attendees joined a farmer group in treated villages in Samastipur, well below other districts. Low engagement among the survey sample could attenuate measured program effects if enrollment is a proxy for receptiveness to the program within the sampling frame. In the online Supplementary Appendix: Data S1, we verify that results using survey outcomes are robust to excluding Samastipur from analysis, indicating that attenuation from the inclusion of uninterested survey respondents is minimal.

Despite high program engagement, we observe little evidence of increased pulse yields among treatment villages. Table 5 reports yields by year and treatment status. Regression reveals no statistically significant difference in yield between treatment and control farmers. In the online

TABLE 5 Pulse productivity by input treatment status.

Variable	Yield (kg./acre) Kharif (1)	Rabi (2)	Zaid (3)
Treat Yr. 1	14.766	−41.347	−27.228
	(23.11)	(122.26)	(54.87)
	[1.000]	[1.000]	[1.000]
Treat Yr. 2	−19.712	65.481	2.866
	(42.18)	(113.67)	(35.83)
	[1.000]	[1.000]	[1.000]
Treat Yr. 3	3.433	−132.453	23.500
	(42.93)	(78.48)	(42.02)
	[1.000]	[1.000]	[1.000]
Year 2	113.998	−123.052	−31.076
	(39.00)	(78.73)	(57.41)
Year 3	70.297	−216.638	−59.724
	(32.17)	(92.90)	(51.85)
Control mean	64.37	466.74	140.84
R-Squared	0.11	0.04	0.20
Observations	555	1179	252

Note: Regressions according to (1). Standard errors clustered at the village level reported in parentheses and sharpened q-values in square brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level after q-value adjustment.

Supplementary Appendix: Data S1, we confirm these results hold regardless of first-year extension intensity.

Measured yield should be interpreted with two caveats in mind. First, yield is only observed conditional on adoption, so there may be selection effects in comparisons of yields between treatment and control. If treatment draws less skilled farmers or more marginal lands into production, then this may lower realized yield. Second, yield is constructed as the ratio of two self-reported measures, and therefore inherently noisy.

4.3 | Production, profitability, and household consumption

The results above indicate by revealed preference that farmers experimented with modern pulse cultivation but did not find it to be more profitable than the alternative. Survey evidence on household production, profits, and consumption supports this interpretation. Evidence on these outcomes is summarized in Figure 6 where we plot estimated treatment effects relative to the first-year control mean, and full regression details are provided in the online Supplementary Appendix: Data S1.

The top panel shows treatment does not produce a lasting statistically detectable difference in pulse production. We report the estimated effect of treatment on production by season and on the self-reported number of months that harvested pulses lasted in the household.[12] Results suggest production rose in treated villages in the first year, consistent with the measured increases in adoption, but subsequently fell back to its control level. While these effects are estimated with noise, other

[12]Self-reported months post-harvest was cut from the final survey round to save time during phone surveying.

related outcomes reinforce the notion that low returns led pulse cultivation to return to pre-treatment levels over time.

Output can either be sold on the market or consumed at home. The second panel of Figure 6 explores the former outlet through household agricultural profitability. We report treatment effects on net agricultural profit, production value, sales revenue, input costs, and total area farmed—a measure of the anticipated returns to agriculture. Across all years and all outcomes, the estimated treatment effect on agricultural profitability is quantitatively small relative to the control mean and statistically indistinguishable from zero. Notably, increased household pulse production in the first year did not translate into measurably greater agricultural profits. This fact suggests that even with modern practices and subsidized inputs, pulses are not more lucrative than whatever they displace.

Even if pulses do not increase profitability, households may benefit from greater protein consumption and dietary diversity. We investigate this possibility in the third panel of Figure 6. The figure reports estimated treatment effects on households' self-reported remaining stock of pulses at the time of survey, in kgs. and in months respectively; per capita pulse consumption in the prior week; daily protein consumption over the prior week; overall household food consumption; and consumption by the main food preparer alone, asked only in years two and three. Estimates mirror the profitability results. Across all years and outcomes, the estimated treatment effect is quantitatively small and statistically indistinguishable from zero. Only self-reported current pulse stocks in year two, after a full treatment year's harvest, have a positive treatment effect with a p-value less than 0.05, but this effect does not survive q-value correction.

Together, panels 2 and 3 indicate increased pulse production in the first project year neither increased farm profits nor did it substantially alter household diets. These null results suggest households did not see benefits when switching to pulse cultivation, explaining farmers' reluctance to continue without subsidies.

4.4 | Impact of output price supports

Increased pulse cultivation encouraged by input support does not persist after supports are removed. In an extension to this paper's input-side evaluation, we investigate whether output price subsidies can complement extension to sustain greater adoption. Table 6 reports the impact of a per-unit output subsidy and a guaranteed price floor on pulse cultivation and sales. Columns 1 and 2 estimate changes in area sown and volume planted, respectively, for the Kharif season. Columns 4 and 5 show the same estimates for the Rabi season. In both seasons, we compare the subsidized crop—black gram in Kharif and red lentil in Rabi—to unsubsidized crops within-household. In both cases, we find little evidence that an output subsidy shifts cultivation toward the subsidized crop.

Even though the scale of production does not vary with the anticipated output price, it appears farmers respond to price signals at harvest. A per-unit price subsidy increased the sale of lentils in the Rabi season, as reported in Column 6 of Table 6. The price floor arm did not see a comparable increase in sales, likely because the market price was sufficiently high that the floor did not bind at the time of sale. This result suggests that, while a one-time experimental subsidy was not enough to affect farmers' input choices, pulse sales respond to price signals. This combination of a sales response but no input response implies that these farm households most likely redirected their production from own-consumption to sales. This behavior might be a reflection of the short-term nature of the output subsidy treatment. Long-term price policy may have more success in shifting the equilibrium as markets develop to accommodate transaction volume—and farmers potentially respond by increasing production.

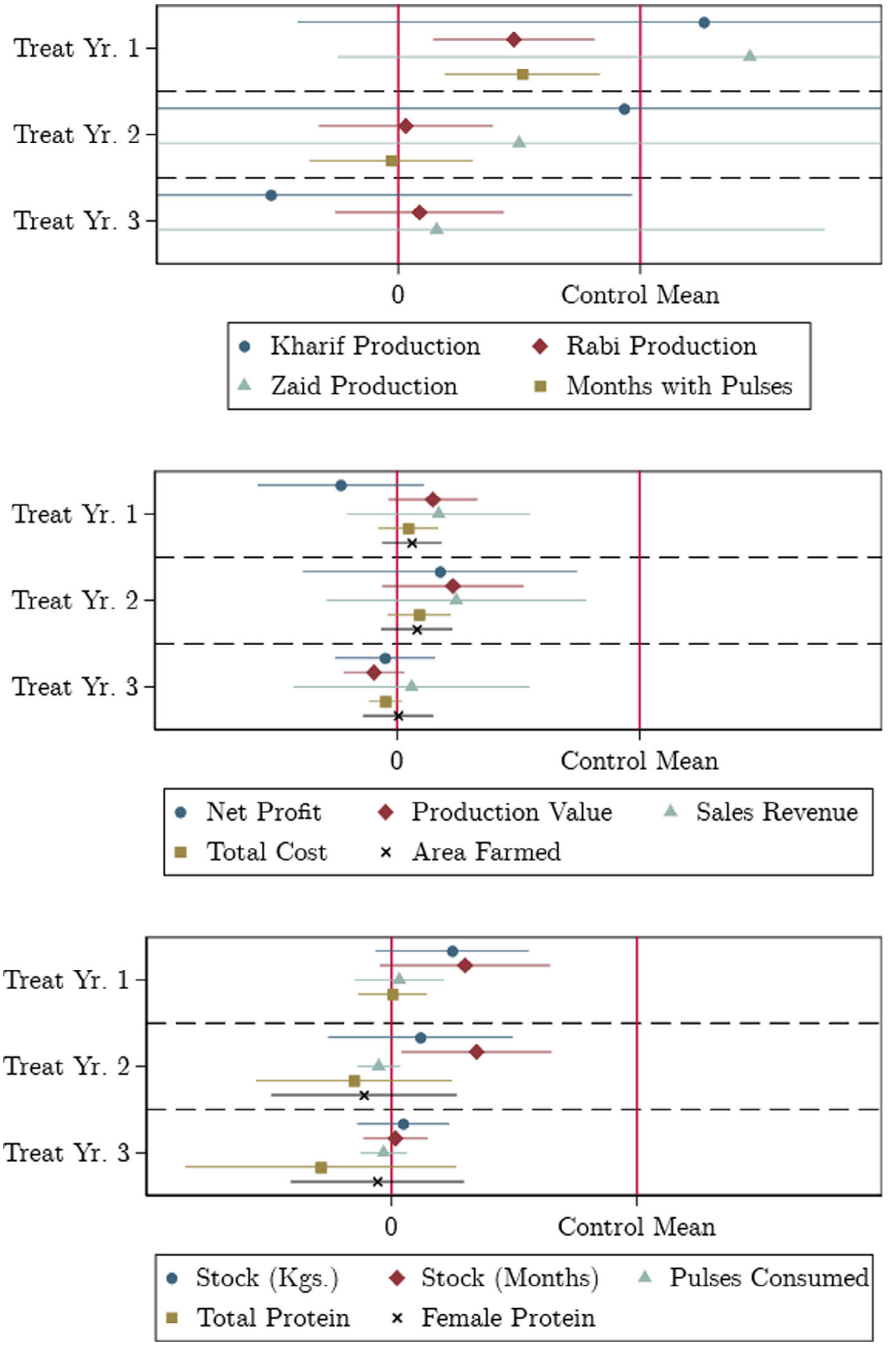

FIGURE 6 Treatment effects on production, profits, and consumption relative to control mean. Graphical representation of estimated treatment effects on production, profits, and consumption with 95% confidence intervals. Each row represents the difference between treatment and control divided by the control mean and can be interpreted as the percent change in the outcome relative to control. We report regression tables and present the same results normalized by standard deviation in the online Supplementary Appendix: Data S1.

TABLE 6 Cultivation and sales by output treatment status.

	Kharif season			Rabi season		
Variable	Area (1)	Sown (2)	Sold (3)	Area (4)	Sown (5)	Sold (6)
Subsidy	−0.000196	0.0941	5.053	0.0440	0.663	112.4**
	(0.205)	(1.305)	(18.67)	(0.152)	(1.757)	(54.83)
Price floor	0.00812	0.0388	−2.632	0.0349	0.515	29.29
	(0.179)	(1.077)	(12.81)	(0.139)	(1.683)	(36.14)
Control mean	0.09	0.98	51.48	0.15	1.86	75.36
HH FEs	X	X		X	X	
R-Squared	0.91	0.91	0.47	0.95	0.94	0.18
Observations	3356	3356	112	10,725	10,725	152

Note: Columns 1, 2, 4, and 5 report regression results according to (3). Columns 3 and 6 report regression results according to (4). Standard errors clustered by village in parentheses. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

5 | CONCLUSION

The interventions we evaluate emerged as part of the Government of India's response to the growing gap between domestic pulse production and consumption. As a complement to options such as expanding imports (Negi & Roy, 2015) and extending public distribution programs to include pulses (Chakrabarti et al., 2018), this pilot is a decentralized alternative to make pulses more available locally by stimulating smallholder production (Sibhatu et al., 2015). Prior observational studies identify lack of extension and underdeveloped local markets as barriers to pulse production (Joshi et al., 2016), especially in Northeastern Indian states (Pandey et al., 2019), and posit that alleviating these barriers could unlock greater pulse yields and production (Reddy & Reddy, 2010). Our findings indicate that extension is insufficient to convince smallholder farmers to devote land to pulses even when they have access to high quality inputs and a viable outlet for commercial sale. While we see short-term effects of input subsidies, these effects fade as incentives phase out. The only glimmer of learning we detect works against pulses as treated farmers appear to realize anew why they prefer other crops. Taken as a whole, these results suggest that even after providing strong short-term adoption incentives, intensive training, and commercial support, pulses simply cannot displace competing crops given prevailing prices and technologies.

These results stand in contrast to the evaluation by Emerick and Dar (2021) in the nearby state of Odisha, which finds sustained farm-level adoption of a flood-tolerant rice variety in response to a comparable input and learning intervention. While our context and study population are similar to theirs, there is one major difference: whereas Emerick and Dar (2021) consider rice farmers' adoption of a novel variety of the same crop, we evaluate adjustment on the margin of crop choice. Farmers in both locations have scaled back pulse production in recent generations in favor of more profitable rice and wheat production. Convincing them to reconsider pulses is a fundamentally different proposition than getting them to adopt a new and better-performing rice variety.

This difference reflects a lasting legacy of the Green Revolution. Prioritizing the production of cheap staples to meet the caloric needs of the 1940s and 1950s laid the groundwork for the nutritional challenges of today. In recent decades, priorities have shifted to include dietary diversity and micronutrient consumption (Pingali, 2012; Welch & Graham, 2000). In India, protein intake, which lags well behind comparison countries (Sharma et al., 2020), is a leading concern. Since pulses are the main source of protein (Kumar et al., 2017) and have historically been integral in traditional cuisines, increased pulse consumption is seen as an important policy target toward balanced diets (Minocha et al., 2019; Tiwari & Shivhare, 2019). Even though Indian agri-food markets are better integrated than they once were, household access to pulses remains the most significant barrier to consumption (John et al., 2021), which makes stimulating local production a compelling way to increase local pulse consumption. Yet, the Green Revolution legacy creates strong headwinds for any such effort to encourage farmers to produce the pulses their grandparents abandoned.

The potential for on-farm interventions to influence farmers' crop choice is naturally limited by the technology available to them. The varieties of pulses on offer today are not significantly more promising than those of the past. By comparison, rice and wheat varieties have improved dramatically through decades of targeted public and private investment. These technological successes have catalyzed a host of institutions, investments, and policies that continue to favor cereals. Leveling the playing field through agricultural extension and market support cannot substantively alter production portfolios as long as the pulse production frontier lags behind that of alternative crops. Serious investment in breeding and agronomy upstream to extend these frontiers is likely a pre-requisite for the kind of on-farm support we evaluate to bring pulses off the periphery and stimulate local pulse production. As long as the accumulated productivity gains and institutional momentum of cereals persist, it is hard to imagine any on-farm intervention will sustainably convince farmers to give up these favored crops for pulses. This study provides rigorous evidence to back up this hard reality.

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CONFLICT OF INTEREST STATEMENT

Authors declare we have no further conflicts of interest. No institution had the right to review results before publication.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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