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Reducing Emissions and Air Pollution from the Informal Sector: Evidence from Bangladesh
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ABSTRACT

We present results from a randomized controlled trial in Bangladesh that introduced operational practices to improve energy efficiency and reduce emissions in 276 "zigzag" brick kilns. 65% of intervention kilns adopted the improved practices. Treatment assignment reduced energy use by 10.3% (p-value<0.001) and decreased CO2 and PM2.5 emissions by 171 metric tons and 0.45 metric tons, respectively, per kiln per year. Valuing the CO2 reductions using a social cost of carbon of $185/MT, we find that the social benefits outweigh costs by a factor of 190 to 1. The intervention, which required no new capital investment, also decreased fuel costs and increased brick quality. Our results demonstrate the potential for privately profitable, as well as publicly beneficial, improvements to address environmental problems in informal industries.

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A randomized controlled trials registry entry is available at
https://www.socialscienceregistry.org/trials/10127

1. Introduction

Informal industries, such as brick manufacturing, are central to the economies of low- and middle-income countries (LMIC)(*1*). In Bangladesh (our study location), they account for as much as 40% of GDP and 80% of employment (*2*). Because it typically operates outside strict government oversight, the informal sector includes many highly polluting industries, including brick manufacturing (*3–5*).[1] In South Asia, most brick manufacturing takes place in informal, traditional coal-fired kilns (*6–8*). They are among the largest sources of greenhouse gas emissions in South Asia (*6*, *9*, *10*), degrading local air quality (*10–14*), health (*6*, *9*, *15–17*) and agricultural productivity (*18*, *19*).

Regulating informal sector pollution is particularly difficult.[2] In Bangladesh, efforts to improve the brick kiln industry over the past 30 years have largely been ineffective (*21–24*), in part because government regulations have not been adequate (*15*) or enforced (*21*, *23–25*). The other dominant approach has been to promote technologically advanced kilns. Modern kilns are five to ten times more expensive to construct and operate (*6*, *7*, *24*)---and therefore particularly onerous for informal firms with limited access to formal credit and technical expertise to adopt (*26*). Perhaps unsurprisingly, the diffusion of such modern kilns has been minimal despite significant promotion efforts, and even more importantly, these kilns have often failed to achieve their purported emissions benefits (*21*, *27–30*).

This background informed our strategy for designing an intervention to improve the environmental performance of Bangladeshi brick kilns. Specifically, we designed an intervention that was incentive-compatible for existing zigzag kiln owners[3] and that did not rely on state

[1] Other examples include leather tanning, metal working and resource extraction (*3*, *5*).
[2] The two most often cited challenges are (a) the difficulty of locating and monitoring entities with no formal registration or other ties to the regulatory apparatus and (b) the difficulty of monitoring emissions from a widely dispersed and small-scale set of industrial units (*3*, *20*).
[3] Zigzag kilns, a type of traditional kiln in the informal sector, are the dominant kiln technology in Bangladesh, representing 81% of the 7,881 registered brick kilns. The other traditional kiln is called a fixed-chimney kiln (17.4%

action. Several relatively modest modifications to the operational practices of informal kilns met these criteria. These practices required no new capital investment and can reduce black carbon, CO_2, and $PM_{2.5}$, while also increasing kiln profitability by reducing costs and increasing brick quality (*32–35*). However, most zigzag kilns in Bangladesh are incorrectly operated, leaving these social and private benefits unrealized (*6*, *21*, *24*, *30*).

Our pilot work suggested that kiln owners were unaware of proper operating practices and their profitability (*22*). Upon being informed of these practices, they were reluctant to introduce them, noting their lack of technical expertise to implement the improvements and their concern about the ability of their workers to adhere to the new practices. Collectively, these barriers appeared to prevent the proper operation of the kilns.

We therefore designed an intervention that provided zigzag kilns with technical training and support to improve kiln performance. Because the improved operational practices changed workers' tasks, we also provided additional information and nudges to owners about incentivizing workers to adopt the improved practices. We implemented the study as a randomized controlled trial (RCT) with a control group and two intervention groups. The first intervention provided technical support (the "technical arm"), and the second provided technical support as well as information and nudges to incentivize worker adherence (the "technical+incentive" arm). To our knowledge, this is the first randomized controlled trial examining energy efficiency in informal brick kilns.

2. Materials and Methods

of all registered kilns). There are 150 modern, formal kilns (hybrid Hoffmann and tunnel kilns) registered in Bangladesh, making up fewer than 2% of total kilns (*31*).

2.1 Experimental Design

During the 2022–2023 brick firing season,[4] we conducted an RCT with three experimental arms: (1) a technical arm, (2) a technical+incentive information arm, and (3) a control arm. We assigned kilns to each of the three experimental arms using stratified randomization with strata defined by the district of operation and baseline brick production.

Kilns assigned to the technical arm received information, intensive training, and technical support to adopt a suite of operational improvements. We focused on five operational improvements: (a) single fireman continuous fuel feeding, (b) improved brick stacking, (c) thicker ash layers on kiln tops, (d) closing the kiln gate with a cavity wall, and (e) complementary use of powdered biomass fuel. These practices improve fuel combustion and reduce heat loss in the kilns, which should improve efficiency and reduce emissions, as well as improve brick quality and reduce fuel expenditures. In initial pilot work, the first two interventions demonstrated the highest gain in fuel efficiency and in the empirical analysis we define a kiln as having adopted the intervention if it adopted at least these two practices. The training highlighted the financial benefits of the operational improvements and included participation from owners who had adopted them during our pilot study, which allowed the intervention team to directly address owner uncertainty about economic returns.

In addition to the information, training and support outlined above, kilns assigned to the technical+incentive arm also received explicit information about the importance of incentivizing workers to adhere to the new practices. These messages were reinforced with examples of strategies to motivate workers, including the use of both financial incentives (e.g., bonuses,

[4] Informal kilns operate seasonally in much of South Asia; in Bangladesh the brick firing season is during the dry months of November-May (coinciding with the off-season for agriculture).

higher wages, return bonuses) and worker amenities (e.g., better working conditions, such as meals, housing, clothing). See Appendix A for details on the interventions.

2.2 Sampling, Data Collection and Measurement

Sampling

Our initial sample randomized 357 zigzag kilns operating across 6 districts in Khulna Division in Bangladesh (Jahsore, Khulna, Jhenaidah, Chuadanga, Kushtia, and Narail). Baseline data collection revealed that 294 kilns met the criteria to receive the technical intervention (owners planned to operate during the upcoming season and would be using coal) and a further 18 kilns later dropped out of the sample because they were shut down by the government (n=9), closed down early (n=6), or refused to participate (n=3).[5] Kiln performance monitoring to collect outcomes data was completed in 276 kilns, which forms the final sample for the analysis. The analytic sample of 276 kilns (as well as the initial sample of 357 kilns and the subsequent sample of 294 eligible kilns) is balanced on a set of baseline kiln and kiln owner characteristics (Tables S3-S8). Ineligibility for the intervention and attrition are uncorrelated with treatment (Table S9).[6]

Data Collection

[5] Due to high coal prices in 2022-2023 some kiln owners in our sample chose not to operate their kiln or reverted to (illegal) exclusive use of firewood. In Table S9, we show that eligibility is uncorrelated with treatment assignment. Further, due to Ramadan (March 22, 2023 - April 21, 2023) falling toward the end of the firing season in 2023, some kiln owners stopped operating earlier than usual. Also, during the 2022-2023 firing season some kilns were demolished by the government before outcome data could be collected. As a result, outcome data from the kiln performance monitoring assessment, which required kilns to be firing, was collected from 276 kilns. The sample remains balanced (Table S8) and attrition for either stopping early or government demolition was uncorrelated with treatment (Table S12).

[6] More kilns in the technical arm were not operated during the 2022-2023 firing season (row 2 of Table S9), but overall eligibility for the intervention was not significantly different by treatment arm. Moreover, kiln owners were not informed of their treatment assignment prior to making decisions about whether to operate, therefore we assume this difference is not due to knowledge of treatment assignment.

Fieldworkers collected baseline data on kiln owner demographics, the location of the kiln, and retrospective information on the previous brick firing season. Adoption of the technical intervention was assessed through an adoption checklist fielded in January-February 2023 and again between March and May 2023, during the kiln performance assessment.

Outcome data were collected during a kiln performance monitoring which was conducted by teams of engineers and took approximately 30 hours per kiln. The assessment included counting and classifying the quality of fired bricks, measuring the quantity of coal consumed during a 24-hour period, weighing a sample of fired bricks, collecting coal samples for measurement of calorific value, and measuring emissions in the flue gas. Appendix D describes the monitoring protocol in detail. After firing was completed for the season, we fielded an endline survey, which collected self-reported information from owners.

Measurement

Our primary outcomes are adoption of the technical intervention; specific energy consumption (a measure of the energy used to fire 1 kg of bricks); the ratio of CO/CO_2 (which captures the completeness of combustion (*36*)); and the percentage of bricks fired of the highest quality (a higher percentage of Class 1 bricks is both an indicator of more efficient combustion and kiln owner benefits). These outcomes are based on detailed and objective data collected during the kiln performance monitoring. Secondary outcomes include additional measures of efficiency—specific fuel consumption (the quantity of coal used to fire 100,000 bricks); CO_2 emissions (calculated by applying IPCC conversion factors to specific energy consumption (*37*)); $PM_{2.5}$ emissions (calculated by applying $PM_{2.5}$ emissions factors (*38*) to specific energy consumption); and measures of working conditions and the use of incentives and amenities for workers (for more details, see Appendix A).[7] In cases in which outcomes can be constructed using both the kiln performance assessment data and endline data, we report endline equivalents in the Supplementary Materials.

2.3 Estimation

We estimate intention-to-treat (ITT) specifications by regressing each outcome on binary indicators for assignment to each intervention arm, as well as an ITT specification that bundles assignment to either intervention arm into a single indicator. Specifically, our primary specification is of the form $y_i = \beta_0 + \beta_1 T_i + \beta_2 I_i + \delta_s + \epsilon_i$ where T_i is a binary indicator equal to 1 if kiln *i* is in the technical treatment arm and I_i is a binary indicator equal to 1 if kiln *i* is in the technical+incentive arm; δ_s are strata fixed effects. In addition, we also estimate ITT regressions of the form $y_i = \tau_0 + \tau S_i + \delta_s + \nu_i$ where S_i is a binary indicator equal to 1 if kiln i was in either treatment arm and zero otherwise. To quantify treatment effects among adopters, we also implement instrumental variable (IV) specifications of the form $y_i = \gamma_0 + \gamma_1 A_i + \delta_s + u_i$ where A_i is a binary indicator equal to 1 if kiln i adopts the two key operational practices---improved brick stacking and single fireman continuous fuel feeding. We estimate this model using a two-stage least squares regression, instrumenting the adoption (A_i) with the treatment status.[8] Our analysis was preregistered with the AEA and ISRCTN. Any specifications that deviate from this plan are indicated in the main text (for more details see Appendix A).

[7] Since the overwhelming majority of fuel used was coal, we use the terms fuel and coal interchangeably (though some kilns use sawdust and small amounts of firewood).

[8] In settings with one-sided non-compliance (specifically, when the population comprises only "compliers" and "never takers" in the language of Imbens and Angrist (*39*)), the Treatment-on-the-Treated (ToT) parameter is equal to the average treatment effect among compliers (sometimes referred to as the LATE). In the presence of always takers---in our case, this is particularly relevant because 20% of control kilns adopted the intervention and can reasonably be thought of as always-takers---this equivalence no longer holds and the ToT parameter is not identified while the LATE continues to be identified and is consistently estimable using IV. For this reason, we refer to our estimand as the IV effect (or equivalently the LATE or the average treatment effect among compliers).

3. Results

Adoption of improved zigzag kiln operation practices

Fig. 1 presents results for adoption by study arm: 66.3% of kilns in the technical arm (59 of 89 kilns) and 64.2% of kilns in the technical+incentive arm (61 of 95 kilns) adopted the intervention. Strikingly, 19.6% of control kilns (18 of 92 kilns) also adopted the intervention even though they were not provided any of the intervention components. The control group take-up provides some revealed preference evidence of the value of the intervention to kiln owners---these owners sent managers and workers to intervention kilns to learn the practices. Estimating the treatment effect on adoption after accounting for the stratified design finds increases in adoption of 45 percentage points (pp) for the technical arm and 44pp for the technical+incentive arm relative to the control arm, ($p<0.001$) (Table S2). We returned to study kilns the following firing season (2023-2024) and found that adoption had increased by 7 to 11 percentage points in both treatment arms (up to 73.2% in the technical arm and 74.4% in the technical+incentive arm). Perhaps most encouragingly, among the 18 control kilns that had adopted during the RCT, all continued to use the improved practices and an additional 28 control kilns, who were trained after the completion of the RCT, also adopted, bringing total adoption to 56.5% of control kilns (Figure S1).[9]

[9] As a condition for participating in the RCT with the potential of being randomly assigned to the treatment group, the intervention was offered to all control kilns in the subsequent firing season (that is, to all control kilns that had not adopted the operational practices in the first year of the experiment and met the original inclusion criteria for the intervention (e.g., used coal and operated their kiln). Of the 65 kilns that were trained, 28 (43%) adopted the two most important practices. All control kilns that had adopted during the RCT continued to use the improved practices in the subsequent firing season, bringing total control kiln adoption to 56.5%.

In what follows, for sake of brevity we discuss the experimental results from the specification that combines the two treatment arms (the arm-specific treatment effects and associated standard errors are also provided in Tables S10 - S16).

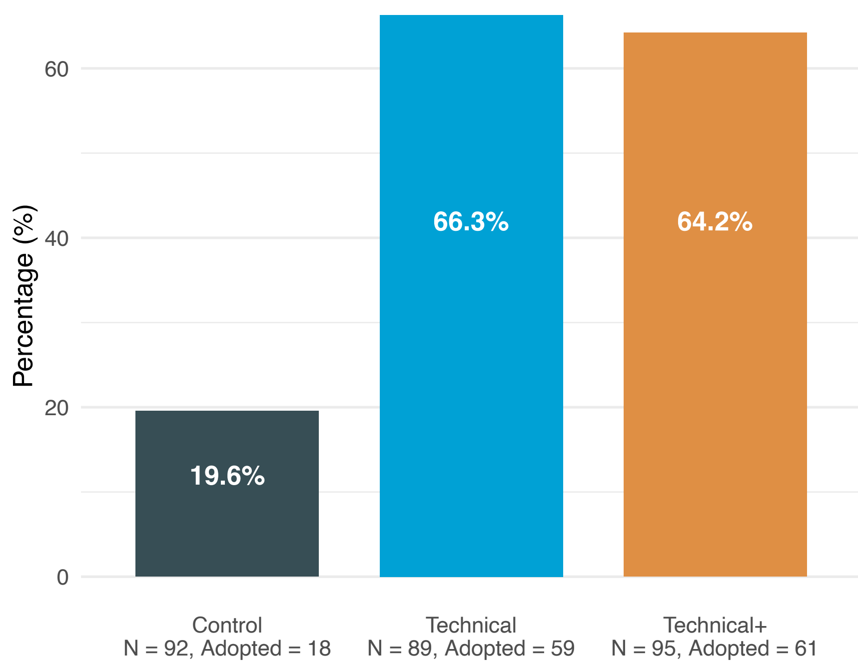

Fig. 1. Adoption by study arm. This figure presents the raw means of adopting double/triple zigzag brick stacking and single fireman continuous feeding by treatment arm.

Intervention Impact on Energy Use and Emissions

Treatment effects for specific energy consumption indicate that energy use was reduced by 0.11 MJ/kg fired brick (95% CI: [0.07,0.16], p-value <0.001; Fig. 2A and Table S10) in the treatment arms, equivalent to a 10.3% reduction relative to the control mean. The IV estimates suggest a 0.25 reduction in MJ/kg fired brick (95% CI: [0.15, 0.35], p-value<0.001) or 22.4% relative to the control mean (Table S10). These results are meaningful from an energy perspective: for instance, the IV 0.25 reduction in energy use brings specific energy consumption in line with the previously reported lowest specific energy consumption values among brick kilns in South Asia for the most efficient coal-burning kilns (*33*). We also find a reduction in fuel use of 1.8 tons/l00,000 bricks (95% CI: [1,2.6], p-value <0.001), which represents an 11% decrease in fuel use relative to the control mean of 16.3 tons/l00,000 bricks (Table S17).

Assignment to the intervention reduced CO_2 emissions by 171 tons over the season (9.8%, 95% CI: [53,289], p-value<0.001), and the IV estimates suggest even larger reductions among adopters of 382 tons (21.5%, 95% CI: [105,660], p-value<0.001) (Fig. 2A and Table S11). The intervention also reduced $PM_{2.5}$ emissions by 0.45 tons over the season (8.8%, 95% CI: [0.139,0.763], p-value<0.001) and the IV estimates are more than double the ITT estimates at 1 ton (19.3%, 95% CI: [0.28,1.7], p-value<0.001) (Fig. 2A and Table S11).[10] Suspended particulate matter (SPM) was measured in a small sample of kilns (8 adopted, 4 non-adopters, see Appendix A) and shows lower values SPM among adopting kilns, however we caution over-interpretation of these data due to the small sample (Fig S2).

Both the ITT and IV results show small and statistically insignificant reductions in the mean CO/CO_2 ratio (Table S22), a measure of combustion efficiency (*36*) that was pre-registered. The measurements collected were noisy (and not all were physically plausible given the expected ranges of O_2, CO_2, and CO). In Appendix E, we test the sensitivity of the CO/CO_2 findings to alternative specifications that drop kilns with implausible values and explore alternative outcomes based on the CO/CO_2 (which were not prespecified; Tables E1 – E14). These results provide suggestive evidence that the intervention significantly reduced both the maximum (Tables E1, E9, E13) and the variance (Tables E2, E3, E6, E7, E10, E14, E15) of the CO/CO_2 ratio, which is indicative of improved combustion efficiency.

[10] Because CO_2 and $PM_{2.5}$ emissions are estimated using the specific energy consumption measured during the kiln performance monitoring, the total season calculations assume the kilns operated with this constant energy use over the entire season. Because energy use varies over a firing season, this may be an unrealistic assumption and we test the sensitivity of the cost-benefit calculation to less efficient levels of energy use. We note that $PM_{2.5}$ emissions were not pre-registered as an outcome, but are calculated using specific energy consumption, which was pre-registered.

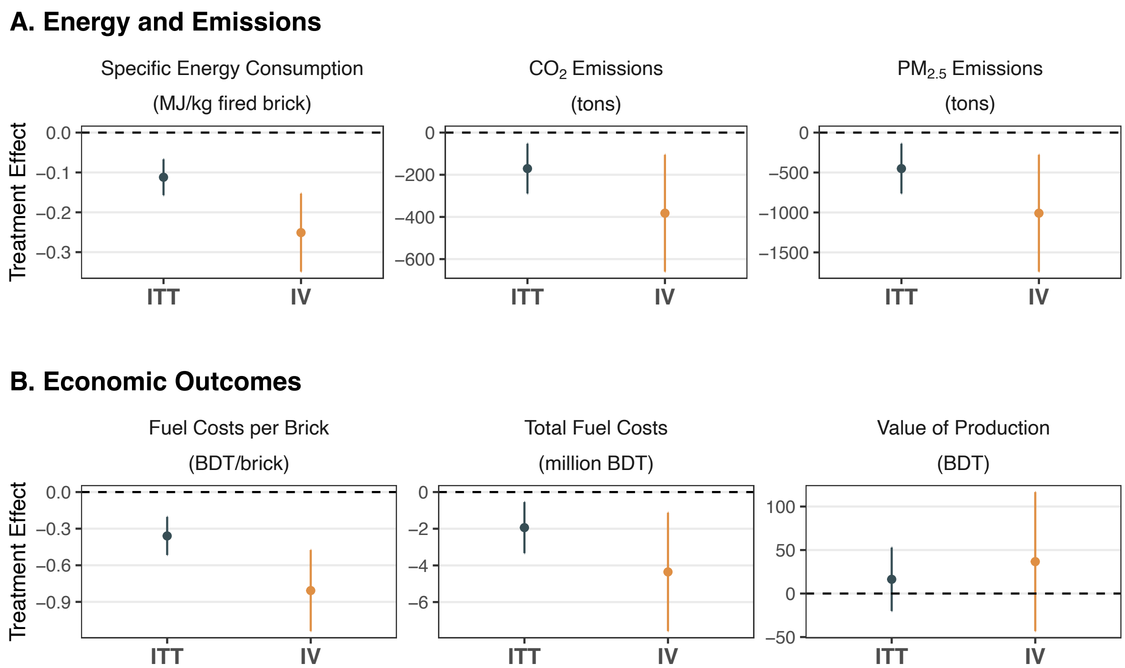

Fig. 2. Intervention impact on energy, emissions, and economic outcomes. Panel A presents the intervention's impact on outcomes related to energy use and emissions. Panel B reports the findings for economic outcomes for kiln owners. Both panels show regression results for the intention-to-treat (ITT) and instrumental variable (IV) specifications for a different outcome. The ITT specification, shown on the left in dark gray, bundles both treatment arms. The IV specification, shown on the right in orange, uses random assignment to either treatment arm as an instrument for adopting the technical intervention, and can be interpreted as the effect of adopting the intervention on a given outcome. Both specifications include randomization strata fixed effects and estimated heteroskedasticity-robust standard errors. In each panel, coefficients are denoted by dots and vertical bars represent 95% confidence intervals around the regression coefficient.

Economic Outcomes

Fuel is kiln owners' most expensive input and a key promise was that the intervention's efficiency gains would reduce fuel use, and therefore spending, per unit of output. Assignment to the intervention reduced spending by Bangladeshi Taka (BDT) 0.36 (USD 0.0031; 95% CI: [0.20,0.52], p-value<0.001) per brick on fuel and the IV estimate suggests a reduction of BDT 0.81 (USD 0.0069; 95% CI: [0.63,0.98], p-value<0.001) per brick (Fig. 2B and Table S13). These magnitudes are large and imply 9.5% and 20.8% reductions in fuel costs/brick for the ITT and IV results, respectively. Applying the per brick estimates to each kiln's total brick production for the season finds that fuel costs were reduced by BDT 1.94 million (USD 16,569; 95% CI: [0.54,3.3], p-value<0.001) or by BDT 4.35 million among adopters (USD 37,153; 95% CI: [1.1,7.6], p-value<0.001, Fig. 2B and Table S14).

Brick kilns produce bricks of varying quality which are sold at correspondingly varying prices. The highest quality are Class 1 bricks, which owners reported selling for BDT 11/brick (USD 0.09) and the lowest quality are sold as broken bricks (BDT 65 per cubic foot or USD 0.55). Assignment to the intervention increased the percentage of Class 1 bricks produced by 6.3 percentage points (95% CI: [4.6,8.0], p-value<0.001), a 8.2% increase, while also reducing the percentage of inferior bricks (Classes 2 and 3, see Fig. 3). The IV estimates suggest a 14.2 percentage point (95% CI: [11.0,17.3], p-value<0.001) increase or 19% (Fig. 3 and Table S15) among adopters. We see similar, though smaller, effect sizes (ITT: 4.9pp (95% CI: [3.0, 6.9]); IV: 11.1pp (95% CI: [7.4, 14.8]) when using kiln owner self-reported average brick quality over the entire season, reported at endline (Fig. S3, Table S28).

Because kiln owners can time brick sales with stock from multiple production seasons, we do not have direct measures of revenues from each kiln and the endogeneity of sales timing would make such measures hard to interpret, even if available. Instead, we estimate the total value of production from the current firing season by multiplying the median reported brick prices for each class of brick by the quantity of each class of brick and summing across the various classes, using the kiln owner's self-reported data on the entire season's production.[11] In Fig. 2B we present the results for total value of production over the firing season and see

[11] We can also calculate this by applying the objective brick quality data measured during the kiln performance assessment to the annual production reported at endline, but as the effect sizes for the objective and self-reported brick quality are similar, the total value of production is also similar (see Table S25). We prespecified a "normalized" version in which we divide the value of production by the total quantity of bricks (see Supplementary Section C for more details). As a result, this normalized measure ends up being driven entirely by differences in brick quality. Thus, we report the effect on brick quality in Fig. 3 and the value of production per brick in the Supplementary Information (Table S26 with monitoring data and S27 using kiln owner self-reports at endline).

positive, but noisy effects of the intervention (both ITT and IV specifications). While the intervention resulted in a larger fraction of Class 1 bricks (Fig. 3), there was no difference in total brick production over the season (Fig. 2B); consequently, we may be underpowered to detect significant differences in the value of production.

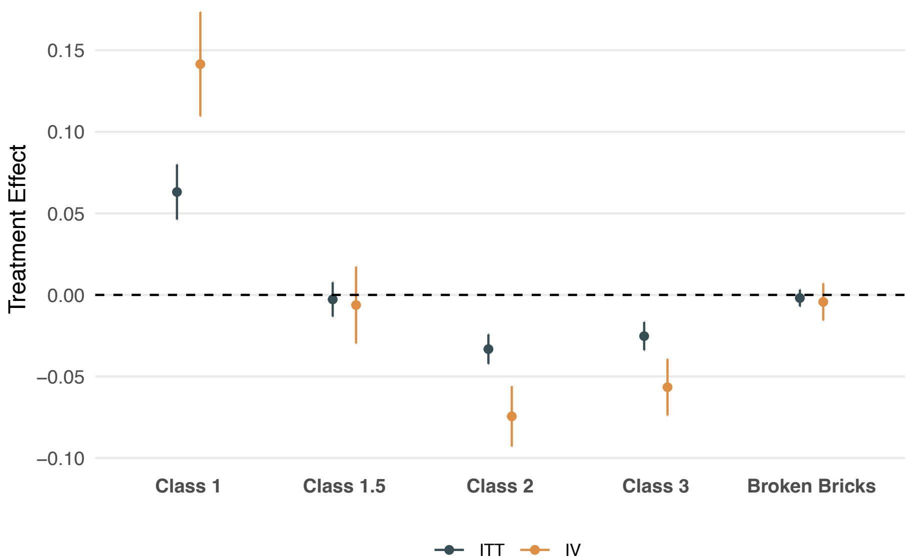

Fig. 3. Intervention impact on distribution of brick quality. This figure presents regression results for the intention-to-treat (ITT) and instrumental variable (IV) specifications for each classification of brick quality as a percentage of total production. The ITT specification, shown on the left in dark gray, bundles both treatment arms. The IV specification, shown on the right in orange, uses random assignment to either treatment arm as an instrument for adopting the technical intervention, and can be interpreted as the effect of adopting the intervention on a given outcome. Both specifications include randomization strata fixed effects and estimated heteroskedasticity-robust standard errors. In each panel, coefficients are denoted by dots and vertical bars represent 95% confidence intervals around the regression coefficient.

Rebound effects

By effectively reducing the price of energy, energy efficiency interventions can potentially increase total energy use if overall production increases (*40–42*). We find a small and statistically insignificant effect of the intervention on total annual brick production (Table S23), which suggests there was not a rebound effect on brick production in our setting.[12]

[12] We explore potential rebound effects through another channel---total number of firing circuits completed (brick production is completed in batches called “circuits,” and a single circuit reflects the bricks fired in a single circle around the kiln)---in the Supplementary Information and, consistent with the null effect on total annual production,

Work Conditions

Because the operational changes promoted by the intervention substantively changed workers' tasks, the technical+incentive intervention encouraged kiln owners to use incentives of their choosing to motivate workers to enhance adoption of the improved technical practices. Although we provided examples of incentives, we did not emphasize a one-size-fits-all approach and left owners and their managers to determine the best approach for their kilns. Arm-specific ITT specifications suggest that the intervention had no effect on explicit incentives that kiln owners report providing to workers (Fig. G4).

Costs

The primary cost for the RCT was the training expense and technical support throughout the season. These included venue costs, staff costs for engineers, material (e.g. handouts, pens), travel and food for participants, as well as "train the trainers" sessions in which the technical lead trained the project engineers. Training was provided at the district level (i.e. to all treatment kilns in the same district) and the total cost was approximately USD 30,544 or about USD 166 (30,544/184) per treatment kiln.

4. Limitations

A limitation of our study is that although we were powered (based on pilot data, see Appendix A for details) to detect differences in the mean CO/CO_2, the estimated effects were noisier (and hence less precise) than anticipated. However, the increased sample size posed unanticipated additional difficulties with flue gas measurement, and this increased measurement

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we do not see any difference due to the intervention (Table S25). We note that both these outcomes were not prespecified.

variability (we describe the measurement protocol in more detail in Appendix D and provide more discussion of these challenges in Appendix E). Even after conducting supplementary analysis excluding unreliable data (these were not prespecified; see Tables E1 – E15), there were few differences in the mean CO/CO_2 but some suggestive evidence that the intervention decreased both the maximum value and variance, which is indicative of improved combustion efficiency. Ultimately, these efforts suggest that mean values alone may not capture combustion efficiency in the CO/CO_2 measure and highlights the need for better approaches for measuring combustion performance and particulate matter emissions from kilns. Nonetheless, the strength and internal consistency of the results on energy use, brick quality, and fuel savings support the overall conclusions of the study.

5. Discussion and Conclusion

We designed an intervention to improve informal brick kiln operations in Bangladesh. The intervention aimed to reduce emissions and costs and increase revenue by introducing a set of operational practices to improve kiln efficiency. We tested the intervention using a randomized controlled trial on a sample of 276 kilns in Khulna division. Demand for the intervention was high with 65% of treatment kilns adopting the key improved practices. Furthermore, 20% of control kilns also adopted these practices despite not receiving any training or the support, which provides compelling revealed-preference evidence of the value of the intervention to kiln owners. Additional adoption in all study arms in the post-intervention period (to about three-quarters in the treatment arms and over one-half of the control arm) provides further evidence that kiln owners valued the intervention.

The efficiency improvements that we promoted achieved large effects, which we captured with high quality and detailed assessments collected from each kiln during 30-hour kiln performance monitoring assessments. Treatment assignment reduced energy use by 10% and coal use by 11% and the instrumental variable estimates suggest reductions that are approximately twice as large (20% and 24% respectively) for adopters. Fuel is the costliest input for brick kilns, and the reductions in fuel use decreased costs per brick by 9.5% (20.8% for adopters). These benefits were achieved without evidence of contemporaneous rebound effects, a common concern in the energy efficiency literature (*35*, *36, 37–42*). Finally, the intervention also increased the quality of the bricks produced as measured by the fraction of Class 1 bricks (the highest quality brick gradation) by 8.2% (18.9% for adopters). Information reported by kiln owners also confirms these results.

The intervention yielded significant social benefits, reducing both CO_2 by 171 MT and $PM_{2.5}$ emissions by 0.45 MT (382 MT and 1 MT among adopters, respectively). If all 6,352 zigzag kilns (*31*) in Bangladesh adopted these efficiency improvements, our results imply that CO_2 would be reduced by 2.4 million MT over a single brick firing season, a 2% reduction in Bangladesh's annual CO_2 emissions (*43*). For context, this is equivalent to the amount of CO_2 emitted from the energy used to power 316,434 homes in the U.S. for 1 year or the CO_2 sequestered by planting over 40 million tree seedlings and allowing them to grow for 10 years (*44*).[13] Although it is difficult to compare the energy performance of different types of kilns, the magnitude of the reductions in energy use we found for adopters are on par with what

[13] We obtained these estimates by multiplying the reduction in CO_2 emissions among adopters (382 MT) by the total number of zigzag kilns in the country (6,352) to get 2,426,464 tons CO_2 emissions, which is equivalent to 2% of Bangladesh's total annual emissions. Then, we used the EPA's CO_2 equivalence calculator, available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator, to convert the CO_2 into the equivalent amounts required to power homes in the US or that would be sequestered by seedlings, for context.

technologically advanced kilns can in principle realize—yet were achieved without any capital investment or large-scale institutional financing (*2,25*).[14]

Assuming a social cost of carbon of $185/MT (*52*), our results also suggest a single year valuation of the reduced carbon emissions of USD 31,635 per kiln (USD 70,670 among adopters). This compares favorably with the cost of delivering the intervention (USD $166 per kiln), implying a benefit-cost ratio of 190 (31,635/166).[15] Given we have not accounted for the health benefits of reduced $PM_{2.5}$ emissions, this calculation presumably underestimates the total social benefits substantially as well (*45*).

An important caveat is that we observed no significant differences in adoption or efficiency between the two treatment arms, despite both the information provided to owners in the technical+incentive arm regarding the profit rationale for offering incentives and the repeated nudges throughout the season. Importantly, however, we also found no evidence that the intervention worsened conditions for this vulnerable and often exploited workforce. Other studies, in which researchers directly provided monetary incentives to workers to adopt an improved operational practice, found large and statistically significant effects of the bonus payments (*46*). Qualitative interviews conducted with kiln owners revealed that owners remained concerned about workers' interest in and ability to adopt the new practices, which suggests more research is needed to identify incentive-compatible strategies for improving work conditions.

[14] We explore whether other input costs changed due to the intervention (Tables S32-S38) and find that spending on sawdust was lower due to the intervention, while all other costs were unchanged. The reduction in sawdust costs is surprising, since the intervention recommended using more sawdust. Reports from the intervention team suggest that due to sawdust supply constraints, owners that had adopted the improved firing and stacking practices and were happy with their operation, opted not to incorporate sawdust.

[15] The benefit-cost ratio implied by the IV estimates is even larger: 425. The estimate of total season CO_2 emissions reduced makes the strong assumption that the specific energy consumption measured during monitoring was constant throughout the season. However, if we instead use the lower bound ITT estimate (52.5 MT, Table S11) to value the CO_2 emissions reduction and calculate the benefit-cost ratio, the intervention is still extremely beneficial from a societal perspective and achieves a BCR of 57.

These outcomes, as well as indicators of labor trafficking and child labor, are explored in detail in a companion paper (*47*).

Our findings add to the fledgling literature measuring the effects of innovative approaches to reducing emissions and pollution in low income countries (*3*, *5*, *20*, *48–50*). We also contribute to a growing literature on the productivity and management capacity of firms in low- and middle-income countries (LMIC), particularly among informal firms (*51–56*). Past research has found that better-managed firms in the United Kingdom were less energy intensive (*54*), but few firm-level interventions in LMICs have been effective (*51*). Our study demonstrates that focused training and technical support provided to both management and labor can effectively reduce energy use and emissions, representing an important opportunity for improving informal enterprises.

Our approach is promising for scaling both within Bangladesh and possibly across South Asia, where brick production is similar. Our study also provides lessons for implementing interventions in other polluting industries in the informal sector, particularly in contexts with weak regulatory enforcement–environments in which aligning private incentives with public policy goals may be necessary. Overall, our results demonstrate that substantial reductions in emissions and air pollution by informal sector kilns are achievable and can be attractive to kiln owners as well.

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Reducing emissions and air pollution from the informal brick sector: evidence from a randomized controlled trial in Bangladesh

Supplementary Materials

July 16, 2024

Contents

A Materials and Methods **1**

A.1 Experimental design 1

A.2 Technical Intervention Details 2

A.3 Sample Selection and Randomization 6

A.4 Data collection 8

A.5 Outcome Measurement Details 11

A.6 Statistical Methods 15

A.7 Incentive Arm Script 16

A.8 Power Calculations 19

B Supplementary Figures **22**

C Supplementary Tables **26**

D Kiln Performance Monitoring Protocol **47**

E Supplementary Discussion of CO/CO_2 Results **56**

A Materials and Methods

A.1 Experimental design

The experimental design was based our theory of change, which emphasizes working with existing zigzag kiln owners and directly considering their profit motives. We hypothesized this strategy would provide an opportunity to quickly improve the dominant production model, achieve immediate reductions in air pollution and greenhouse gas emissions, and simultaneously increase kiln profits. This was informed by our pilot study, critical analysis of past efforts and their effectiveness *(15, 21-25, 27-31)*, a kiln-led initiative in Mexico *(50)*, and research within economics on management interventions *(51-56)*, energy efficiency *(40,42)*, and technology adoption *(26, 46, 57-59)*.

The RCT contained three experimental arms: (1) technical, (2) technical+, and (3) control. Kilns assigned to the technical arm received information, intensive training, and technical support to adopt a suite of operational improvements that included improved firing practices, improved brick setting, and increased insulation (see Section A.2 below). These operational improvements have the potential to both reduce emissions and energy use, as well as increase kiln profitability, if done correctly, via reduced fuel expenditures and increased revenue from producing more high quality bricks.[1]

The training highlighted the financial benefits of these improvements and included live participation from owners who had adopted them during our pilot study in order to directly address owners' uncertainty regarding economic returns. The training was delivered in the form of initial orientation sessions for owners and their managers, then separate sessions for firing and loading sardar (labor supervisors). These initial sessions were followed by on-site training of sardar and workers in brick loading and firing. Throughout the brick firing season, our team provided technical support to help owners and their workers implement the new practices.

Kilns assigned to the technical+ arm received everything delivered to the technical arm in terms of technical training and support, plus additional information and encouragement that targeted owners to address workers' misaligned incentives. Suggestions included a mix of financial (e.g., bonuses, higher wages, return bonuses) and nonfinancial incentives (e.g., better working conditions, such as meals, housing, and clothing). These examples were directly informed by the experience of other kiln owners successfully operating ZZKs, our own pilot study in Jashore district, and the management literature *(46)* – including evidence from brick kilns in Nepal *(60)* and garment factories in Bangladesh *(61)*. The implementation included a preliminary group meeting with all owners assigned to the technical+ arm, in which our team explained the profit-based case for incentivizing workers to adopt the new practices, the importance of workers' properly adhering to the new technical practices and giving them enough time, training, and positive reinforcement to adopt the new practices, and descriptions of several ways to incentivize workers to adhere to the new practices (see section A.7 below for the script). A handout that described the importance of motivating workers to adopt the new technical practices was left with owners at this initial meeting. Our team conducted two follow-up "nudge" visits to all kilns in the technical+ arm. At the first follow-up nudge visit,

[1] Brick quality is an indicator of both improved efficiency and kiln owner benefits. When bricks are fired in a traditional kiln, the highest quality or properly baked bricks are classified as Class-1 bricks and sold for a higher price than inferior classes. See Section A.5 for more details.

they gave owners a poster that presented a few simplified key messages about the importance of incentives as a reminder.

The control arm received no information or training from our team but participated in all data collection efforts.

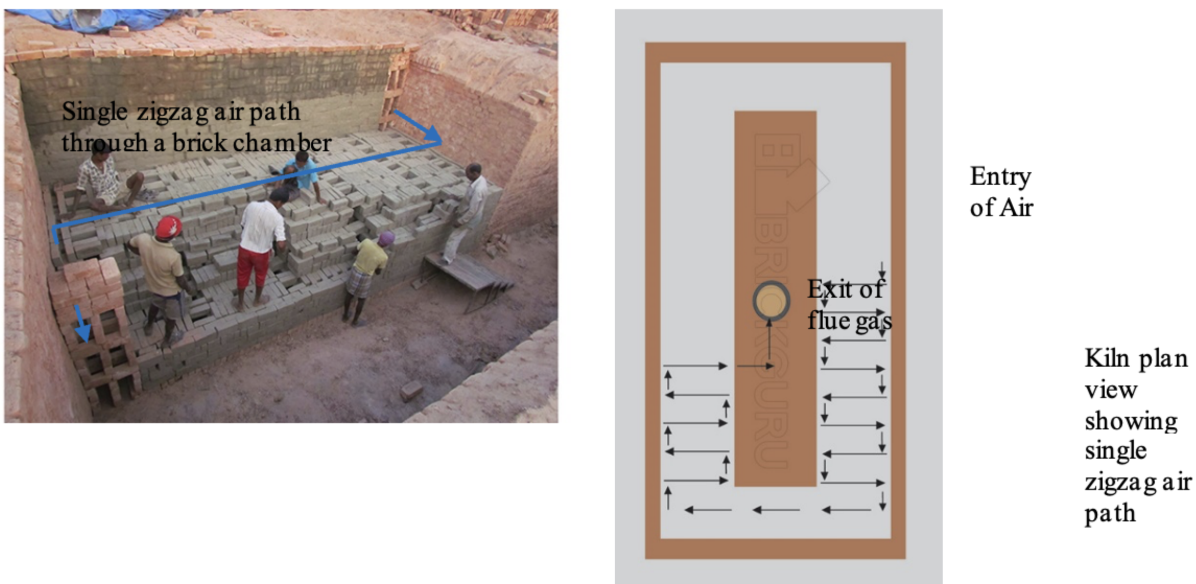
This project was reviewed and approved by Institutional Review Boards (IRBs) at Stanford University (#67263) and ICDDR,B (PR-22052).

A.2 Technical Intervention Details

Less dense brick stacking with multiple (two or three) zigzag air paths

The existing practice was dense brick setting with single zigzag air path (Fig. A.1). Typical packing density[2] and packing fraction[3] was in the range of 1,050-1,150 kg/m3 and 60%-65%, respectively.

Figure A.1: Dense zigzag brick stacking with single zigzag path

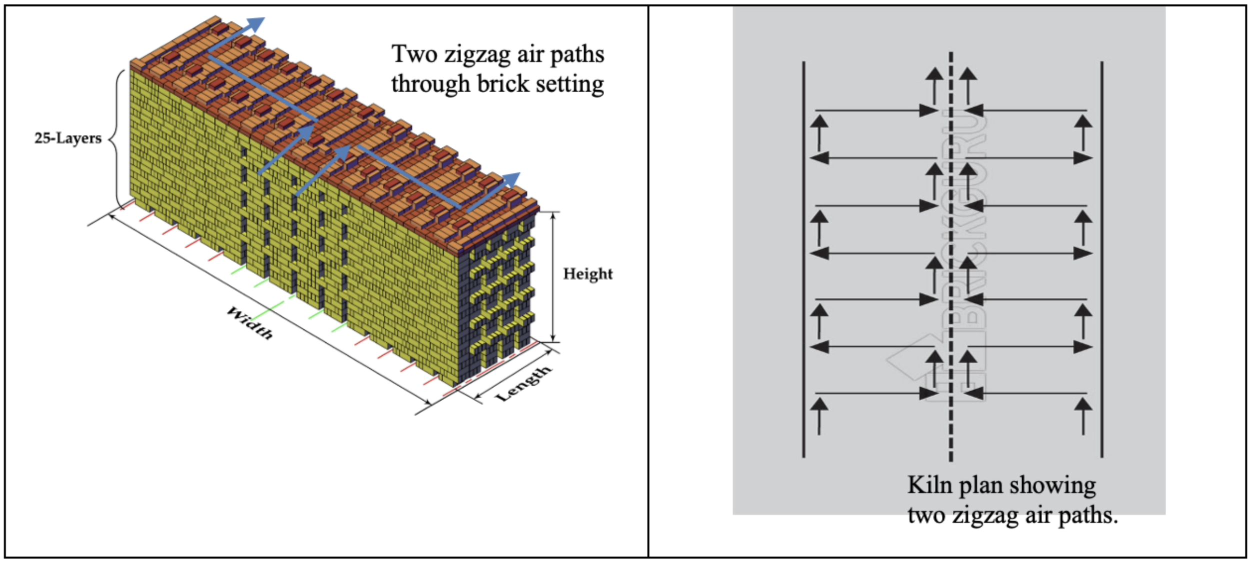


The technical intervention introduced brick stacking that was less dense and formed two or three zigzag air paths. The typical packing density and packing fraction of the setting was in the range of 900-1,000 kg/m3 and 50%-55%, respectively. A less dense brick setting with two zigzag air paths is shown in Fig. A.2. A kiln with less dense brick setting results in better distribution of air in the brick setting, which leads to uniform distribution of heat and temperature and a higher percentage of Class-1 bricks. Better air distribution improves the combustion of coal, and thus reduces the generation of black carbon and small particulates. Also, less dense brick setting results in less pressure loss, and hence requires less energy to drive the fan to create kiln draft.

[2]Packing density (kg/m3) is the weight of green bricks stacked per m3 of kiln chamber volume.

[3]Packing fraction of brick setting (in %) can be defined as the volume of bricks stacked in a chamber to the volume of the chamber.

Figure A.2: Dense zigzag brick stacking with single zigzag path



Single fireman continuous fuel feeding

The fuel is fed through the feed holes provided at the roof of the kiln by firemen. As per the existing fuel feeding practice, fuel is fed by two or three firemen simultaneously (Fig. A.3) at intermittent intervals—i.e., the firemen feed coal simultaneously for an interval of 10-15 minutes, followed by a non-feeding interval of 15-20 minutes. Intermittent feeding by two or three firemen simultaneously results in the accumulation of fuel in the kiln, which does not receive sufficient air for combustion. This results in incomplete combustion, unburnt fuel, and black smoke (excessive particulate matter emissions).

Figure A.3: Intermittent fuel feeding by 2 or 3 firemen simultaneously

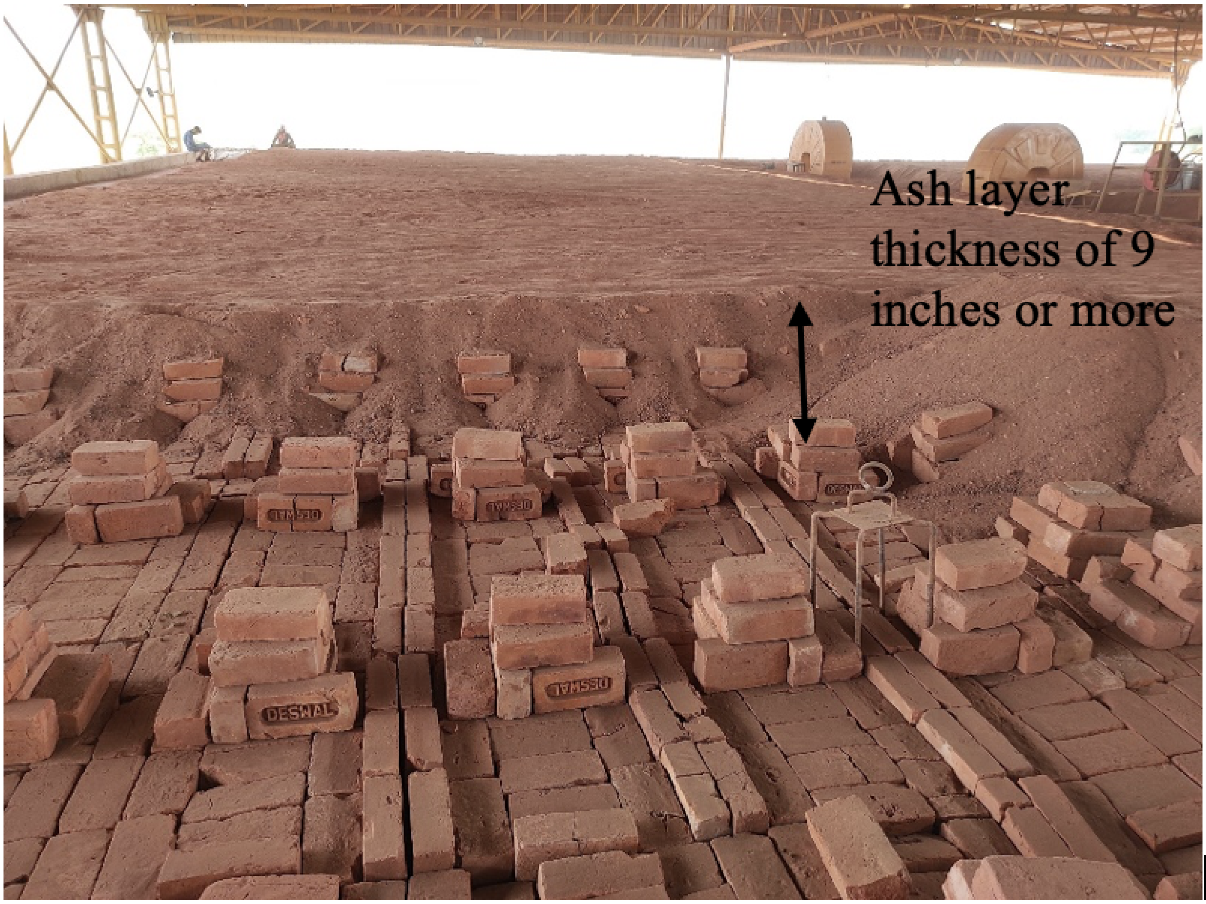
In the improved practice (technical intervention), a single fireman (Fig. A.4) feeds fuel continuously for 30 minutes. After 30 minutes he pauses, and his place is taken by his partner fireman. The fuel is fed sequentially in all chambers in the firing zone. This cycle is repeated continuously in the firing zone. In this way, fuel is fed in small quantities continuously, which causes the coal to receive adequate air for combustion. As a result, it burns completely and results in less wasted fuel and less black smoke. It also enables more uniform heat distribution across the kiln cross-section.

Figure A.4: Continuous fuel feeding by a single fireman

Thicker ash layer on the kiln top

The layer of ash on the top of the brick setting serves as the kiln's temporary roof and provides insulation against heat loss. As per the existing practice, the layer of ash has a thickness of approximately 6 in (Fig. A.5). In the improved practice (technical intervention), kilns are encouraged to increase the layer of ash to 9 in or more. Improved insulation due to the thicker ash layer reduces heat loss as well as the in-leakage of cold air into the kiln, helps reduce fuel consumption, and ensures that the top layers of the brick setting will attain a high temperature for baking and thus increase the percentage of Class-1 bricks.

Figure A.5: Ash layer on top of the brick setting



Closing kiln entry gates with an ash-filled cavity wall

Entry gates are openings in the outer wall of the brick kiln that give workers access to the kiln in order to stack green bricks and remove fired bricks. Once green bricks are stacked, a temporary wall of bricks is made to close the entry gates and seal the kiln. As per the existing practice, the temporary wall to close entry gates is a one-brick (approximately 10 in) thick single wall. As per the improved practice, the wall thickness is increased to 30 in. The wall now consists of two walls: an inner wall of 15-in thickness and an outer wall of 10-in thickness. The two walls are separated by a cavity (5-in thickness) filled with ash. The increased thickness of wicket gate walls and the presence of ash reduces heat loss and air leakage, and thus reduces the amount of coal required to maintain the kiln's temperature. Bricks set close to the entry gate attain a high temperature for baking, which in turn increases the percentage of Class-1 bricks.

Use of powdered biomass fuel in the newly inducted chamber in the fuel feeding zone

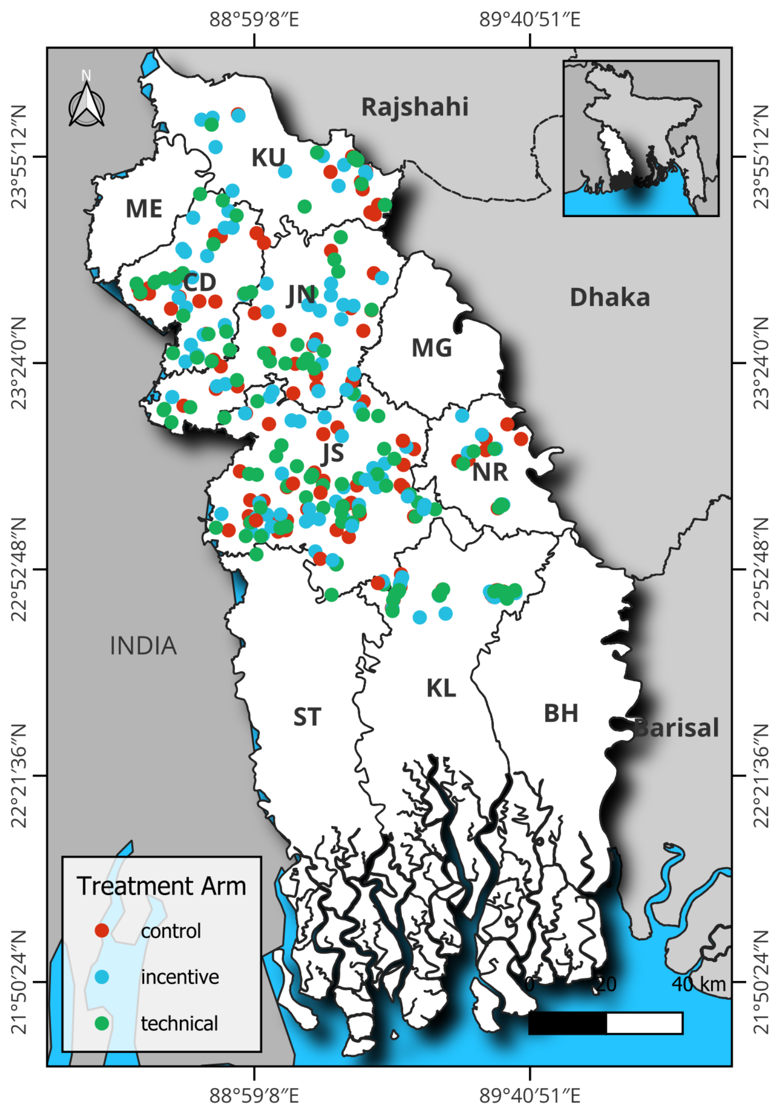
In a zigzag kiln, the fire moves around the kiln's firing chamber (a single cycle around the kiln is referred to as completing a circuit). As the fire moves, a new chamber enters the fuel feeding zone every 8-12 hours. The temperature of a newly inducted chamber is initially lower (<500°C). In the existing practice, coal is fed into the newly inducted chamber. Since the newly inducted chamber has a low temperature, the coal fed is not able to burn completely; this gives rise to black smoke (particulate matter) and CO emissions. In the improved practice, kilns are encouraged to feed saw dust and other powdery biomass fuels with high volatile matter content and low ignition temperatures into the newly inducted chamber (Fig. A.6). These fuels are able to burn completely at a low temperature. Once the newly inducted chamber has attained a temperature higher than 700°C, coal begins to be fed.

Figure A.6: Sawdust for feeding in newly inducted chambers in the fuel feeding zone

A.3 Sample Selection and Randomization

We obtained lists of all zigzag kilns operating in Khulna Division from the division and district Brick Manufacturing Owners Associations. The initial sampling frame included 410 zigzag kilns operating in 7 of the 10 districts of Khulna Division. Based on initial conversations with the leadership of each district level Brick Manufacturing Owners Association to gauge their interest in supporting the study and the number of available kilns, we ultimately selected 6 districts for inclusion: Jahsore, Khulna, Jhenaidah, Chuadanga, Kushtia, and Narail. We aimed to enroll 300 kilns in the trial, based on our power calculations and logistical considerations. Figure A.7 presents a map of the study districts and kiln locations in Khulna Division.

Figure A.7: Map of Study Kilns, Khulna Division, Bangladesh

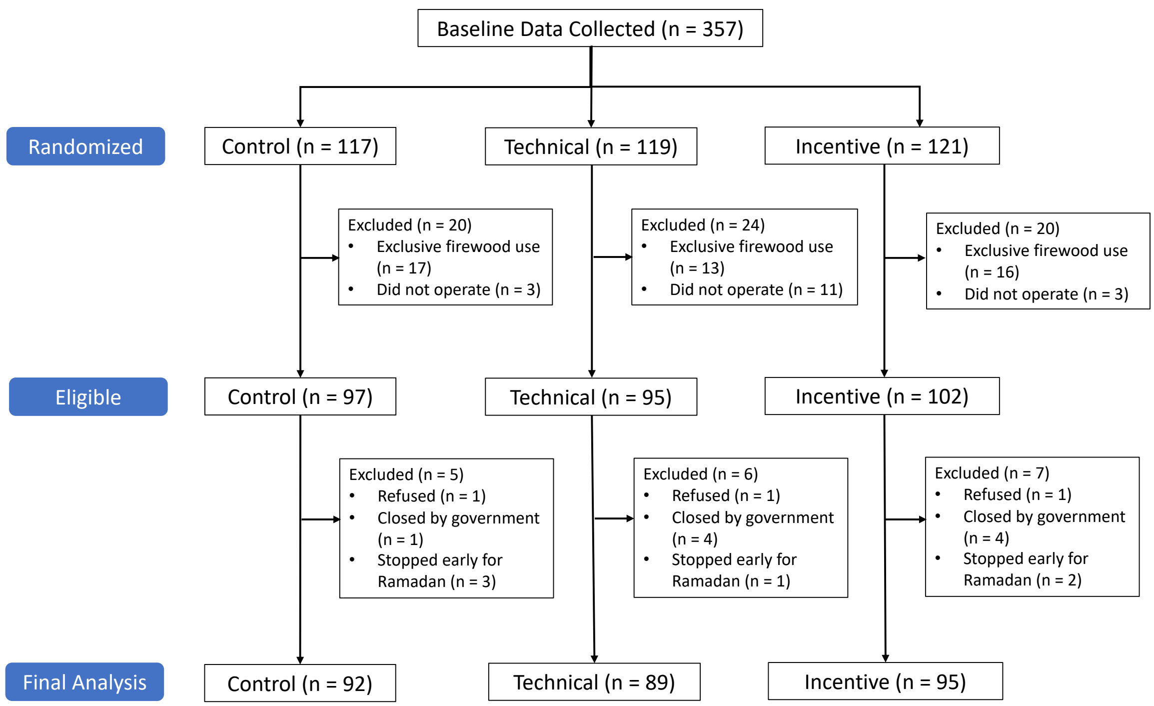


Notes: The study was conducted in the 6 districts indicated on the map: Jahsore, Khulna, Jhenaidah, Chuadanga, Kushtia, and Narail. Kilns assigned to control arm are shown in red, the technical arm in green, and the technical+incentive arm in blue.

Field research assistants completed consent procedures and collected baseline data from an initial sample of 328 kilns from these 6 districts. During the baseline data collection, we learned that many of the initial 410 kilns chose not to operate their kiln that season due to the high price of coal or switching to exclusively using firewood, which rendered them ineligible for the technical intervention. Based on this information, our team collected baseline data from an additional 29 kilns in Jashore District to enroll them in the trial. Thus, we enrolled 357 kilns, which were then randomized into technical (n = 119), incentive (n = 121), and control (n = 117) arms, stratified by district and the prior season's production of bricks. We ran randomized kilns 1,000 times to create 1,000 different potential allocations and selected the allocation that maximized the sum of p-values across all balance tests *(62-64)*.[4] The overall sample of 357 kilns was balanced on a set of baseline kiln and kiln owner characteristics, as was the initial sample of 328 kilns and the additional 29 kilns from Jashore.

Figure A.8 presents a flowchart of the intervention kilns from baseline data collection to the final analytic sample and Fig A.9 is a timeline of all study activities.

Figure A.8: Flowchart of sample size from baseline data to final analytic sample



Notes: Flowchart of sample size from baseline data collection to final analytic sample. Reasons for dropout at each stage, as well as number of kilns that dropped out for each reason, are reported.

A.4 Data collection

We developed four quantitative data collection tools: (1) a baseline/endline questionnaire, (2) an adoption checklist, (3) a kiln performance monitoring tool, and (4) a worker survey. The baseline questionnaire collected information on kiln owner demographics, the GPS location

[4] Balance tests were done using the following variables: owner experience, owner education, existence of additional owners, knowledge of pilot intervention in Jashore, interaction with pilot kilns in Jashore, year they changed to ZZK, location, adjacency to water, count of bricks fired in previous year, percent Class 1 bricks in the preceding year, production cost estimates per thousand bricks, number of workers in each kiln job, and average weight of fired bricks.

of the kiln, retrospective information on the previous brick firing season (production, costs, revenue), and baseline information about kiln construction and operation.

Initial adoption visits were conducted between January and February 2023, after intervention kilns had been trained. The adoption checklist assessed take-up of the technical intervention components and collected some information on fuel use. We conducted extensive kiln performance monitoring between March and May 2023, after kilns had completed several rounds of brick firing and the firing process had reached an equilibrium in terms of energy use (typically, more coal is used in early rounds of firing, when the ground is cold and wet and green bricks contain more moisture). The performance assessment took approximately 30 hours per kiln and included classifying fired bricks, measuring the quantity of fuel consumed during 24-hours, counting the chambers in which fuel feeding occurred during monitoring, collecting coal samples for measurement of calorific value, and measuring emissions in the flue gas. The kiln performance monitoring tool included the same adoption checklist to assess take-up of the technical intervention components at a second point in time. These visits were not announced in advance to kiln owners. The data collected during the kiln performance monitoring was extremely detailed (see Dand includes objective measures of brick quality, brick quantities, and fuel use. However, we note that the measures were collected at a single point in time and thus are not representative of seasonal averages.

Fieldworkers were unable to complete the performance monitoring assessment in all kilns because kilns had to be operational during these visits and many kilns closed operation early due to the timing of Ramadan. Also, several kilns had been demolished or shut down by the government before the monitoring could be completed; see Appendix D for the kiln performance monitoring protocol. Our team ultimately completed kiln performance monitoring of 276 kilns, which is the primary analytic sample (Fig. A.8). Tables S3-S9 demonstrate that our sample remains balanced after each of these instances of dropout, and attrition due to these reasons is not correlated with the treatment. Data from the kiln performance assessments are used to construct the primary outcomes for this study.

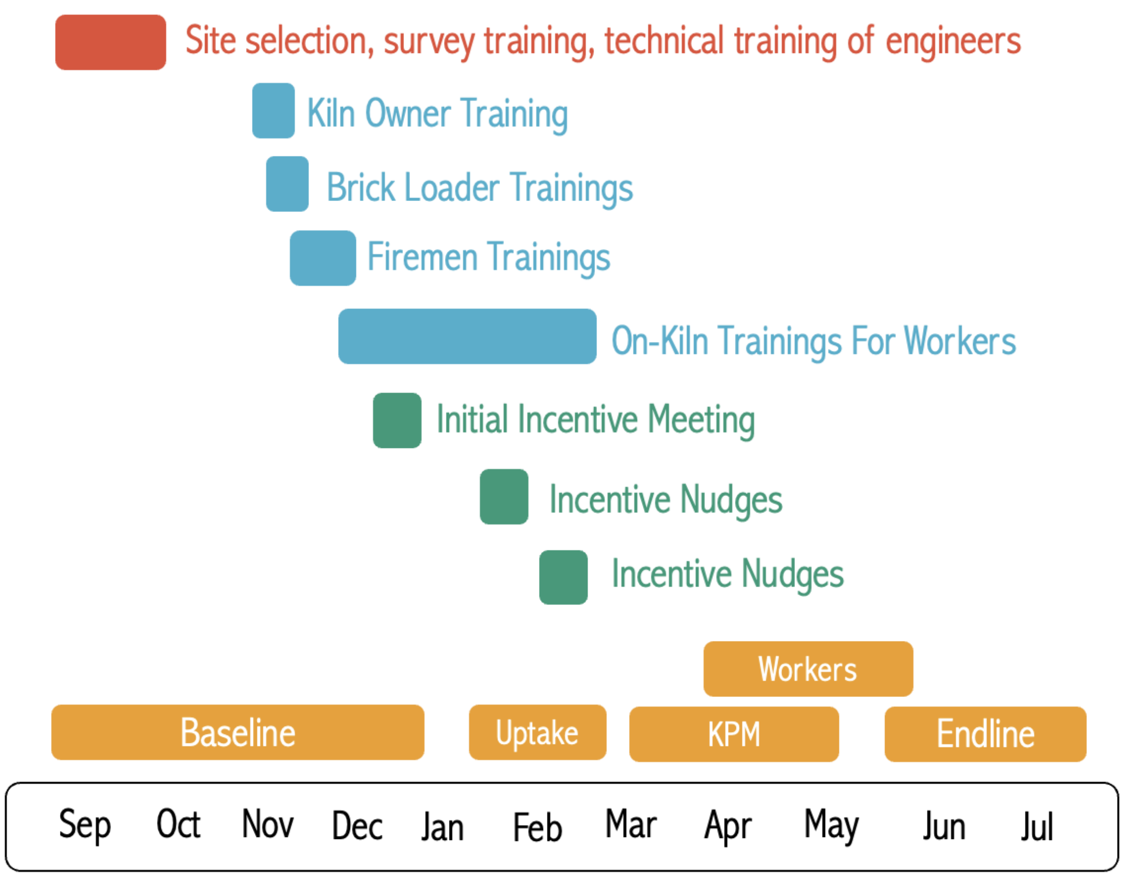
In a subsample of 12 kilns in 4 different districts, a trained team from the Bangladesh University of Engineering and Technology measured suspended particulate matter (SPM) in the chimneys using an isokinetic sampler. Four kilns from each arm were considered in the subsample. Since the stacks lacked any sampling hole and were too thick, these measurements were performed by constructing a temporary chimney that diverted gas from the main chimney and facilitated the necessary particulate matter, moisture content, and velocity measurements. Measurements were performed for a sufficient time to capture the effect of coal feeding and idle time. A simple comparison of SPM by adoption status is presented in Fig. S2, as the small sample precludes any rigorous statistical analysis.

A separate trained team conducted a survey of 1,746 workers across 293 of the study kilns (this sample size did not differ from the final analytic sample size, Fig. A.8, because kilns did not have to be operational at the time of the survey and was conducted at a different time). The goal of this survey was to understand the working conditions at these kilns, as well as worker characteristics and any benefits/incentives workers received. Using questions about working conditions, wages, contracts, and safety considerations, we also calculated the prevalence of labor trafficking according to standardized indicators and the existence of child labor. For each kiln, six individuals were interviewed: five workers spread across four job types (brick molders, brick loaders, brick unloaders, and firemen) and one sardar (work supervisor). Because some job types left early for Ramadan, we allowed for multiple workers of the same job type to be surveyed in order to obtain six individuals per kiln.

The baseline questionnaire was revised and used for endline data collection, which was collected from 328 (out of the original 357) kilns between June and July 2023. The endline survey sample is larger than the kiln performance monitoring sample because this survey did not require that kilns be operational during data collection.

Our primary outcomes are mostly derived from the kiln performance monitoring data. However, certain elements, such as brick prices and fuel spending, were collected only at endline from owners. In cases in which outcomes could be constructed using data reported at endline instead of the kiln performance monitoring data—such as specific fuel consumption, brick production by class, value of production, and fuel spending—we present results using the endline data in Tables S29, S19 and S27. The kiln owner measures reported at endline also differ in their reference period, as owners were asked to recall answers based on the entire season. In contrast, the kiln performance monitoring was collected at a single point in time during the firing season. However, we generally prefer the more objective measures from the kiln performance monitoring data, which are also not subject to recall bias.

Figure A.9: Timeline of fieldwork activities



A.5 Outcome Measurement Details

In this section we provide detailed explanations of the outcomes assessed in the main manuscript.

Specific Energy Consumption (SEC)
SEC is defined as the thermal energy used in megajoules (MJ) for firing 1 kg of brick (MJ/kg of fired brick); lower SEC is associated with higher energy efficiency. The SEC was calculated based on data collected during kiln performance monitoring over a period of 24 ± 2 hours and is calculated according to the following equation:

$$SEC = \frac{H_{in}}{M_{fbr}} \tag{1}$$

where M_{fbr} is the mass of fired bricks produced during the monitoring period and H_{in} is the total thermal energy input to the kiln during the monitoring period, which is calculated as the energy input from external fuel fed into the kiln plus the energy input from internal fuel added to the bricks during soil preparation plus the energy input from organic matter present in the brick soil.

None of the study kilns were used internal fuel during the soil preparation process. The quantity of organic matter in agricultural soil in Bangladesh is small and has declined in recent years *(65)*. Thus, the energy input from organic matter was not considered. Only thermal energy input from the external fuel fed into the kiln during the period of monitoring was considered in our calculations. Therefore, H_{in} is calculated according to the following equation:

$$H_{in} = \sum_{i=1}^{n} M_{fe,i} \times CV_{fe,i} \tag{2}$$

where $M_{fe,i}$ is the mass of external fuel (i) fed into the kiln during the monitoring period and $CV_{fe,i}$ is the gross calorific value of fuel i in MJ/kg.

Samples of around 1.5 kg fuel of all the fuels being used were collected from the monitored kilns. Of the collected fuel samples, 45 coal samples (Indonesian coal = 35; Indian coal = 3; South African coal = 7) and 21 biomass samples (sawdust = 14; rice husk = 7) were tested for their gross calorific value (GCV) using the ASTM D 5865 standard in a laboratory. The mean GCV value for each type of fuel was used to calculate SEC (Equation 1). Results are shown in Table S10.

CO_2 Emissions
CO_2 emissions from brick firing were estimated following UNFCC approved methodology *(37*. Specifically, CO_2 emissions were calculated as tons of CO_2 entire season brick production according to the following equation:

$$CO2e = SEC \times M_{fbr} \times CEF \times CC \times Production \tag{3}$$

where SEC is the specific energy consumption of the kiln (Equation 1), M_{fbr} is the mass of 100,000 fired bricks, CEF is the IPCC default carbon emission factor for the other bituminous coal (25.8 tC/TJ), CC is the carbon to CO2 conversion factor, which is 44/12 or 3.67, and $Production$ is the total number of bricks produced over the entire season, reported by owners at endline. Results are shown in Table S11.

$PM_{2.5}$ Emissions

$PM_{2.5}$ emissions from brick firing were estimated using the energy-based emission factor for $PM_{2.5}$ emissions. The emission factor for zigzag kilns in Bangladesh *(38)* was used in these calculations.

$$PM2.5 = SEC \times M_{fbr} \times EF_{PM2.5} \times Production \tag{4}$$

where SEC is the specific energy consumption of the kiln (Equation 1), M_{fbr} is the mass of 100,000 fired bricks, $EF_{PM2.5}$ is the $PM_{2.5}$ energy-based emission factor for coal-based zigzag kilns in Bangladesh (0.25±0.18 g of $PM_{2.5}$/MJ of energy input *(38)*), and $Production$ is the total number of bricks produced over the entire season, reported by owners at endline. Results are shown in Table S12.

Fuel Spending

Fuel is a kiln owner's most expensive input. By reducing the quantity of fuel used to fire a fixed quantity of bricks (e.g., the specific fuel consumption described below), the technical intervention should reduce the amount of money owners spend on fuel per unit of output. We calculated two measures of fuel spending per quantity of bricks produced. The first is based on the more objective measures of fuel consumption and quantity of bricks that were fired using that coal collected during kiln performance monitoring. Specifically, we calculated the fuel spending per brick using the following equation:

$$FS = \frac{\sum_{i=1}^{n} Q_i \times P_i}{N} \tag{5}$$

where Q_i is the quantity of fuel i consumed during the monitoring (or reported in the endline) and P_i is the price/ton reported for fuel i. N is the total number of bricks fired during monitoring. These results are shown in Table S13. Then, to estimate the total savings on fuel, we applied this per brick measure to the to quantity of bricks produced during this season, which was reported by kiln owners at endline (Table S14. Tables S20 and S21 report the comparable results using only spending on coal.

Brick Quality

Brick quality is an indicator of both improved efficiency and kiln owner benefits. When bricks are fired in a traditional kiln, the highest quality or properly baked bricks are classified as Class 1 bricks and sold for a higher price than inferior classes. Fired bricks get their strength from ceramic reactions that take place at a high temperature. The temperature depends on the type of soil; for Bangladesh, this is around 1,000°C. In the kiln, bricks must be raised to this finishing temperature and the temperature should be maintained for a few "soaking" hours to ensure that the entire brick has attained uniformity *(66)*. Class 1 bricks are obtained only when both the finishing temperature and soaking-time conditions are met. If the temperature is lower or sufficient soaking time is not provided, then under-fired (Class 2 and Class 3) bricks are produced. If the temperature or soaking time is exceeded, over-fired bricks are produced (which end up being crushed and sold in cubic feet of broken bricks). The intervention improves the uniformity in kiln temperature in the cross-section, and thus should result in a larger percentage of bricks that achieve the correct finishing temperature and soaking time. In other words, the fraction of bricks that are the highest quality—Class 1—should increase.

During the kiln performance monitoring, the evaluation team organized fired bricks that were unloaded from the kiln that day into classes (Class 1, Class 1.5, Class 2, Class 3, broken bricks) and recorded how many bricks in each class were unloaded. This was used to calculate the percentage of total bricks unloaded during the monitoring period that fell into each category. Results for the % of Class 1 bricks are shown in Table S15 and the entire distribution is shown in the main manuscript in Fig. 3. Also, during the endline survey owners reported the percentage of their total annual production this firing season that fell into each quality class. This measure was used in the supplementary analysis (Table S29 and Fig S3).

Value of Production

Since kiln owners can time brick sales from multiple production seasons, we do not have direct measures of revenues from each kiln and the endogeneity of sales timing would make such measures hard to interpret, even if available. Instead, we calculate the expected value of production by multiplying the median reported brick prices for each class of brick by the production of each class of brick, then normalizing by the total quantity of bricks produced according to the following equation:

$$VoP = \frac{\sum_{i=1}^{5} Q_i \times P_i}{N} \tag{6}$$

where Q_i is the quantity of brick class i for $i \in$ {Class 1, Class 1.5, Class 2, Class 3, and broken bricks} measured during the monitoring (or reported in the endline) and P_i is the median price reported for brick class i. N is the total number of bricks unloaded, counted, and classified during monitoring (or in some specifications, N is the total production reported by owners in the endline). This "normalized" measure ends up being driven entirely by differences in brick quality. Thus, we report the effect on brick quality in Fig. 3 and the value of production per brick in Table S26 with monitoring data and Table S27 using kiln owner self reports at endline. We also calculate the total value of production for the entire season using the kiln owner reported data on brick quality and production at endline, which is equivalent to $VoP = \sum_{i=1}^{5} Q_i \times P_i$. These results are reported in Table S16. We can also calculate this by applying the objective brick quality data measured during the kiln performance assessment to the annual production reported at endline, but as the effect sizes for the objective and self-reported brick quality are similar, the total value of production is also similar (Table S28)

CO/CO_2 ratio

Particulate matter emitted with the flue gases from brick kiln chimneys causes air pollution. There are two main sources of primary particles in flue gas in a brick kiln:

1. Particles from incomplete combustion. This includes soot, tar particles, and char particles.

2. Particles originating from inorganic material in the fuel, primarily ash in the fuel.

In the case of complete combustion, the carbon (C) present in the fuel gets converted into carbon dioxide (CO_2). If the combustion is not complete, some of the carbon gets converted into carbon monoxide (CO). The carbon monoxide to carbon dioxide (CO/CO_2) ratio is a good measure of the completeness of combustion *(36)*. The CO/CO_2 ratio is strongly influenced by the kiln's operation and particularly by the fuel feeding status.

During kiln performance monitoring, measurements of CO and CO_2 were carried out using a flue gas analyzer for a period of around 2 hours per kiln. The analysis was conducted at the point at which flue gases exit the trench and enter the flue duct on their way to the chimney. The fuel feeding status (feeding/non-feeding) was also recorded for the duration of the flue gas analysis. The flue gas analyzer provided data at 5-second intervals, which was first averaged over 1-minute intervals. The ratio of CO/CO_2 was calculated for each time step, and these were averaged over the duration of flue gas monitoring to yield an average CO/CO_2 for the kiln. In addition to the average, the maximum CO/CO_2, standard deviation, and interquartile range were calculated (note that only the average was prespecified). See Section D for a detailed discussion of data quality issues with CO/CO_2 and supplementary analyses that explore the sensitivity of results to dropping abnormal values, as well as estimate specifications on the maximum and variance.

Specific Fuel Consumption (SFC)
SFC is defined as the amount of fuel used in tons for firing 100,000 bricks (tons of coal/100,000 bricks); a lower SFC is indicative of more efficient use of coal. This is the metric used by most brick kiln owners to estimate the efficiency of a kiln. SFC was calculated based on data collected during kiln performance monitoring over a period of 24 ± 2 hours and is calculated according to the following equation:

$$SFC = \frac{\sum_{i=1}^{n} M_{fe,i}}{N_{fbr}} \times 100000 \tag{7}$$

where $M_{fe,i}$ is the mass of external coal (i) fed into the kiln during the period of monitoring and N_{fbr} is the number of bricks fired during the period of monitoring. Additionally, specific coal consumption is calculated as the equivalent measure, based only on coal used (rather than all fuels used). Since coal is used in the largest quantities, specific fuel consumption and specific coal consumption are similar (Table S18).

Annual Production
The total quantity of bricks (in 100,000s) produced during this firing season (2022-2023) was collected from owners during the endline survey. This measure, which was not prespecified, was used to assess potential rebound effects and results are shown in Table S23.

Circuits Completed
In a zigzag kiln, the fire moves around the kiln's firing chamber (a single cycle around the kiln is referred to as completing a circuit). The total number of firing circuits completed was collected from owners during the endline survey. On average, kilns in our sample completed 5 firing circuits during the 2022-2023 season. This measure, which was not prespecified, was used to assess potential rebound effects and results are shown in Table S24.

Worker Incentives and Work Conditions
To analyze the impact of the worker incentive arm and the specific messaging delivered, we examined outcomes related to the provision of any benefits, provision of any benefits to the firing or loading teams, and the presence of several aspects of better working conditions:

whether the kiln provides meals, cooking fuel, or a shed for resting. These are shown in Figure S4.

A.6 Statistical Methods

To estimate the treatment effects of the intervention, we regressed outcomes on indicator variables for treatment status.

$$Y_i = \beta_0 + \beta_1 T_i + \beta_2 I_i + \gamma_s + \epsilon_i \tag{8}$$

where Y_i is an outcome of interest for kiln i, T_i is a binary indicator for assignment to the technical only arm, and I_i is a binary indicator for assignment to the incentive arm. The coefficients on each treatment indicator, β_1 and β_2, respectively, capture the "intention-to-treat" (ITT) effect of assignment to the treatment arms on each of the outcomes relative to the control arm and δ_s is an indicator for the strata. We will also estimate a version of Equation 8 in which we bundle treatment into a single treatment indicator that captures the ITT effect of assignment to either treatment arm (Equation 9). Heteroskedasticity-robust standard errors are calculated for all specifications.

$$Y_i = \delta_0 + \delta_1 G_i + \gamma_s + \epsilon_i \tag{9}$$

Because we did not expect all 200 kilns assigned to the treatment arms will adopt the technical intervention (where adoption is defined as taking up both of the recommended brick stacking and firing practices), we also estimated instrumental variable (IV) specifications. This allows us to quantify the impact of the technical intervention among the kilns that *actually* took up the recommended practices. Because non-adoption and noncompliance are not random but likely the result of systematic differences between kiln owners that are likely correlated with the outcomes, our second approach is to use the random assignment as an instrument for adoption in an instrumental variables analysis that measures the local average treatment effect (LATE)among the kilns that took up the intervention (e.g., the compliers) *(67)*.

In the absence of defiers (so that only compilers, never-takers and always-takers are present in the language of Imbens and Angrist *(39)*, the ToT parameter is equal to a weighted average of the treatment effect among compliers and the treatment effect among always-takers. If we rule out always-takers, then the ToT parameter is equal to the average treatment effect (ATE) among compliers and is consistently estimable using IV. In the presence of always takers (which is likely the case in our setting since 20% of control kilns adopted the intervention) the ToT is no longer identified, although the ATE among compliers continues to be identified (and is consistently estimable using IV). For this reason we refer to our estimand at the IV effect (or equivalently the LATE).

To estimate the IV, we used the following two-stage least squares (2SLS) approach:

$$A_i = \theta_0 + \theta_1 G_i + \gamma_s + \epsilon_i \tag{10}$$

$$Y_i = \gamma_0 + \gamma_1 A_i + \gamma_s + u_i \tag{11}$$

Equation 10 is the first stage in which adoption (A_i) of the two most critical intervention components (double or triple zigzag brick setting and single fireman continuous coal feeding) is predicted with the randomly assigned treatment (using a bundled treatment indicator, G_i). Then, in the second stage, Equation 11, we regress an outcome on the instrumented adoption and γ_1 captures the IV effect of adopting the intervention on the outcome. Heteroskedasticity-robust standard errors are calculated for all specifications.

We explore heterogeneity in the primary outcomes across dimensions such as kiln owner years of experience in the brick industry, kiln owner education, whether the kiln owner is involved in other businesses, and kiln location. Our preregistered analysis plan specified that we would examine heterogeneity in the primary outcomes by baseline kiln characteristics, including owner's experience, owner's education, location on highland, and whether the kiln is a joint proprietorship. For brevity, we present these results in Table S31 and find no significant differences in the treatment effects by these characteristics at the standard 5% level. Although our pre-analysis plan includes a correction for multiple hypothesis testing for the heterogeneous models, we do not make this correction given that the uncorrected interaction terms are statistically insignificant.

Our analysis was preregistered with AEA and the ISRCTN. Any specifications that deviate from this plan are stated in the main text.

A.7 Incentive Arm Script

Kilns that were randomized into the technical+incentive arm received a detailed information session along with the hands-on training provided with the technical intervention. In these information sessions, our team described how our pilot work increased brick quality while decreasing fuel use, and that achieving these benefits depends on the ability to align worker incentives with the new production method, providing evidence that pilot firms that increased worker pay experienced greater benefits. The complete script is as follows:

[Begin Script]

I'm here to talk to you about how you can get more profit in this year's brick production. We are glad you are working with us to implement the new practices, but their success depends on every worker on your kiln. Our team is here to help with technical training and assistance to make sure your workers have the proper skills to implement everything correctly. **If everyone on your kiln works together and follows the instructions, you will use less coal and increase your production of Class-1 bricks. As a result, these new practices will increase your profit and your kiln will be more successful.**

How do we know this?

Our team worked with similar brick kilns in Jashore, and a 14% increase in the percentage of Class-1 bricks and a 20% reduction in coal spending per brick in kilns that successfully followed the recommended practices of single fireman continuous coal feeding and double zigzag brick setting owners saw, compared to kilns using traditional methods.

What's more interesting is that the owners from Jashore that provided more incentives and benefits to their workers had even higher Class-1 bricks (on average, 5 percentage points higher) and lower coal spending (on average, 0.42 Taka less per brick) compared to kilns that did not offer additional incentives.

How can you reap the same benefits?

The workers on your kiln are crucial for the success of this new practice. They have to learn the new practices and at first they may not want to change from the old way of doing things. If your workers invest the time to master the new skills it will lead to huge benefits for you . Now, you can imagine when they are learning the new practices they might more slowly which might reduce their pay. If they do not feel motivated to adopt the new practices, they may take shortcuts or not learn it properly unless you find a way to include them in the success you will have from these new practices.

You may also consider the time and effort you are putting in to having your workers trained on these new practices. They are learning many new skills which will make your kiln successful. You will benefit if you can use the same workers next season, because they will already have the experience and training on these new practices. If you can encourage workers to return, it will be very beneficial to your kiln operation and production.

Because all workers on your kiln must be successfully adopt these practices and work together to increase your production and profit, we recommend any incentives or extra bonus be offered to all workers.

We have some suggestions that other kiln owners like you have used and found to be successful at increasing their kiln performance, getting better performance from workers, and commitments from workers to return to the same kiln:

1. Providing some extra monetary incentives to the workers to motivate them to follow this new practice properly. This will be easily covered by your increased profit /production soon. Because all workers on your kiln must be successfully adopt these practices and work together to increase your production and profit, we recommend incentives be offered to all workers. Successful kiln owners have used incentives differently for different categories of workers, for example, firing workers are given lump sum bonuses after a circuit, whereas unloaders and loaders are given bonuses in terms of 1000 bricks.

2. There are easy improvements you can make for your workers to make them happier and healthier to motivate them be more productive. If your kiln gets a reputation for being a good place to work, where workers are well-taken care of, your workers are more likely to return next season and more workers will want to work for you.

How can you make incentives and benefits work for you?

When offering these incentives, it is very important that the workers themselves receive the benefit. Otherwise, they will not be motivated to adopt the new practices, trust will be lost, and your kiln will not benefit. You may encourage the sardars to provide these benefits to workers so that the workers will adopt the practices. Some owners provide benefits directly to the workers to make sure they receive them. A common practice of successful owners is to announce a particular day and time and request all workers and sardars be present, then owners hand over bonuses/bakhshish by themselves. This practice is successful because everyone will give credit to the owner for the extra benefits.

It is also important that you provide the incentives and benefits in a timely manner and early in the season. If it is too late, the workers may not be encouraged to follow the new practices and you will not see the benefit in time.

[Ask: Any questions on what we have talked about so far?]

What are examples of monetary incentives and good working conditions that you can provide?

We have put together a list of suggestions from successful kiln owners for you to think about:

1. You may offer a 'Bakhshish' from the higher earnings that you will get by adopting our suggested practices. For example, you can offer a Bakhshish to your workers such as 5-10%, which can be shared across all the workers. One successful kiln owner has provided 10000 Tk to the loading Sardar for adopting the new system and he committed to providing it subsequently in the next rounds of brick stacking. If you inform them at the beginning of each circuit about the Bakhshish and the importance of following the new practices to achieve a higher amount, it will motivate their performance during the circuit.

2. You may offer a bonus (onudan) to the workers if your kiln achieves a certain level of class-1 bricks in each circuit. We have provided a guideline for the bonuses depending on the share of class-1 bricks. For example, you may offer BDT 5000 if your kiln achieves 80-85% class-1 bricks in a cycle, BDT 6000 if you achieve 85-90% class-1 bricks, and BDT 7000 if you achieve >90% class-1 bricks. You can adjust the schedule given your kiln's performance. We suggest you inform workers at the beginning of the circuit about the bonus to motivate their performance and deliver the payment at the end of the circuit once the brick quality has been assessed.

3. You can also provide 'Bakhshish' of extra Taka 50 per 1000 bricks if your kiln achieves 80-85% class-1 bricks, extra Taka 100 per 1000 bricks if your kiln achieves 85-90% class-1 bricks, or extra Taka 150 per 1000 bricks if your kiln achieves >90% class-1 bricks.

4. Some of the recommended practices will require more time involvement for the workers. For example, in the new method, workers need to increase the ash layers by 9-12 inches from the previous setting. In the new method, fire travels faster and more loading of bricks is necessary to keep up the fire travel in a circuit. In both cases, you can consider increasing the wages of the workers by Taka 10-50 per 1000 bricks to account for the changes.

5. You may offer a return bonus if workers return to your kiln the next season. Inform them of the bonus offer before the end of the current season, so that it can encourage them to return the next year. For example, some kiln owners have offered a bonus equal to 20% of the workers current wages if they return the following season, which will be paid only after they return.

6. You might see that some of your workers want to leave for other working options during the firing season, especially on agricultural fields. To prevent workers who have been trained on these new and improved practices from leaving in the middle of an active

season, kiln owners have provided instant bonuses in cash. By making your kiln a more desirable and better paying place to work, the workers will not want to leave for other options.

7. Many kiln owners have successfully retained a higher presence of workers by offering 'attendance bonuses.' You can offer some bonuses for the top 5 workers who are most regular in your kilns to motivate all the workers to avoid shirking.

A.8 Power Calculations

Based on our pilot results, we have estimated effect sizes for the "intention-to-treat" (ITT) effect of each experimental arm, as well as an estimate of adopting (IV) that accounts for imperfect compliance with the intervention (both from kilns assigned to the treatment arm that did not take-up the intervention practices and from control kilns that sought to learn the intervention practices) by using random assignment to both arms as an instrument for adoption. These results for each of the three outcomes are summarized in Table A.1 below. We first calculate the minimum detectable effect size (MDES) assuming both arms have equal effect sizes, a significance level of 0.05 and power of 0.9. Then, because there is suggestive evidence from our pilot that the incentive arm encouraged better adherence to the improved operating practices and resulted in better outcomes, we also calculate our statistical power for detecting differences between the incentive and technical arms.

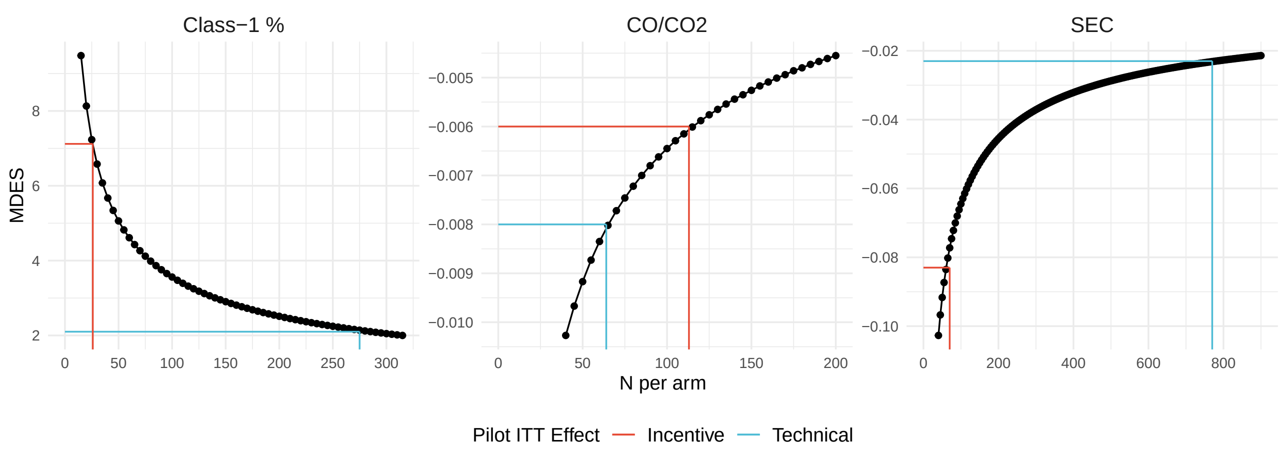
Table A.1: Estimated Effect Sizes from Pilot Study

Outcome	**Control Group Mean**	**Technical ITT**	**Incentive ITT**	**TOT**
Class-1 (%)	66	2.1	7.12	9.22
CO/CO_2 (ratio)	0.04	-0.008	-0.006	-0.014
SEC (MJ/kg-fired brick)	1.28	-0.023	-0.083	-0.107

Fig. A.10 presents the minimum detectable effect sizes against the sample size per treatment arm for the percent of class-1 bricks produced, CO/CO_2 ratio, and specific energy consumption. The estimated ITT effects for each arm from the pilot study are indicated in red (incentive arm) and blue (technical arm). These scenarios indicate that with a sample size of 100 kilns per experimental arm (300 total kilns), we are powered for all three outcomes with 90% power in most cases. For class-1 bricks the incentive arm performed much better, producing 7.12 percentage points more class-1 bricks than the control group and we would be powered to detect an effect size of this magnitude with only 25 kilns per arm. The effect size for the technical arm was much smaller (2.1 percentage points higher than the control group) and with 100 kilns per arm, we would not be powered to detect such a small difference. However, 2.1 percentage points is an extremely conservative estimate for a potential effect size. The minimum detectable effect size for 100 kilns per arm at 90% power is 3.56 percentage points.

This is half the magnitude of the incentive arm and still relatively conservative, particularly when considering the TOT estimate of 9.22 percentage points among adopters.

Figure A.10: Minimum Detectable Effect Sizes for RCT Outcomes



For the CO/CO_2 ratio, with 100 kilns per arm, we almost are powered for the more conservative ITT effect attained by the incentive arm but more than sufficiently powered to detect the larger effect size attained by the technical arm. With 100 kilns per arm at 90% power, we are powered to detect an effect size of -0.0064 in the CO/CO_2 ratio, while we would need only 65 kilns per arm to detect an effect as large as -0.008, which is what the technical arm attained in the pilot. Somewhat surprisingly, the measured CO/CO_2 ratio in the pilot was lower in the technical arm than in the incentive arm. This may simply reflect that the CO/CO_2 ratio is a cross-sectional measure that we captured based on data from a few hours in each kiln and so may not accurately reflect the performance over the whole season. Indeed, the first CO/CO_2 ratio was measured before the incentive arm was even rolled out. Nevertheless, the calculations suggest that we will have sufficient power to be able to detect changes in CO/CO_2 ratio with the interventions.

Similar to the percent of Class-1 bricks, our pilot results suggest kilns assigned to the incentive arm had a much lower specific energy consumption (SEC). While we will not be powered to detect effect sizes as small as what the pilot found in the technical arm, we are powered to detect effect sizes smaller than what the technical arm attained. With 100 kilns per arm at 90% power, we are powered to detect an effect size of -0.065 in SEC, while we would need 70 kilns per arm to detect an effect as large as -0.083, which is the ITT effect for the incentive arm compared to the control group. We summarize the minimum detectable effect sizes for a study with 100 kilns per arm with power of 80% and 90% in Table A.2.

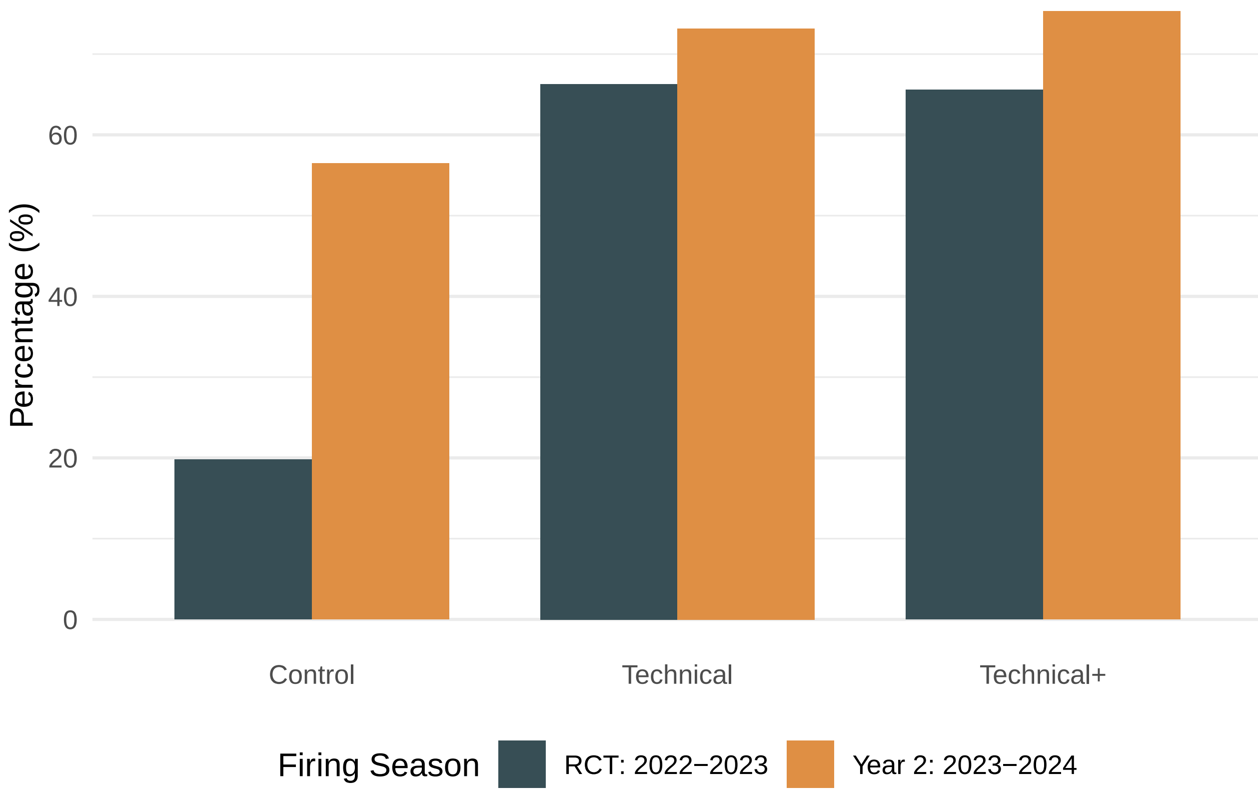
It is also of interest to assess the power for detecting differences between the two arms. Although we were not powered in the pilot to statistically detect differences in the exploratory outcomes between the technical and incentive arms, our pilot provides suggestive evidence that kilns assigned to the incentive arm performed better than the technical-only arm, although statistically, we cannot rule out equivalent effects. Using these effect sizes and assuming 100 kilns per arm, we estimated the power we can expect to attain for each outcome, which is presented in Table A.2. Given the small differences between the two arms, we are underpowered except for the percent of class-1 bricks, where we estimate having 80% power to detect a difference of 5 percentage points.

Table A.2: Minimum Detectable Effect Sizes and Power for 100 kilns per arm

	MDES		**Power b/w treatment arms**
	Power: 0.9	Power: 0.8	
Class-1 (%)	3.56	3.08	0.81
CO/CO_2 (ratio)	-0.0064	-0.0056	0.19
SEC (MJ/kg-fired brick)	-0.065	-0.056	0.23

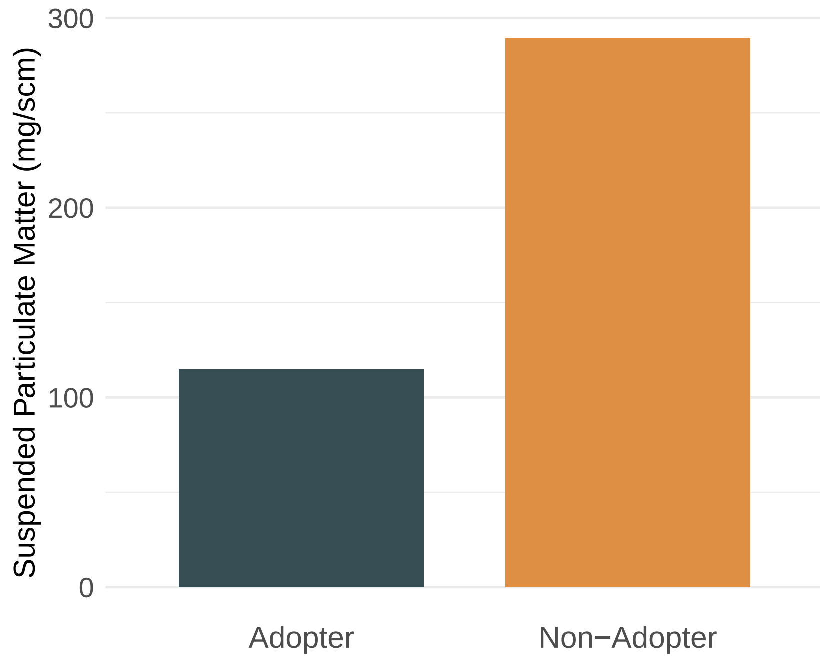
B Supplementary Figures

Fig. S1: Year 2 Adoption by Treatment Arm



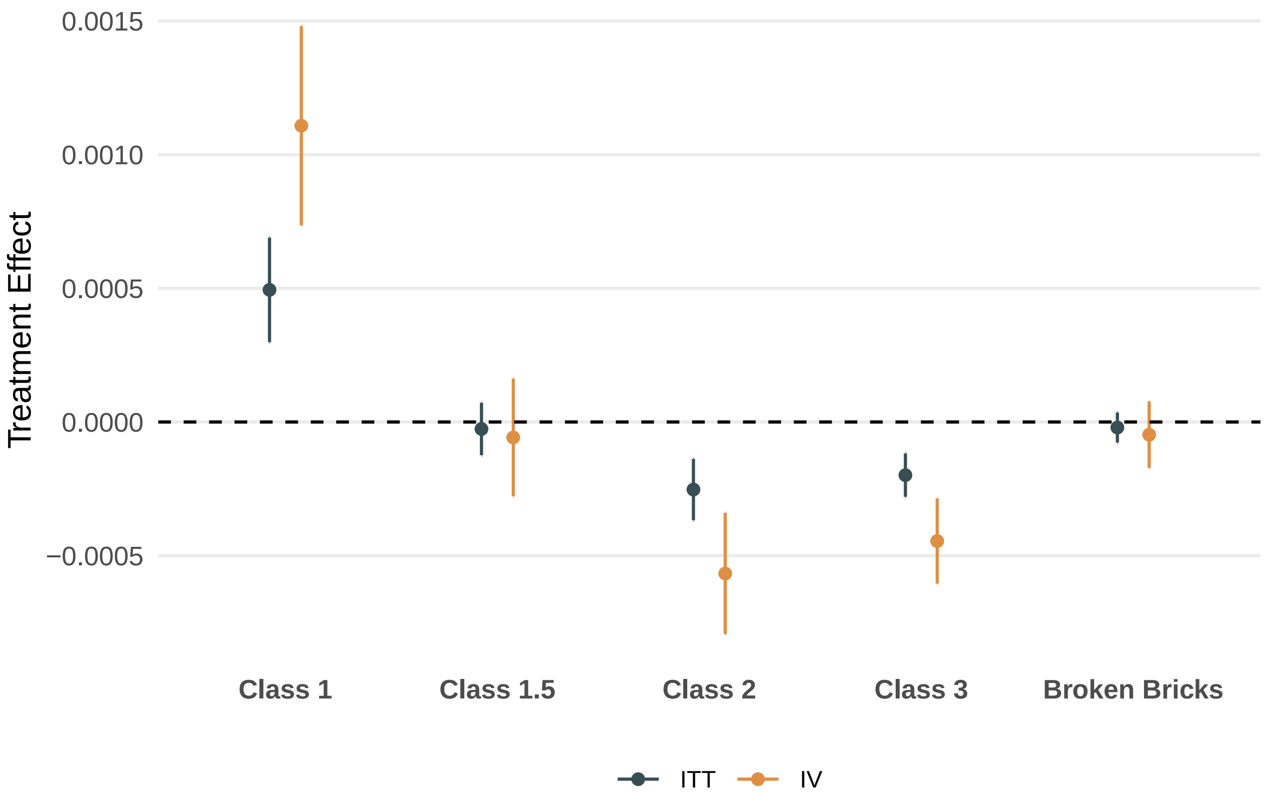
Notes: This figure presents the raw means of adopting double/triple zigzag brick stacking and single fireman continuous feeding by treatment arm across two firing seasons. Results from the RCT firing season (2022-2023) are shown in grey and results from a follow-up conducted during the subsequent year's firing season (2023-2024) are shown in orange.

Fig. S2: Mean Suspended Particulate Matter by Adoption



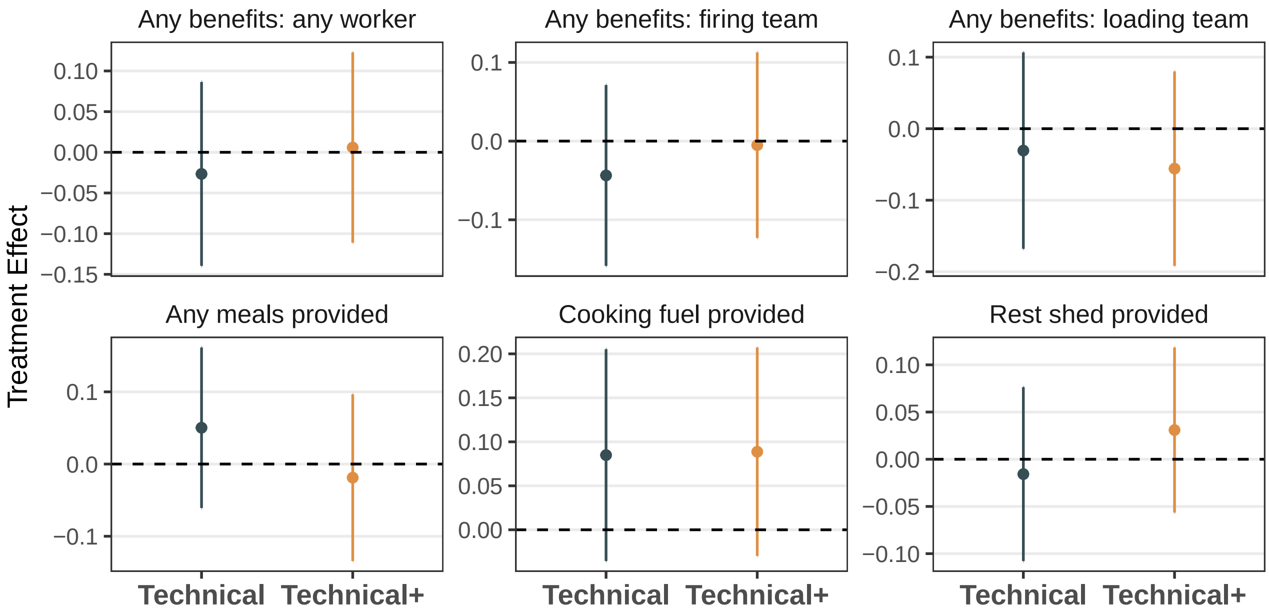
Notes: Suspended particulate matter was measured in a subsample of 12 kilns (8 adopters, 4 non-adopters).

Fig. S3: Intervention Impact on Distribution of Brick Quality (Endline)



Notes: This figure presents regression results for the intention-to-treat (ITT) and instrumental variable (IV) specifications for each classification of brick quality as a percentage of total production, using data reported by kiln owners at endline. The ITT specification, shown on the left in dark gray, bundles both treatment arms. The IV specification, shown on the right in orange, uses random assignment to either treatment arm as an instrument for adopting the technical intervention, and can be interpreted as the effect of adopting the intervention on a given outcome. Both specifications include randomization strata fixed effects and estimated heteroskedasticity-robust standard errors. In each panel, coefficients are denoted by dots and vertical bars represent 95% confidence intervals around the regression coefficient.

Fig. S4: Effect on Working Conditions and Benefits



Notes: This figure presents regression results for the intention-to-treat (ITT) specifications for outcomes related to improved working conditions and provision of benefits to workers. In each panel, the coefficients for the Technical Arm are shown on the left in dark gray and the coefficients for the Incentive+ Arm are shown on the right in orange. The specification includes randomization strata fixed effects and estimated heteroskedasticity-robust standard errors. In each panel, coefficients are denoted by dots and vertical bars represent 95% confidence intervals around the regression coefficient.

C Supplementary Tables

Table S1: Summary Statistics

Outcome	Control	Incentive	Technical
Specific Fuel Consumption (tons/100,000 bricks)	16.1 (3.3)	14.2 (3.0)	14.2 (2.7)
Specific Energy Consumption (MJ/kg fired brick)	1.07 (0.20)	0.94 (0.18)	0.95 (0.18)
CO/CO\\$_2$ (Mean ratio)	0.032 (0.014)	0.031 (0.018)	0.030 (0.016)
CO2 Emissions (tons/100,000 bricks)	31.3 (5.6)	27.7 (5.3)	28.0 (5.1)
PM2.5 (kg/100,000 bricks)	83 (15)	73 (14)	74 (14)
Expected Value of Production (BDT/brick)	10.44 (0.19)	10.62 (0.20)	10.61 (0.21)
Fuel Spending (BDT/brick)	3.74 (0.71)	3.37 (0.66)	3.26 (0.77)
Annual Production (100,000 bricks)	62 (15)	63 (13)	63 (12)
Circuits Completed (Total number)	5.01 (1.31)	5.09 (1.19)	5.18 (1.11)
Class 1 (%)	78 (7)	84 (7)	84 (7)
Class 1.5 (%)	4.1 (4.6)	3.9 (5.8)	3.4 (3.9)
Class 2 (%)	8.2 (3.7)	4.9 (3.5)	5.0 (3.2)
Class 3 (%)	6.5 (3.6)	3.9 (3.4)	4.1 (3.6)
Broken Bricks (%)	3.24 (2.12)	3.07 (1.94)	3.19 (2.57)
Any benefits: any worker	74 (80%)	77 (81%)	70 (79%)
Any benefits: firing team	74 (80%)	76 (80%)	69 (78%)
Any benefits: loading team	37 (40%)	34 (36%)	36 (40%)
Any meals provided	75 (82%)	76 (80%)	77 (87%)
Cooking fuel provided	67 (73%)	79 (83%)	73 (82%)
Rest shed provided	83 (90%)	88 (93%)	79 (89%)
N	92	95	89

Table S2: Adoption By Intervention Component

	Adopter	Stacking	Feeding	Ash Layer	Cavity Wall	Sawdust	Total Practices
Technical Arm	0.45***	0.42***	0.45***	0.05	0.05	-0.02	0.95***
	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.06)	(0.17)
Technical+ Arm	0.44***	0.44***	0.44***	0.09*	0.07	-0.10+	0.95***
	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.06)	(0.16)
N	276	276	276	276	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regression includes randomization strata fixed effects. Adoption (column 1) is defined as adoptiong both the improved stacking (column 2) and improved coal feeding (column 3) practices.

Balance Tests

Table S3: Original Sample Results (N = 328)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	14.1	8.2	15.5	10.1	14.3	9.7	0.82	0.4	0.25
Jashore Intervention Knowledge	0.29	0.46	0.32	0.47	0.28	0.45	0.98	0.57	0.55
Jashore Owner Interaction	0.48	0.51	0.50	0.51	0.61	0.50	0.69	0.79	0.86
Zigzag Year	2015	4	2014	4	2014	4	0.62	0.67	0.36
Water Adjacent	0.62	0.49	0.60	0.49	0.62	0.49	0.96	0.79	0.84
Bricks Fired (Lakhs)	8.0	1.0	8.0	1.2	8.0	1.2	0.8	0.89	0.68
Circuits Completed	5.9	1.6	5.8	1.5	5.9	1.8	0.76	0.61	0.37
Class 1 Production Share (%)	64.6	11.4	65.9	10.5	64.9	10.8	0.85	0.33	0.26
Production Cost Estimate BDT (per 1K Bricks)	8,754.4	1,155.4	8,529.8	1,192.9	8,666.2	1,032.8	0.51	0.36	0.14
Fired Brick Weight (kg)	3.37	0.25	3.41	0.22	3.41	0.23	0.19	0.98	0.2
Total Workers	108.6	27.8	107.8	31.5	109.3	34.2	0.91	0.74	0.81
Higher Secondary+	0.60	0.49	0.61	0.49	0.60	0.49	0.97	0.87	0.9
Highland	0.72	0.45	0.72	0.45	0.72	0.45	0.99	0.97	0.96
Joint Ownership	0.31	0.47	0.34	0.48	0.37	0.49	0.34	0.68	0.58
Shared Sardar	0.12	0.32	0.13	0.34	0.14	0.35	0.57	0.82	0.73
	N = 112		N = 108		N = 108				

Table S4: Jashore Expansion Sample Results (N = 29)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	17.0	6.4	17.2	8.5	20.9	10.3	0.38	0.39	0.97
Jashore Intervention Knowledge	1.0	0.0	0.73	0.47	1.0	0.0	0.28	0.066	0.05
Jashore Owner Interaction	0.33	0.50	0.62	0.52	0.33	0.50	0.94	0.32	0.36
Zigzag Year	2014	2	2015	2	2014	2	0.61	0.49	0.22
Water Adjacent	0.44	0.53	0.64	0.50	0.67	0.50	0.2	0.9	0.14
Bricks Fired (Lakhs)	7.83	0.61	7.4	1.3	8.00	0.75	0.61	0.18	0.3
Circuits Completed	6.4	1.4	6.5	1.5	6.4	1.7	0.81	1.0	0.84
Class 1 Production Share (%)	69.4	1.7	68.6	4.5	68.9	4.9	0.15	0.52	0.053
Production Cost Estimate BDT (per 1K Bricks)	9,055.6	300.5	9,000.0	591.6	9,044.4	133.3	0.94	0.83	0.82
Fired Brick Weight (kg)	3.37	0.11	3.38	0.11	3.34	0.13	0.68	0.58	0.89
Total Workers	98.0	29.3	117.5	26.5	98.2	28.8	0.99	0.15	0.17
Higher Secondary+	0.56	0.53	0.45	0.52	0.33	0.50	0.41	0.58	0.73
Highland	0.89	0.33	0.73	0.47	0.89	0.33	0.86	0.34	0.28
Joint Ownership	0.33	0.50	0.18	0.40	0.44	0.53	0.69	0.22	0.42
	N = 9		N = 11		N = 9				

Table S5: Combined Sample Results (N = 357)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	14.3	8.1	15.7	9.9	14.8	9.8	0.62	0.53	0.23
Jashore Intervention Knowledge	0.36	0.48	0.37	0.49	0.36	0.48	0.94	0.84	0.77
Jashore Owner Interaction	0.44	0.50	0.53	0.51	0.53	0.51	0.78	0.68	0.51
Zigzag Year	2015	3	2014	4	2014	4	0.68	0.77	0.48
Water Adjacent	0.60	0.49	0.61	0.49	0.62	0.49	0.68	0.83	0.84
Bricks Fired (Lakhs)	8.0	1.0	8.0	1.2	8.0	1.2	0.74	0.81	0.94
Circuits Completed	6.0	1.6	5.8	1.5	5.9	1.8	0.76	0.67	0.42
Class 1 Production Share (%)	64.9	11.1	66.2	10.1	65.2	10.5	0.95	0.37	0.36
Production Cost Estimate BDT (per 1K Bricks)	8,776.8	1,116.8	8,573.3	1,157.1	8,695.3	997.6	0.5	0.36	0.14
Fired Brick Weight (kg)	3.37	0.24	3.41	0.21	3.40	0.22	0.22	0.94	0.19
Total Workers	107.8	27.9	108.6	31.1	108.5	33.9	0.93	0.95	0.88
Higher Secondary+	0.60	0.49	0.60	0.49	0.58	0.50	0.75	0.78	0.97
Highland	0.74	0.44	0.72	0.45	0.74	0.44	0.97	0.75	0.72
Joint Ownership	0.31	0.47	0.33	0.47	0.38	0.49	0.29	0.44	0.78
Shared Sardar	0.11	0.31	0.12	0.32	0.13	0.34	0.58	0.81	0.74
	N = 121		N = 119		N = 117				

Table S6: Operated Sample Results (N = 340)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	14.4	8.1	15.6	9.9	14.8	9.9	0.69	0.6	0.32
Jashore Intervention Knowledge	0.36	0.48	0.37	0.48	0.37	0.49	0.77	0.86	0.92
Jashore Owner Interaction	0.42	0.50	0.53	0.51	0.53	0.51	0.79	0.67	0.5
Zigzag Year	2015	3	2014	4	2014	4	0.47	0.86	0.4
Water Adjacent	0.61	0.49	0.61	0.49	0.63	0.48	0.66	0.87	0.78
Bricks Fired (Lakhs)	8.01	0.98	7.9	1.2	8.0	1.2	0.94	0.44	0.36
Circuits Completed	6.0	1.6	5.9	1.5	6.0	1.8	0.92	0.86	0.77
Class 1 Production Share (%)	64.8	11.1	66.6	8.8	65.5	10.5	0.88	0.19	0.17
Production Cost Estimate BDT (per 1K Bricks)	8,788.1	1,126.2	8,578.0	1,203.8	8,674.1	999.8	0.36	0.54	0.16
Fired Brick Weight (kg)	3.38	0.24	3.41	0.21	3.40	0.22	0.43	0.79	0.3
Total Workers	107.4	27.7	109.2	31.5	109.2	33.7	0.78	0.92	0.69
Higher Secondary+	0.59	0.49	0.58	0.50	0.57	0.50	0.6	0.82	0.77
Highland	0.73	0.45	0.72	0.45	0.73	0.45	0.99	0.77	0.77
Joint Ownership	0.31	0.47	0.32	0.47	0.38	0.49	0.3	0.4	0.86
Shared Sardar	0.11	0.31	0.11	0.32	0.13	0.34	0.58	0.64	0.93
	N = 118		N = 108		N = 114				

Table S7: No Government Interference Sample Results (N = 348)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	14.4	8.2	15.6	9.9	14.8	9.9	0.66	0.57	0.28
Jashore Intervention Knowledge	0.38	0.49	0.38	0.49	0.35	0.48	0.87	0.78	0.9
Jashore Owner Interaction	0.44	0.50	0.52	0.51	0.52	0.51	0.79	0.68	0.51
Zigzag Year	2015	3	2014	4	2014	4	0.69	0.69	0.43
Water Adjacent	0.59	0.49	0.59	0.49	0.62	0.49	0.68	0.83	0.84
Bricks Fired (Lakhs)	8.0	1.0	8.0	1.2	8.0	1.2	0.7	0.71	1.0
Circuits Completed	6.0	1.6	5.8	1.5	5.9	1.8	0.82	0.53	0.36
Class 1 Production Share (%)	65.2	10.9	66.3	10.0	65.2	10.5	0.92	0.36	0.45
Production Cost Estimate BDT (per 1K Bricks)	8,773.4	1,123.6	8,558.4	1,174.4	8,684.1	994.5	0.44	0.38	0.13
Fired Brick Weight (kg)	3.37	0.24	3.41	0.22	3.40	0.22	0.26	0.86	0.21
Total Workers	107.1	28.1	108.1	30.4	108.2	33.9	0.84	0.98	0.86
Higher Secondary+	0.59	0.49	0.59	0.49	0.58	0.50	0.74	0.77	0.97
Highland	0.74	0.44	0.73	0.45	0.73	0.44	0.96	0.8	0.83
Joint Ownership	0.32	0.47	0.33	0.47	0.38	0.49	0.26	0.4	0.77
Shared Sardar	0.1	0.3	0.11	0.32	0.12	0.33	0.64	0.89	0.73
	N = 117		N = 115		N = 116				

Table S8: Analytic Sample Results (N = 276)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	15.4	8.5	16.5	10.1	14.6	9.7	0.64	0.26	0.46
Jashore Intervention Knowledge	0.37	0.49	0.37	0.49	0.36	0.48	0.82	0.91	0.92
Jashore Owner Interaction	0.44	0.51	0.58	0.50	0.52	0.51	0.77	0.48	0.33
Zigzag Year	2015	4	2014	4	2014	3	0.96	0.22	0.2
Water Adjacent	0.60	0.49	0.62	0.49	0.63	0.49	0.45	0.92	0.4
Bricks Fired (Lakhs)	8.0	1.0	7.9	1.2	8.1	1.1	0.36	0.12	0.45
Circuits Completed	6.1	1.5	6.0	1.5	6.1	1.8	0.9	0.59	0.45
Class 1 Production Share (%)	65.4	11.0	67.2	8.3	65.8	10.3	0.84	0.087	0.18
Production Cost Estimate BDT (per 1K Bricks)	8,810.4	1,215.1	8,581.1	1,284.3	8,683.2	1,039.5	0.29	0.77	0.22
Fired Brick Weight (kg)	3.38	0.24	3.40	0.19	3.39	0.23	0.56	0.85	0.43
Total Workers	107.9	28.9	111.2	31.5	110.8	34.8	0.75	0.67	0.46
Higher Secondary+	0.60	0.49	0.56	0.50	0.53	0.50	0.14	0.45	0.49
Highland	0.72	0.45	0.71	0.46	0.72	0.45	0.83	0.73	0.58
Joint Ownership	0.32	0.47	0.31	0.47	0.37	0.49	0.46	0.35	0.83
Shared Sardar	0.11	0.31	0.11	0.32	0.11	0.31	0.68	0.99	0.66
	N = 95		N = 89		N = 92				

Table S9: Attrition Tests

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Exclusive Firewood Use	0.13	0.34	0.11	0.31	0.15	0.35	0.76	0.42	0.62
Not Operated This Season	0.025	0.156	0.092	0.291	0.026	0.159	0.98	0.028	0.029
Not Operated or Exclusive Firewood Use	0.16	0.37	0.2	0.4	0.17	0.38	0.79	0.45	0.29
Demolished or Stopped by Gov	0.033	0.180	0.034	0.181	0.0085	0.0925	0.16	0.16	1.0
Dropped out (all reasons)	0.21	0.41	0.25	0.44	0.21	0.41	0.93	0.4	0.46

Arm-Specific Regression Results

Table S10: Specific Energy Consumption (MJ/kg fired brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.25***	-0.22***	-0.27***
			(0.05)	(0.05)	(0.06)
Bundled Treatment		-0.11***			
		(0.02)			
Technical Arm	-0.10***				
	(0.03)				
Technical+ Arm	-0.12***				
	(0.03)				
Control Mean	1.09	1.09	1.12	1.13	1.12
Percent Change	-9.2% (T) -11.3% (T+)	-10.3%	-22.4%	-19.8%	-24.3%
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S11: CO_2 Emissions (tons)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-382.26**	-339.39*	-409.54*
			(140.86)	(146.36)	(161.82)
Bundled Treatment		-170.70**			
		(60.05)			
Technical Arm	-153.12*				
	(64.46)				
Technical+ Arm	-187.51**				
	(68.27)				
Control Mean	1942.38	1941.33	1982.27	2017.78	1991.40
Percent Change	-7.9% (T) -9.7% (T+)	-8.8%	-19.3%	-16.8%	-20.6%
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S12: $PM_{2.5}$ Emissions (tons)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-1.01**	-0.90*	-1.08*
			(0.37)	(0.39)	(0.43)
Bundled Treatment		-0.45**			
		(0.16)			
Technical Arm	-0.40*				
	(0.17)				
Technical+ Arm	-0.50**				
	(0.18)				
Control Mean	5.13	5.13	5.23	5.33	5.26
Percent Change	-7.9% (T)	-8.8%	-19.3%	-16.8%	-20.6%
	-9.7% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S13: Fuel Costs (BDT/brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.81***	-0.91***	-0.69***
			(0.17)	(0.21)	(0.18)
Bundled Treatment		-0.36***			
		(0.08)			
Technical Arm	-0.41***				
	(0.10)				
Technical+ Arm	-0.31***				
	(0.09)				
Control Mean	3.79	3.79	3.88	3.89	3.86
Percent Change	-10.9% (T)	-9.5%	-20.8%	-23.3%	-17.8%
	-8.1% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S14: Total Fuel Costs (million BDT)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-4.35**	-5.02**	-3.43+
			(1.64)	(1.84)	(1.84)
Bundled Treatment		-1.94**			
		(0.71)			
Technical Arm	-2.33**				
	(0.79)				
Technical+ Arm	-1.57+				
	(0.80)				
Control Mean	23.07	23.09	23.56	24.06	23.46
Percent Change	-10.1% (T)	-8.4%	-18.5%	-20.9%	-14.6%
	-6.8% (T+)				
N	276	276	276	181	187

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S15: Class 1 Bricks (%)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			0.14***	0.14***	0.14***
			(0.02)	(0.02)	(0.02)
Bundled Treatment		0.06***			
		(0.01)			
Technical Arm	0.06***				
	(0.01)				
Technical+ Arm	0.06***				
	(0.01)				
Control Mean	0.77	0.77	0.75	0.75	0.76
Percent Change	8.1% (T)	8.2%	18.9%	18.6%	18.8%
	8.3% (T+)				
N	276	276	276	181	187

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S16: Endline Total Value of Production (BDT)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			36.70	41.99	36.26
			(40.60)	(44.23)	(47.57)
Bundled Treatment		16.36			
		(18.54)			
Technical Arm	17.75				
	(20.49)				
Technical+ Arm	15.04				
	(21.15)				
Control Mean	638.62	638.54	634.59	644.64	636.17
Percent Change	2.8% (T)	2.6%	5.8%	6.5%	5.7%
	2.4% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from kiln owner self-reports at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S17: Specific Fuel Consumption (tons/100,000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-4.13***	-4.27***	-4.00***
			(0.91)	(0.97)	(1.08)
Bundled Treatment		-1.84***			
		(0.41)			
Technical Arm	-1.91***				
	(0.42)				
Technical+ Arm	-1.77***				
	(0.46)				
Control Mean	16.28	16.28	16.73	16.79	16.76
Percent Change	-11.7% (T)	-11.3%	-24.7%	-25.4%	-23.9%
	-10.9% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S18: Specific Coal Consumption (tons/100,000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-2.49***	-2.42**	-2.45**
			(0.67)	(0.74)	(0.79)
Bundled Treatment		-1.11***			
		(0.32)			
Technical Arm	-1.11**				
	(0.35)				
Technical+ Arm	-1.11**				
	(0.37)				
Control Mean	14.54	14.54	14.81	14.72	14.83
Percent Change	-7.6% (T)	-7.6%	-16.8%	-16.4%	-16.5%
	-7.6% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S19: Endline Fuel Costs (BDT/brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.28	-0.29	-0.31
			(0.19)	(0.19)	(0.23)
Bundled Treatment		-0.13			
		(0.09)			
Technical Arm	-0.13				
	(0.09)				
Technical+ Arm	-0.13				
	(0.10)				
Control Mean	3.90	3.90	3.93	3.85	3.92
Percent Change	-3.2% (T)	-3.2%	-7.2%	-7.5%	-7.9%
	-3.2% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S20: Coal Costs (BDT/brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.72***	-0.78***	-0.63**
			(0.18)	(0.21)	(0.20)
Bundled Treatment		-0.32***			
		(0.08)			
Technical Arm	-0.36***				
	(0.10)				
Technical+ Arm	-0.28**				
	(0.10)				
Control Mean	3.68	3.68	3.75	3.76	3.74
Percent Change	-9.7% (T)	-8.7%	-19.1%	-20.7%	-16.8%
	-7.7% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S21: Total Coal Costs (million BDT)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-3.74*	-4.27*	-2.94
			(1.65)	(1.81)	(1.91)
Bundled Treatment		-1.67*			
		(0.72)			
Technical Arm	-1.99*				
	(0.79)				
Technical+ Arm	-1.35				
	(0.84)				
Control Mean	22.36	22.37	22.78	23.21	22.68
Percent Change	-8.9% (T)	-7.4%	-16.4%	-18.4%	-13.0%
	-6.1% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S22: Mean CO/CO_2 Ratio

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0020	-0.0032	-0.0004
			(0.0039)	(0.0045)	(0.0048)
Bundled Treatment		-0.0009			
		(0.0018)			
Technical Arm	-0.0014				
	(0.0021)				
Technical+ Arm	-0.0004				
	(0.0021)				
Control Mean	0.03	0.03	0.03	0.03	0.03
Percent Change	-4.7% (T)	-3.0%	-6.7%	-10.8%	-1.2%
	-1.3% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S23: Annual Production (100,000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			1.77	2.31	1.80
			(3.84)	(4.16)	(4.50)
Bundled Treatment		0.79			
		(1.73)			
Technical Arm	0.89				
	(1.91)				
Technical+ Arm	0.69				
	(1.98)				
Control Mean	61.72	61.71	61.52	62.60	61.67
Percent Change	1.4% (T)	1.3%	2.9%	3.7%	2.9%
	1.1% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S24: Circuits Completed (Total number)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			0.18	0.16	0.16
			(0.34)	(0.38)	(0.40)
Bundled Treatment		0.08			
		(0.15)			
Technical Arm	0.09				
	(0.17)				
Technical+ Arm	0.07				
	(0.17)				
Control Mean	5.04	5.04	5.02	5.02	5.02
Percent Change	1.8% (T)	1.6%	3.6%	3.2%	3.2%
	1.4% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S25: Total Value of Production (BDT)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			42.84	47.82	43.99
			(40.53)	(44.15)	(47.62)
Bundled Treatment		19.10			
		(18.56)			
Technical Arm	19.87				
	(20.52)				
Technical+ Arm	18.38				
	(21.22)				
Control Mean	642.33	642.29	637.68	647.94	639.50
Percent Change	3.1% (T)	3.0%	6.7%	7.4%	6.9%
	2.9% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Total value of production is calculated by applying the objective brick quality data measured during the kiln performance assessment to the annual production reported at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S26: Value of Production Per Brick (BDT/brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			0.39***	0.38***	0.41***
			(0.04)	(0.05)	(0.05)
Bundled Treatment		0.18***			
		(0.02)			
Technical Arm	0.17***				
	(0.03)				
Technical+ Arm	0.18***				
	(0.03)				
Control Mean	10.40	10.40	10.36	10.35	10.36
Percent Change	1.6% (T)	1.7%	3.8%	3.6%	4.0%
	1.8% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S27: Endline Value of Production (BDT/brick)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			0.30***	0.29***	0.29***
			(0.05)	(0.06)	(0.06)
Bundled Treatment		0.13***			
		(0.03)			
Technical Arm	0.14***				
	(0.03)				
Technical+ Arm	0.13***				
	(0.03)				
Control Mean	10.34	10.34	10.31	10.30	10.31
Percent Change	1.3% (T)	1.3%	2.9%	2.9%	2.8%
	1.3% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from kiln owner self-reports at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S28: Total Value of Production (BDT)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			42.84	47.82	43.99
			(40.53)	(44.15)	(47.62)
Bundled Treatment		19.10			
		(18.56)			
Technical Arm	19.87				
	(20.52)				
Technical+ Arm	18.38				
	(21.22)				
Control Mean	642.33	642.29	637.68	647.94	639.50
Percent Change	3.1% (T)	3.0%	6.7%	7.4%	6.9%
	2.9% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Total value of production is calculated by applying the objective brick quality data measured during the kiln performance assessment to the annual production reported at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S29: Endline Class 1 Bricks (%)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			0.00***	0.00***	0.00***
			(0.00)	(0.00)	(0.00)
Bundled Treatment		0.00***			
		(0.00)			
Technical Arm	0.00***				
	(0.00)				
Technical+ Arm	0.00***				
	(0.00)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	5.1% (T)	4.9%	11.1%	10.7%	10.8%
	4.8% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from kiln owner self-reports at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S30: Endline Specific Fuel Consumption (tons/100,000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-3.04**	-2.86**	-3.46**
			(1.04)	(1.08)	(1.27)
Bundled Treatment		-1.36**			
		(0.46)			
Technical Arm	-1.24**				
	(0.47)				
Technical+ Arm	-1.47**				
	(0.52)				
Control Mean	17.44	17.43	17.76	17.54	17.77
Percent Change	-7.1% (T)	-7.8%	-17.1%	-16.3%	-19.5%
	-8.4% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from kiln owner self-reports at endline. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table S31: Heterogeneous Treatment Effects

	Specific Energy Consumption			Class 1 Bricks (%)		
	Experience	Education	Location	Experience	Education	Location
Bundled Treatment	-0.07	-0.08*	-0.10*	0.04**	0.07***	0.06***
	(0.04)	(0.03)	(0.04)	(0.01)	(0.01)	(0.01)
Owner Experience	0.00			0.00		
	(0.00)			(0.00)		
Treatment X Owner Experience	-0.00			0.00		
	(0.00)			(0.00)		
Higher Secondary+		0.02			0.02	
		(0.04)			(0.02)	
Treatment X Higher Secondary+		-0.06			-0.02	
		(0.05)			(0.02)	
Highland			-0.02			0.01
			(0.05)			(0.02)
Treatment X Highland			-0.02			-0.00
			(0.05)			(0.02)
N	276	276	276	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regression includes randomization strata fixed effects. Kiln characteristics (owner experience, education, and kiln location) are from baseline data and outcomes are derived from the kiln performance monitoring. Kiln owner experience is measured in years, higher secondary+ is a binary indicator that equals 1 if the owner has attained higher secondary schooling or more, and highland indicates a kiln is located on highland (as opposed to lowland).

Changes In Other Costs

Table S32: Sawdust Spending (bdt/ton)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			-4940.88+
			(2359.27)
Bundled Treatment		-2206.90+	
		(1012.37)	
Technical Arm	-1921.35*		
	(816.86)		
Technical+ Arm	-2479.92+		
	(1216.39)		
Control Mean	4136.8272	4119.7609	4648.6108
Percent Change	-46.44% (T)	-53.57%	-106.29%
	-59.95% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S33: Soil (BDT per 1000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			27.43
			(20.44)
Bundled Treatment		12.34	
		(8.82)	
Technical Arm	1.59		
	(11.56)		
Technical+ Arm	22.62*		
	(10.04)		
Control Mean	904.1681	904.8106	901.9309
Percent Change	0.18% (T)	1.36%	3.04%
	2.50% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S34: Molding (BDT per 1000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			9.89
			(20.29)
Bundled Treatment		4.39	
		(9.37)	
Technical Arm	6.58		
	(11.21)		
Technical+ Arm	2.30		
	(11.54)		
Control Mean	1019.0770	1018.9460	1017.8700
Percent Change	0.65% (T)	0.43%	0.97%
	0.23% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S35: Coal preparation (BDT per season)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			17494.21
			(15052.72)
Bundled Treatment		7750.48	
		(6757.44)	
Technical Arm	13239.60+		
	(7089.23)		
Technical+ Arm	2502.05		
	(7588.85)		
Control Mean	205152.0457	204823.9791	202911.6725
Percent Change	6.45% (T)	3.78%	8.62%
	1.22% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S36: Brick loading (BDT per 1000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			13.59
			(11.99)
Bundled Treatment		6.07	
		(5.96)	
Technical Arm	5.85		
	(6.01)		
Technical+ Arm	6.27		
	(6.85)		
Control Mean	310.8949	310.9078	309.4494
Percent Change	1.88% (T)	1.95%	4.39%
	2.02% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S37: Firemen cost (BDT per season)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			45656.58
			(27563.92)
Bundled Treatment		20386.10+	
		(11061.27)	
Technical Arm	18452.90		
	(17893.69)		
Technical+ Arm	22234.53		
	(13494.12)		
Control Mean	1054595.0730	1054710.6139	1049819.4170
Percent Change	1.75% (T)	1.93%	4.35%
	2.11% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

Table S38: Brick unloading (BDT per 1000 bricks)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable
Adopted Intervention			8.35
			(8.03)
Bundled Treatment		3.73	
		(3.22)	
Technical Arm	3.35		
	(5.19)		
Technical+ Arm	4.09		
	(2.64)		
Control Mean	201.7603	201.7828	200.8886
Percent Change	1.66% (T)	1.85%	4.16%
	2.03% (T+)		
N	276	276	276

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Heteroscedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects.

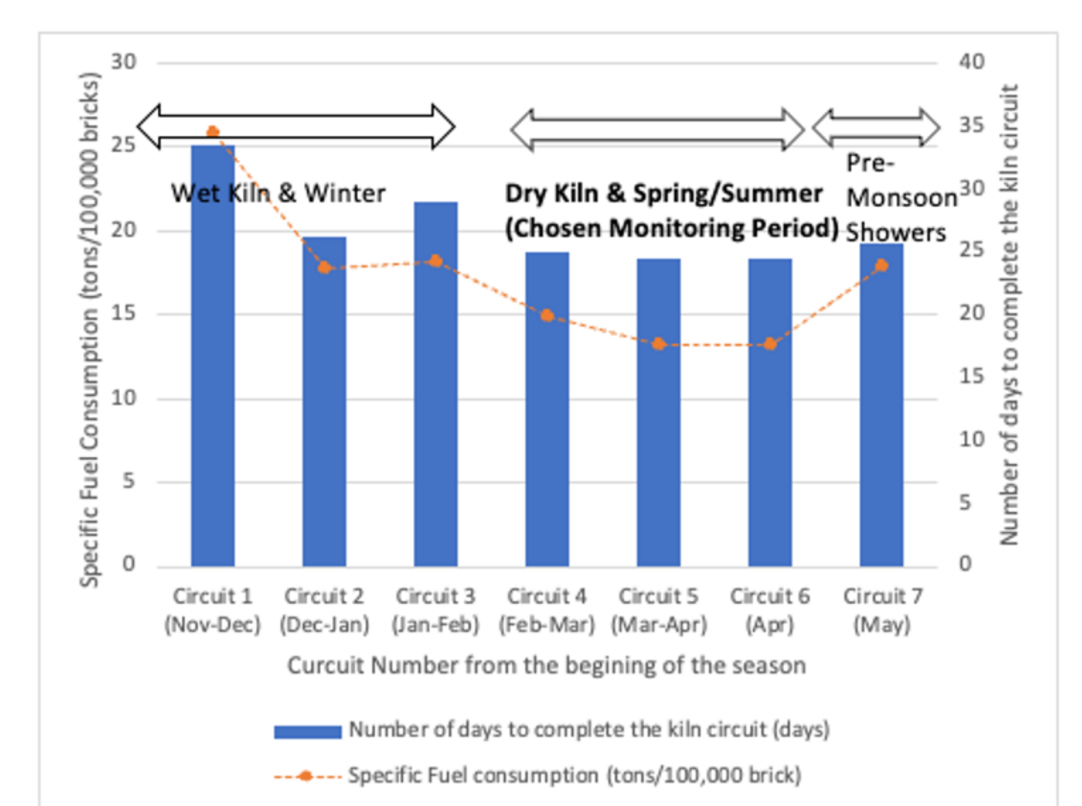
D Kiln Performance Monitoring Protocol

Kiln performance monitoring was carried out in 276 kilns to collect outcomes for the trial (see Fig. A.9 for the field activities timeline). Each monitoring visit was spread over 3 days (from 2 pm on Day 1 to around 10 am on Day 3). The monitoring teams consisted of one engineer and one research assistant. They were further assisted by one or two workers/helpers.

Timing of Monitoring

The performance of a brick kiln varies throughout a brick-firing season. Circuit-wise performance data were collected from a zigzag kiln located near Kolkata in India.[5] Data on the time taken to complete one kiln circuit and the SFC for a circuit are plotted in Fig. D.1.

Fig. D.1: Circuit-wise variation in the number of days required to complete the circuit and specific fuel consumption



The brick-firing season can be divided into three phases:

1. Initial Phase (November to Mid-February): This is the winter period, during which the kiln structure and ground are wet from the water absorbed during the rainy season and green bricks loaded in the kiln have higher moisture content. As a result, the SFC and the time required to complete one circuit are higher.

2. Mid-Phase (Mid-February to end April): This is the spring and summer period. After a few circuits have been completed, the kiln structure and ground dry up; due to the dry

[5] Personal communication between Greentech and Ashok Tewari, Owner, LMB Brick Kiln, Howrah, Kolkata.

weather, green bricks loaded in the kiln have lower moisture. The kiln achieves a steady state, and SFC is lowest.

3. End Phase (May-June): By this time, pre-monsoon rains are common and SFC again rises.

Based on this information, kiln performance monitoring was carried out during the mid-phase of the kiln operation when the kiln is operating at steady state. All kilns were monitored between February 20, 2023, and May 11, 2023.

To ensure that kiln performance was monitored when kiln operation was not disturbed and was representative of normal kiln operation, the following criteria were applied:

- The weather at the time of monitoring was dry.
- The kiln was not experiencing any shortage of labor to operate the kiln.
- The kiln had an adequate quantity of coal and green bricks for normal operation.
- The fire was located in the straight portion (which has a zigzag brick setting) of the kiln circuit.

Each monitoring team was equipped with following equipment and materials:

1. A platform balance scale (50-100 kg, with LC of 10 gm)
2. A container for fuel measurement
3. Flue gas analyzer and equipment
4. Fully charged and cleaned flue gas analyzer
5. Flue gas analyzer probe packed in PVC pipe case
6. Flue gas charger
7. 2 ft steel tube for placement of the probe
8. Napkin/cloth/tissues for cleaning the analyzer
9. Cloth and umbrella for protecting the flue gas analyzer
10. KANE Live program downloaded and installed on the mobile device/tablet.
11. Steel measuring tape (5 m)
12. Steel scale (12 in)
13. Tarpaulin sheets to cover an area of 10 m x 10 m
14. Zip polythene bags (2 kg size), labels, permanent marker, cello tape for sealing fuel sample bags.
15. Computer tablet for data recording and entry in ODK

16. Hardback notebook and pens
17. Placards for marking unloaded brick stacks
18. Bicycle pump for cleaning the probe
19. Set of multiplugs for electrical connections
20. Screwdrivers/tester.

The complete schedule of activities during the monitoring period is reported inTable D.1

Table D.1: Activity Schedule

Day & Time	**Activity**
Day 1	
08:00	The two-member team and helpers with all necessary equipment and materials arrive at the brick kiln site.
08:00 – 09:00	Meet brick kiln manager and brief him on the key tasks the team will be performing over next 2 days and the support required from kiln management. After initial briefing, request that he introduce the team to loading and unloading supervisors and the head fireman/firing supervisor. Tour the kiln with the kiln manager. Find key information on the kiln through questions and observations:

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	**Activity**
	• Is the kiln's operation normal, or are there any operational issues—e.g. a shortage of workers, shortage of green bricks, etc.? • Observe the location of the fuel feeding/firing zone. The fuel feeding zone should be in the straight part of the kiln circuit. Check brick loading and unloading locations. • List the fuels being used. • How many chambers are being completed in a day (24-hour period)? • What is the approximate quantity of fuel used in 24 hours? • The type of brick setting and number of bricks loaded in one chamber. • Where is crushed fuel stored, and what is the quantity? Is there sufficient space for storing the weighed fuel for monitoring? • Time of the last chamber shifting and time when the next shifting is planned. • What is the typical schedule for the unloading operation, and where are unloaded bricks stacked? This is the basic information required for kiln monitoring, which can be used to fine tune the monitoring plan.
09:00 onward	One team member, with assistance from workers, starts the process of weighing and storing fuel:

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	Activity
	• Using buckets of known volume and weight and a balance scale, individually weigh 5 buckets of each fuel and note the weight. Take the average of the 5 measurements to calculate the average weight of fuel/bucket and the density of each type of fuel. • Ask the kiln manager the amount of fuel required for 24 hours (also cross-check with your estimations). Calculate the number of buckets required of each fuel to obtain 1.1 times the 24-hour requirement. • Spread the tarpaulin on the ground. • Start the process of collecting the required quantities of fuel on the tarpaulin. This will require help from at least 2 workers and can take 3-4 hours. Use tokens to count the number of buckets. • When the fuel collection is complete, enter the initial quantity of each type of fuel on the ODK form. • Collect fuel samples in zip bags and label each with the number generated by the ODK, date of collection, and name of the fuel.
09:00 onward	The second team member prepares to start the 24-hour fuel consumption trial: • Observe kiln operations and complete Sections 1 to 4 on the ODK form. • Talk to firemen and coal persons and explain what the 24-hour fuel consumption trial will entail. Ask that they not add excess coal to containers/drums before the next chamber shifting. • Usually, a chamber shifting takes place sometime between 10:00 and 13:00 hrs. The aim should be to start the trial by lunchtime on day 1. • Supervise the start of the 24 hours fuel consumption trial.

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	**Activity**
11:00 onward	Ask the unloading sardar where they intend to stack fired bricks the next day and request that he organize the stacks so that it is easy to count the number of bricks. Check the unloading plan for the next day with him.
14:00 – 18:00 hrs	Carry out flue gas analysis (Option 1).

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	Activity
	• Ensure that flue gas monitoring is not done immediately after the shifting of a chamber and that there is a gap of at least 1 hour. • The duration of flue gas monitoring is 2 hours. The total time required is close to 2.5 hours, which includes setting up the instrument and packing it after the measurements. • The measurements are collected at the shunt. Lift the shunt a few inches and place the pipe, which acts as the monitoring port. Insert and position the probe (at this point, the probe is not connected to the flue gas analyzer) inside the pipe. Ensure that there is no leakage of air from around the pipe by covering it with ash. Also ensure that the gap between the probe and the pipe is sealed with clay. • Switch on and self-calibrate the flue gas analyzer in open air. After self-calibration, connect the flue gas analyzer with the probe and ensure that the flue gas analyzer reading is displayed correctly on the computer tablet (using the KANE Live program). Flue gas analyzer readings are to be saved periodically both on the tablet and in the flue gas analyzer's memory. Ensure that the flue gas analyzer and the tablet remain connected by Bluetooth during the entire 2 hours of monitoring. The flue gas analyzer should be placed vertically and protected from dust and heat (by the cloth and umbrella). • While one team member is setting up the flue-gas analyzer, the second team member should be stationed near the fuel feeding zone to observe fuel feeding during the flue gas monitoring. • The clock on the flue gas analyzer should match the watch of the person monitoring the fuel feeding operation. • Once both team members are ready, flue gas monitoring begins. The team member stationed at the fuel feeding zone should record the fuel feeding status during the entire flue gas monitoring period. • Photograph the flue gas monitoring and fuel feeding operations, which are to be uploaded on the ODK. • After completion of the 2-hour monitoring, disconnect the probe, turn off the flue gas analyzer, and clean the flue gas analyzer, pipe, and tube externally. • After returning to the base, clean the moisture trap, check/replace the filter, and put the flue gas analyzer on the charger. Blow the flue gas probe with the bicycle pump to clean it. Periodically connect the probe and check for leaks.

Table D.1 – *Continued from previous page*

Day & Time	Activity
14:00 -18:00	After the unloading operation for the day has been completed, count the number of bricks (row wise) for each stack and record in a table format in the notebook. Place placards on unloaded brick stacks and/or mark using lime wash. Instruct the kiln manager/unloading sardar to stack the bricks in the marked stacks or in a separate new stack the next day. Broken bricks should be collected separately in a new heap. • Before leaving the site, check the firing operation to ensure that only fuel from the weighed lot is being used. Also instruct the firing supervisor to tell all firemen and coal loaders that only fuel from the weighed lot is to be used during the night. • Photograph the fan, chimney, and loading chamber to be uploaded on the ODK.
Day 2	
08:00 onwards	One team member should observe unloading operations. • Ensure that (a) unloading only takes place from the straight region of the trench and not from the gully region; (b) unloaded bricks are being stacked in the marked stacks; and (c) almost an equal number of bricks are being unloaded from the top and bottom parts of the kiln stacking. If that is not the case, ask that the kiln manager and unloading sardar ensure that by the end of the day's unloading, an almost equal number of bricks from the top and bottom parts of the kiln stacking are unloaded. • Photograph of the unloading to be uploaded on the ODK.
08:30 -11:30	If the flue gas analysis was not carried out on Day 1, it can be carried out during this time slot (Option 2)
09:00 onward	Completion of the 24-hour monitoring:

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	Activity
	• The other team member should observe the fuel feeding and talk to firemen to find out when the next chamber shifting is likely to take place. Also check the quantity of weighed fuel available, and ask that they not add excess coal to the containers before the next chamber shifting. • On completion of fuel measurement monitoring: Note the end time and sketch the kiln and mark the position of the fire. Also put a marker on the kiln and take a photograph. Note the number of chambers that have been completed/closed during the 24-hour monitoring. • Ensure that all drums that have remaining pre-weighed fuel are emptied and calculate the quantity of remaining fuel using the standard bucket measurement. • Check the remaining pre-weighed fuel on the tarpaulin in the fuel storage area and estimate the quantity using the standard bucket measurement. • Record the remaining weight of each fuel type on the ODK. • Record the number of chambers completed during 24 hours on the ODK. • Usually, the total duration of the monitoring is 24±2 hours. In some cases, if the monitoring was started on the afternoon of Day 1, the monitoring period can be reduced in order to finish monitoring during the 2 days. However, the monitoring period should not be less than 20 hours
14:00-16:00	After the unloading operation for the day has been completed, count the unloaded bricks by class.

Continued on next page

Table D.1 – *Continued from previous page*

Day & Time	Activity
	• Count the number of bricks by rows, subtract the initial numbers, and calculate the number of bricks stacked on that day by quality class. • Arrange the broken bricks in a cuboid shape and measure to calculate the volume and, from that, the number of bricks (1 cubic ft = 8.5 bricks) • Enter the number of unloaded bricks of each quality on the ODK. • Randomly select and weigh 20 samples of unloaded Class 1 bricks in a lot size of 5 and enter on the ODK.
16:00-17:00	Check that all data have been recorded and photographs taken and that the data are correctly recorded on the ODK. Meet with the Kiln Manager/Owner, thank them for their cooperation, brief them regarding the preliminary results—e.g., specific fuel consumption, % distribution of the quantity of bricks, and interpretation of the flue gas analysis results.

E Supplementary Discussion of CO/CO_2 Results

During the kiln performance assessment, trained fieldworkers collected approximately 2 hours of continuous measurements of O_2 , CO_2 , and CO in the flue gas from each kiln. Incomplete combustion of fuel results in more particulate matter in brick kiln emissions, and the ratio of CO to CO_2 (CO/CO_2) in the flue gas is a good measurement of the completeness of combustion; higher values indicate less complete combustion.

Our analysis plan prespecified the mean CO/CO_2 as a primary outcome. ITT and IV results suggest small and statistically insignificant reductions in the mean CO/CO_2 associated with the intervention (Table S22). Measurement of the flue gas of brick kilns poses challenges due to the high dust and moisture load in the flue gases, which limit the duration of monitoring. Our power calculations were based on estimated effects from the pilot we conducted. However, the increased sample size posed additional unanticipated challenges with the flue gas measurements, which increased variability in the measurements. The industrial flue gas analyzers used in the study were manufactured in Europe and are designed to measure flue gas in modern industries, in which flue gas has lower dust and moisture loads. Because of the excessive dust and moisture in the brick kilns' flue gases, frequent replacement of the filters used to trap dust was necessary and the maximum duration of measurement was 2 hours per kiln. Also, the instruments required cleaning after each measurement and frequent servicing. Instead of the direct extractive flue gas analyzer used in the study, use of a dilution gas sampling apparatus could have allowed longer measurement duration and may have resulted in more precise data.

Furthermore, because brick kilns lack a standard porthole—which would enable a leak-proof setup for monitoring—a temporary arrangement was used at each kiln that required constant attention to ensure leak-proof conditions. The simultaneous recording of fuel feeding intervals was also required, and thus a highly skilled 2- to 3-person team was necessary to collect measurements from a single kiln. The measurements collected were noisy, and not all measurements were physically plausible given the expected ranges of O_2 , CO_2 , and CO. The flue gas analyzers required frequent servicing and recalibration, and their heavy use during approximately 2 hours of collecting measurements from each of 276 kilns put substantial stress on the devices.

Immediately following fuel feeding intervals, CO and CO_2 spikes result in CO/CO_2 peaks, which are highly correlated with particulate matter emissions. Intermittent feeding, with more intervals of feeding and non-feeding, results in more spikes of CO/CO_2 that reach higher values. In contrast, more continuous feeding results in more constant levels of CO/CO_2. Therefore, we also explored alternative specifications that estimated the impact of the intervention on measures of variability of the CO/CO_2, such as the standard deviation and interquartile range (IQR) and maximum CO/CO_2 instead of the mean (these outcomes were not prespecified). These results are presented in Tables E.1 - E.3. We see that the standard deviation of the CO/CO_2 was significantly lower in both the ITT and IV specifications (Table E.2).

To address data quality issues in the flue gas measurements, we estimated alternative specifications in which we dropped kilns that had measurements outside physically plausible ranges, were feeding fuel for less than 33% of the monitoring time (which is indicative of unusual operational behavior), or both conditions were met. When we repeated the analysis for the mean CO/CO_2 dropping kilns that had measurements outside physically plausible ranges, were feeding fuel for less than 33% of the monitoring time, or both conditions were met, the treatment effects for the mean CO/CO_2 remained statistically insignificant but were more precisely estimated (Tables E.4, E.8, and E.12).[6] Results for the maximum CO/CO_2 and measures of variance, excluding kilns with data quality issues, find significant reductions in the maximum (Tables E.5 and E.13), the standard deviation (Tables E.6, E.10, and E.14), and IQR (E.7, E.11, E.15) due to the intervention, although some estimated effects are significant only at the 10% level.

This supplementary analysis suggests that while there was no difference in the mean CO/CO_2 attributable to the intervention, the variance of CO/CO_2 was reduced, as was the maximum (once observations with poor data quality were dropped). Overall, this analysis suggests that the mean may not be the optimal measure of CO/CO_2 and highlights the need for better methods for measuring particulate matter emissions from kilns.

[6]Balance tests show that within these reduced samples that drop abnormal observations treatment is not balanced on all baseline characteristics. See Tables E.16- E.18.

Table E.1: Max CO/CO_2 Ratio

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0082	-0.0112	-0.0053
			(0.0064)	(0.0074)	(0.0075)
Bundled Treatment		-0.0037			
		(0.0030)			
Technical Arm	-0.0048				
	(0.0035)				
Technical+ Arm	-0.0025				
	(0.0035)				
Control Mean	0.06	0.06	0.06	0.06	0.06
Percent Change	-8.0% (T)	-6.1%	-13.7%	-18.6%	-8.8%
	-4.2% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table E.2: SD CO/CO_2 Ratio

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0029*	-0.0030+	-0.0031*
			(0.0014)	(0.0016)	(0.0016)
Bundled Treatment		-0.0013*			
		(0.0007)			
Technical Arm	-0.0013+				
	(0.0008)				
Technical+ Arm	-0.0013+				
	(0.0007)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-13.0% (T)	-13.1%	-29.4%	-29.7%	-30.9%
	-13.2% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table E.3: IQR CO/CO_2 Ratio

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0035	-0.0033	-0.0040
			(0.0022)	(0.0025)	(0.0025)
Bundled Treatment		-0.0016			
		(0.0010)			
Technical Arm	-0.0015				
	(0.0011)				
Technical+ Arm	-0.0016				
	(0.0011)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-14.9% (T)	-15.6%	-35.0%	-33.4%	-40.5%
	-16.3% (T+)				
N	276	276	276	181	187

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding.

Table E.4: Mean CO/CO_2Ratio (dropping abnormal feeding)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0025	-0.0039	-0.0006
			(0.0043)	(0.0049)	(0.0053)
Bundled Treatment		-0.0011			
		(0.0019)			
Technical Arm	-0.0015				
	(0.0022)				
Technical+ Arm	-0.0006				
	(0.0023)				
Control Mean	0.03	0.03	0.03	0.03	0.03
Percent Change	-5.1% (T)	-3.5%	-8.2%	-13.0%	-2.1%
	-2.1% (T+)				
N	256	256	256	164	174

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with total feeding time below 33\%, which indicates abnormal operation.

Table E.5: Max CO/CO_2 Ratio (dropping abnormal feeding)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0078	-0.0108	-0.0043
			(0.0068)	(0.0079)	(0.0081)
Bundled Treatment		-0.0034			
		(0.0031)			
Technical Arm	-0.0046				
	(0.0036)				
Technical+ Arm	-0.0022				
	(0.0035)				
Control Mean	0.06	0.06	0.06	0.06	0.06
Percent Change	-7.6% (T)	-5.6%	-13.1%	-18.0%	-7.1%
	-3.7% (T+)				
N	256	256	256	164	174

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with total feeding time below 33\%, which indicates abnormal operation.

Table E.6: SD CO/CO_2 Ratio (dropping abnormal feeding)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0031*	-0.0031+	-0.0030+
			(0.0015)	(0.0017)	(0.0017)
Bundled Treatment		-0.0013+			
		(0.0007)			
Technical Arm	-0.0013+				
	(0.0008)				
Technical+ Arm	-0.0013+				
	(0.0007)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-13.5% (T)	-13.3%	-30.7%	-30.6%	-30.4%
	-13.0% (T+)				
N	256	256	256	164	174

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with total feeding time below 33\%, which indicates abnormal operation.

Table E.7: IQR CO/CO_2 Ratio (dropping abnormal feeding)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0039+	-0.0041+	-0.0039
			(0.0023)	(0.0024)	(0.0027)
Bundled Treatment		-0.0017+			
		(0.0010)			
Technical Arm	-0.0018+				
	(0.0011)				
Technical+ Arm	-0.0016				
	(0.0012)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-18.2% (T)	-16.9%	-39.3%	-40.7%	-38.9%
	-15.8% (T+)				
N	256	256	256	164	174

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with total feeding time below 33\%, which indicates abnormal operation.

Table E.8: Mean CO/CO_2 Ratio (dropping abnormal values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0023	-0.0022	-0.0016
			(0.0039)	(0.0046)	(0.0048)
Bundled Treatment		-0.0011			
		(0.0018)			
Technical Arm	-0.0011				
	(0.0021)				
Technical+ Arm	-0.0010				
	(0.0022)				
Control Mean	0.03	0.03	0.03	0.03	0.03
Percent Change	-3.6% (T)	-3.5%	-7.8%	-7.3%	-5.4%
	-3.4% (T+)				
N	264	264	264	171	181

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O2, $ ext\{CO\}_\{2\}$, and CO outside normal ranges for more than 50\\% of the monitored time, which indicates abnormal operation.

Table E.9: Max CO/CO_2 Ratio (dropping abnormal values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0097	-0.0106	-0.0085
			(0.0064)	(0.0076)	(0.0075)
Bundled Treatment		-0.0044			
		(0.0030)			
Technical Arm	-0.0047				
	(0.0036)				
Technical+ Arm	-0.0041				
	(0.0035)				
Control Mean	0.06	0.06	0.06	0.06	0.06
Percent Change	-7.8% (T)	-7.3%	-16.1%	-17.6%	-14.1%
	-6.8% (T+)				
N	264	264	264	171	181

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O2, $ ext\{CO\}_\{2\}$, and CO outside normal ranges for more than 50\\% of the monitored time, which indicates abnormal operation.

Table E.10: SD CO/CO_2 Ratio (dropping abnormal values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0032*	-0.0030+	-0.0036*
			(0.0014)	(0.0017)	(0.0016)
Bundled Treatment		-0.0015*			
		(0.0007)			
Technical Arm	-0.0013				
	(0.0008)				
Technical+ Arm	-0.0016*				
	(0.0007)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-13.2% (T)	-14.6%	-32.2%	-30.1%	-36.3%
	-15.8% (T+)				
N	264	264	264	171	181

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O2, $ ext\{CO\}_\{2\}$, and CO outside normal ranges for more than 50\\% of the monitored time, which indicates abnormal operation.

Table E.11: IQR CO/CO_2 Ratio (dropping abnormal values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0033	-0.0030	-0.0039
			(0.0023)	(0.0026)	(0.0026)
Bundled Treatment		-0.0015			
		(0.0011)			
Technical Arm	-0.0014				
	(0.0012)				
Technical+ Arm	-0.0016				
	(0.0012)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-13.7% (T)	-14.9%	-33.0%	-30.4%	-39.5%
	-16.0% (T+)				
N	264	264	264	171	181

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O2, $ ext\{CO\}_\{2\}$, and CO outside normal ranges for more than 50\\% of the monitored time, which indicates abnormal operation.

Table E.12: Mean CO/CO_2 Ratio (dropping abnormal feeding & values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0035	-0.0039	-0.0020
			(0.0045)	(0.0052)	(0.0055)
Bundled Treatment		-0.0015			
		(0.0019)			
Technical Arm	-0.0018				
	(0.0023)				
Technical+ Arm	-0.0012				
	(0.0023)				
Control Mean	0.03	0.03	0.03	0.03	0.03
Percent Change	-5.9% (T)	-4.9%	-11.6%	-13.0%	-6.8%
	-3.9% (T+)				
N	247	247	247	156	168

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O\$_2\$, CO_2, CO outside normal ranges for more than 50% of the monitored time and with total feeding time below 33%, which indicates abnormal operation.

Table E.13: Max CO/CO_2 Ratio (dropping abnormal feeding & values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0098	-0.0118	-0.0067
			(0.0070)	(0.0083)	(0.0084)
Bundled Treatment		-0.0041			
		(0.0031)			
Technical Arm	-0.0051				
	(0.0037)				
Technical+ Arm	-0.0032				
	(0.0036)				
Control Mean	0.06	0.06	0.06	0.06	0.06
Percent Change	-8.6% (T)	-6.9%	-16.4%	-19.6%	-11.1%
	-5.4% (T+)				
N	247	247	247	156	168

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O\$_2\$, CO_2, CO outside normal ranges for more than 50% of the monitored time and with total feeding time below 33%, which indicates abnormal operation.

Table E.14: SD CO/CO_2 Ratio (dropping abnormal feeding & values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0034*	-0.0034+	-0.0034+
			(0.0016)	(0.0018)	(0.0018)
Bundled Treatment		-0.0014*			
		(0.0007)			
Technical Arm	-0.0015+				
	(0.0008)				
Technical+ Arm	-0.0014+				
	(0.0008)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-14.6% (T)	-14.4%	-33.9%	-34.0%	-33.9%
	-14.2% (T+)				
N	247	247	247	156	168

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O\$_2\$, CO_2, CO outside normal ranges for more than 50% of the monitored time and with total feeding time below 33%, which indicates abnormal operation.

Table E.15: IQR CO/CO_2 Ratio (dropping abnormal feeding & values)

	Intention-to-Treat (Separate)	Intention-to-Treat (Bundled)	Instrumental Variable	Instrumental Variable (Technical)	Instrumental Variable (Technical+)
Adopted Intervention			-0.0043+	-0.0045+	-0.0041
			(0.0025)	(0.0026)	(0.0030)
Bundled Treatment		-0.0018+			
		(0.0011)			
Technical Arm	-0.0020+				
	(0.0011)				
Technical+ Arm	-0.0016				
	(0.0012)				
Control Mean	0.01	0.01	0.01	0.01	0.01
Percent Change	-19.7% (T)	-18.0%	-42.6%	-44.6%	-41.4%
	-16.5% (T+)				
N	247	247	247	156	168

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Heteroskedasticity-robust standard errors are in parentheses. Regressions include randomization strata fixed effects. Outcome data are derived from measurements collected during kiln performance monitoring. Adoption is defined as adopting double/triple zigzag brick stacking and single fireman continuous feeding. Sample excludes kilns with O\$_2\$, CO_2, CO outside normal ranges for more than 50% of the monitored time and with total feeding time below 33%, which indicates abnormal operation.

Table E.16: Above 33 Pct Fuel Feeding Sample Results (N = 255)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	15.7	8.5	17.0	10.2	13.9	9.6	0.25	0.074	0.4
Jashore Intervention Knowledge	0.37	0.49	0.40	0.49	0.35	0.48	0.82	0.72	0.88
Jashore Owner Interaction	0.44	0.51	0.58	0.50	0.58	0.50	0.47	0.8	0.32
Zigzag Year	2015	4	2014	4	2015	3	0.58	0.055	0.17
Water Adjacent	0.61	0.49	0.60	0.49	0.62	0.49	0.6	1.0	0.6
Bricks Fired (Lakhs)	8.06	0.97	7.9	1.1	8.1	1.1	0.72	0.15	0.23
Circuits Completed	6.1	1.5	6.0	1.5	6.2	1.9	0.98	0.53	0.43
Class 1 Production Share (%)	65.3	10.6	67.1	8.3	65.4	10.4	0.42	0.031	0.24
Production Cost Estimate BDT (per 1K Bricks)	8,842.3	1,220.9	8,606.3	1,317.3	8,673.5	1,060.4	0.19	0.97	0.23
Fired Brick Weight (kg)	3.38	0.24	3.40	0.19	3.40	0.23	0.4	0.95	0.4
Total Workers	108.8	28.7	111.5	30.3	110.8	35.2	0.89	0.57	0.47
Higher Secondary+	0.60	0.49	0.57	0.50	0.56	0.50	0.27	0.47	0.72
Highland	0.72	0.45	0.73	0.45	0.69	0.46	0.48	0.73	0.74
Joint Ownership	0.32	0.47	0.29	0.46	0.38	0.49	0.32	0.18	0.68
Shared Sardar	0.11	0.31	0.12	0.33	0.099	0.300	0.91	0.64	0.55
	N = 92		N = 82		N = 81				

Table E.17: Under 50 Out Of Range Sample Results (N = 264)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	15.5	8.5	17.0	10.2	15.0	9.8	0.75	0.24	0.34
Jashore Intervention Knowledge	0.36	0.48	0.38	0.49	0.35	0.48	0.89	0.89	0.98
Jashore Owner Interaction	0.46	0.51	0.6	0.5	0.54	0.51	0.87	0.46	0.39
Zigzag Year	2015	4	2014	4	2014	4	0.9	0.2	0.24
Water Adjacent	0.61	0.49	0.64	0.48	0.64	0.48	0.48	0.73	0.3
Bricks Fired (Lakhs)	8.0	1.0	7.9	1.2	8.1	1.1	0.33	0.17	0.59
Circuits Completed	6.1	1.6	6.0	1.5	6.1	1.9	0.88	0.7	0.54
Class 1 Production Share (%)	65.1	10.9	67.5	8.2	66.0	10.3	0.98	0.071	0.11
Production Cost Estimate BDT (per 1K Bricks)	8,817.1	1,225.1	8,574.9	1,307.8	8,725.6	1,025.2	0.35	0.6	0.19
Fired Brick Weight (kg)	3.38	0.24	3.40	0.19	3.39	0.22	0.53	0.91	0.44
Total Workers	108.0	29.1	112.5	31.2	111.4	35.4	0.68	0.54	0.3
Higher Secondary+	0.60	0.49	0.59	0.49	0.53	0.50	0.11	0.21	0.75
Highland	0.71	0.46	0.72	0.45	0.72	0.45	0.93	0.84	0.76
Joint Ownership	0.32	0.47	0.30	0.46	0.36	0.48	0.55	0.29	0.63
Shared Sardar	0.11	0.31	0.12	0.33	0.11	0.32	0.61	0.88	0.49
	N = 93		N = 83		N = 88				

Table E.18: Under 50 Out Of Range Or Above 33 Pct Fuel Feeding Sample Results (N = 272)

Balance Variable	Technical+ Mean	Technical+ Std. Dev.	Technical Mean	Technical Std. Dev.	Control Mean	Control Std. Dev.	T+ - C (p-val)	T - C (p-val)	T+ - T (p-val)
Owner Experience (Years)	15.5	8.5	16.8	10.1	14.6	9.7	0.6	0.19	0.37
Jashore Intervention Knowledge	0.37	0.49	0.38	0.49	0.36	0.48	0.82	0.89	0.94
Jashore Owner Interaction	0.44	0.51	0.58	0.50	0.52	0.51	0.77	0.48	0.33
Zigzag Year	2015	4	2014	4	2014	3	0.99	0.17	0.17
Water Adjacent	0.61	0.49	0.62	0.49	0.63	0.49	0.52	0.85	0.42
Bricks Fired (Lakhs)	8.0	1.0	7.9	1.2	8.1	1.1	0.35	0.11	0.44
Circuits Completed	6.1	1.5	6.0	1.5	6.1	1.8	0.91	0.72	0.59
Class 1 Production Share (%)	65.2	10.9	67.3	8.3	65.8	10.3	0.88	0.084	0.17
Production Cost Estimate BDT (per 1K Bricks)	8,819.0	1,218.6	8,595.6	1,299.0	8,683.2	1,039.5	0.28	0.81	0.24
Fired Brick Weight (kg)	3.38	0.24	3.40	0.19	3.39	0.23	0.61	0.81	0.44
Total Workers	108.1	29.0	111.7	31.0	110.8	34.8	0.75	0.54	0.36
Higher Secondary+	0.60	0.49	0.58	0.50	0.53	0.50	0.14	0.26	0.75
Highland	0.71	0.45	0.73	0.45	0.72	0.45	0.87	0.91	0.78
Joint Ownership	0.32	0.47	0.30	0.46	0.37	0.49	0.49	0.26	0.65
Shared Sardar	0.11	0.31	0.12	0.32	0.11	0.31	0.68	0.84	0.53
	N = 94		N = 86		N = 92				