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Effects of Brick Kiln Industry on Agricultural Productivity

A Natural Experiment in Bangladesh

Moogdho M. Mahzab

M. Mehrab Bakhtiar

Martin Mattsson

Md Sadat Anowar

Poverty, Gender, and Inclusion Unit

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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AUTHORS

Moogdho M. Mahzab (M.Mahzab@cgiar.org) is a Research Fellow in the Poverty, Gender, and Inclusion (PGI) Unit of the International Food Policy Research Institute (IFPRI), Dhaka, Bangladesh.

M. Mehrab Bakhtiar (M.Bakhtiar@cgiar.org) is a Research Fellow in IFPRI's PGI Unit, Washington, DC.

Martin Mattsson (martin.mattsson@nus.edu.sg) is an Assistant Professor in the Department of Economics at the National University of Singapore.

Md Sadat Anowar (S.anowar@cgiar.org) is a Research Analyst in IFPRI's PGI Unit, Dhaka, Bangladesh.

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ABSTRACT

Agriculture remains central to Bangladesh’s economy and food security, yet it is increasingly threatened by the rapid expansion of informal brick manufacturing that extracts fertile topsoil from cropland and generates heavy local pollution. This paper provides national-scale causal evidence on how brick kiln expansion affects vegetation health and agricultural productivity by combining long-run satellite observations with geolocated kiln data. We construct a spatiotemporal panel of unions and municipalities using annual the Moderate Resolution Imaging Spectroradiometer normalized difference vegetation index (MODIS NDVI) from 2002–2024 and a high-resolution inventory of 9,187 brick kilns detected through satellite imagery and machine learning. Using a continuous and staggered difference-in-differences design, we find no evidence of differential pre-trends, but we do find a clear and persistent deterioration in vegetation health following kiln establishment. The magnitude is economically meaningful: a marginal increase in kiln presence is associated with roughly a 1 percent annual decline in local vegetation productivity, with effects that persist and accumulate over time. These results are consistent with long-run soil degradation and chronic environmental exposure around kiln sites, and they imply substantial hidden costs of informal industrial growth in densely cultivated landscapes. The findings highlight the urgency of stronger enforcement of siting rules, of incentives for cleaner production technologies, and of land-use planning that protects high-productivity agricultural zones.

Keywords: Agricultural productivity, food security, environmental externalities, vegetation health, remote sensing, brick kilns, causal inference, Bangladesh

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Author contributions

Moogdho Mahzab: Conceptualization, methodology, funding acquisition, and final manuscript writing.

Mehrab Bakhtiar: Funding acquisition, analysis, manuscript review, and editing.

Martin Mattsson: Bric kilns data provision, manuscript review, and editing.

Sadat Anowar: Data analysis, original draft writing, and visualization.

ACRONYMS

ATT	Average treatment effect on the treated
BBS	Bangladesh Bureau of Statistics
BIHS	Bangladesh Integrated Household Survey
CNNs	Convolutional neural networks
CSDiD	Continuous and staggered difference-in-differences
DiD	Difference-in-differences
DRIPW	Doubly robust inverse probability weighting
EVI	Enhanced vegetation index
FASAL	Forecasting Agricultural Output using Space, Agro-meteorology and Land based Observations
FCKs	Fixed chimney kilns
GIS	Geographic information system
GoB	Government of Bangladesh
IFPRI	International Food Policy Research Institute
ISRO	Indian Space Research Organisation
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized difference vegetation index
RCT	Randomized controlled trial
SAVI	Soil-adjusted vegetation index
VCI	Vegetation condition index

1. INTRODUCTION

Agriculture remains central to Bangladesh's economic structure and rural livelihoods, with nearly half of the labor force directly dependent on the sector for employment and income generation. The sector plays a pivotal role in ensuring food security, sustaining rural economies, and supporting national growth objectives. However, agricultural productivity is increasingly threatened by the rapid expansion of informal rural and peri-urban industries, most notably the brick manufacturing sector. Brick kilns commonly extract fertile topsoil from surrounding agricultural fields for brick molding, directly deteriorating both soil quality and arable depth. In parallel, kiln emissions contribute to severe air pollution, releasing high concentrations of particulate matter and combustion by-products that impair vegetative health (UNDP, 2015; Motalib et al., 2015). Asia produces around 87 percent of the global clay bricks demand of 1.5 trillion bricks per year, with about 20 percent of this production taking place in South Asia (Weyant et al., 2014). Bangladesh is the fourth largest brick producer in the world, with between 7,000 to 9,000 brick kilns in the country producing about 27 billion bricks annually, highlighting the scale at which these industries interact with agricultural landscapes (Climate and Clean Air Coalition, 2017).

Despite agriculture's central role in Bangladesh's economy, existing measures of agricultural performance rely largely on survey- and census-based statistics, which are limited in their ability to capture localized and persistent environmental pressures associated with informal industrial activity. In this study, we combine long-run satellite observations with spatially resolved data on brick kiln expansion to examine how industrial growth affects agricultural landscapes. This paper employs satellite-based measures of agricultural performance alongside geolocated brick kiln data to examine the long-run environmental impacts of kiln expansion on agricultural productivity. Using a continuous and staggered difference-in-differences framework (Callaway & Sant'Anna, 2021), the study combines annual Moderate Resolution Imaging Spectroradiometer MODIS normalized difference vegetation index (MODIS NDVI) data from 2002–2024 with a high-resolution, machine-learning-derived inventory of 9,187 brick kilns to

construct a spatiotemporal panel of over 7,000 unions and municipalities across Bangladesh. The empirical results reveal a pronounced and persistent decline in vegetation health following kiln activation. Pre-treatment estimates show no significant differences, supporting the parallel-trends assumption, while post-treatment effects demonstrate sharp and accelerating deterioration in NDVI. The average treatment effect is statistically significant and negative and increases with time—indicating cumulative vegetation loss consistent with soil degradation, particulate deposition, and chronic air pollution exposure.

By integrating satellite-derived measures of vegetative health, spatially resolved industrial activity, and quasi-experimental econometric methods, this study provides national-scale causal evidence linking brick kiln expansion to sustained agricultural degradation in a developing-country context. These findings underscore an urgent need for regulatory enforcement, cleaner kiln technologies, and spatial zoning reforms to mitigate industrial pollution and preserve agricultural sustainability in Bangladesh's densely cultivated landscape.

2. CONTRIBUTION TO THE LITERATURE

This study contributes to interconnected literatures on the environmental externalities of industrial activity, land degradation, and agricultural productivity in developing countries. First, it advances research on industrial externalities by providing causal evidence on how informal industrial expansion affects agricultural systems. While industrialization can enhance agricultural productivity through mechanization and input use, it can also generate substantial ecological costs, including soil degradation, loss of biodiversity, and food safety concerns, particularly in South Asia (Saritha & Jangra, 2024). Brick kilns are a prominent source of such environmental stress due to their reliance on fertile topsoil and emissions of particulate matter and black carbon, which have long-term implications for soil fertility and crop performance. Although prior studies document the environmental and health impacts of brick kilns, direct evidence linking kiln expansion to agricultural productivity outcomes remains limited. This paper addresses this gap by systematically quantifying the effects of brick kiln proliferation on vegetation health and agricultural productivity in Bangladesh, one of the world's most kiln-dense agrarian economies.

Second, the paper contributes to the growing literature that uses satellite-based indicators to study agricultural productivity on a scale. Vegetation indices derived from satellite imagery, particularly the NDVI, have been widely used to capture crop vigor, photosynthetic activity, and biomass accumulation (Rouse et al., 1974; Tucker, 1979). A large body of empirical work demonstrates strong correlations between NDVI and crop growth and yield, supporting its use as a proxy for agricultural productivity in data-constrained settings (Lobell et al., 2015). Empirical applications in South Asia further reinforce this relationship. NDVI is used operationally by the Indian Space Research Organisation (ISRO) under the Forecasting Agricultural Output using Space, Agro-meteorology and Land based Observations (FASAL) program for rice yield forecasting (ISRO, 2012), while studies in Bangladesh and India document close correspondence between MODIS-derived NDVI and rice yields across multiple seasons and agroecological contexts (Sarker et al., 2019; Shanmugapriya et al., 2019; Sahoo et al., 2024). Building on

this literature, our study uses long-run satellite data to examine how localized environmental pressures from industrial activity translate into persistent changes in agricultural productivity.

Third, the paper complements recent work on the institutional and regulatory environment of Bangladesh's brick sector. Miller et al. (2024) show that brick production operates within weakly regulated labor markets, where productivity gains do not translate into improved worker welfare. While their focus is on labor exploitation, the institutional conditions they identify—limited oversight and strong cost-minimization incentives—are equally relevant for understanding environmental externalities. Extending this line of inquiry, our study shifts attention from within-kiln labor conditions to off-site impacts, demonstrating how brick kiln activity degrades surrounding agricultural land and reduces crop productivity. Together, these findings suggest that the social costs of brick production extend beyond labor conditions to encompass broader ecological and agricultural harms.

Overall, this paper contributes new evidence on how informal industrialization interacts with land use, environmental quality, and agricultural productivity in rapidly transforming economies. By documenting persistent productivity losses associated with brick kiln expansion, the study provides policy-relevant insights for environmental regulation, spatial zoning, and sustainable land management in Bangladesh and similar agrarian settings.

3. BACKGROUND

The brick sector plays a pivotal role in Bangladesh's construction sector, supplying the dominant building material used across both urban and rural areas. Fired clay bricks remain popular because they are inexpensive, durable, and widely accessible, and the industry provides significant employment opportunities in peri-urban and rural communities. However, the brick sector, which has coal as its main fuel, is also among the country's most environmentally harmful industries, generating severe air pollution and contributing to soil degradation and declining agricultural productivity.

Traditional brick-firing technologies, including fixed chimney kilns (FCKs), zigzag kilns, and newer hybrid Hoffmann Kilns, release substantial amounts of black carbon, PM_{2.5}¹, sulfur oxides, and carbon dioxide into the atmosphere. These pollutants drive severe local air contamination while also contributing to broader climatic impacts. Brick kilns use coal as their primary fuel and emit substantial amounts of sulfur dioxide (SO₂) that can oxidize into sulfate and combine with ambient ammonia (NH₃) to form ammonium sulfate, an important part of "secondary PM_{2.5}," causing substantial health problems.

Furthermore, because these kilns depend on inefficient combustion methods, they elevate ambient PM_{2.5} levels and emit short-lived climate pollutants such as black carbon, which can influence regional climate systems by disrupting rainfall and temperature patterns. In addition to these environmental pressures, the brick industry is one of Bangladesh's most significant stationary sources of greenhouse gas emissions (Haque et al., 2018).

The environmental impacts of brick kilns reach well beyond air emissions. In developing countries, soil degradation is widely recognized as a major threat to food security (Chen, 2007). In Bangladesh, brick production is one of the principal contributors of agricultural soil loss, as the industry relies heavily on the extraction of fertile topsoil from cropland (Huq and Shoaib, 2013). A particularly important yet often

¹ PM_{2.5} refers to fine particulate matter with an aerodynamic diameter of 2.5 micrometers or less. Due to its small size, PM_{2.5} can penetrate deep into the lungs and enter the bloodstream, posing significant risks to human health and contributing to environmental and agricultural impacts.

overlooked consequence is the large-scale extraction of fertile topsoil from farmland to obtain raw material for brick production. Although this offers farmers short-term financial gains, it strips away the nutrient-rich upper soil layer, lowers organic content, and degrades soil structure, ultimately reducing the long-term productive capacity of agricultural land (Biswas et al., 2018). Most brick kilns are located on productive agricultural land, with a typical kiln occupying approximately 2.4 hectares of farmland (Luby et al., 2015). At the national level, the brick sector is estimated to consume around 45 million tons of clay annually, exerting substantial pressure on soil resources and agricultural sustainability (Guttikunda and Khaliqzaman, 2014).

Farmers residing near the kilns reported persistent negative effects on both homestead vegetation and cultivated crops, noting declines in fruit production, early fruit drop, and overall reduced vegetable yields. (Hossain et al., 2019). Since producing a single brick requires about 3 kg of soil, Bangladesh's annual output of 27 billion bricks consume roughly 81 billion kg of soil, the lion's share of which comes from topsoil. Because this upper soil layer contains essential organic matter and nutrients crucial for sustainable crop production, its extraction for brick manufacturing accelerates land degradation and ultimately diminishes agricultural yields.

Bangladesh's historical experience of extreme food insecurity, culminating in the 1974 famine, entrenched rice security and agricultural productivity as top policy priorities aimed at preventing famine recurrence and maintaining social stability (Sen, 1981; Ahmed, Haggblade, and Chowdhury, 2000). According to World Bank Open Data, per capita arable land has decreased in Bangladesh from 0.16 hectares in 1961 to 0.05 hectares in 2023, a decrease of approximately 69 percent. By comparison, the global rate of decrease in arable land during this period is about 52 percent. Thus, in conjunction with the decrease in arable land, the use of nutrient enriched topsoil for brick making represents a structural risk to Bangladesh's long-term food security through its adverse effects on agricultural productivity.

The environmental pressures generated by the brick industry also translate into significant public health harms. Research on spatial exposure shows that communities located downwind of kiln concentrations face higher incidences of respiratory diseases, including pneumonia, illustrating how widely kiln emissions disperse (Brooks et al., 2023).

The regulatory framework governing brick kilns in Bangladesh remains inconsistent and only partially effective. While the Brick Manufacturing and Brick Kiln Establishment (Control) Act outlines requirements for approved fuel sources, minimum chimney heights, and mandated distances from farmland and water bodies, actual enforcement on the ground is limited. As a result, many kilns continue to operate informally, avoiding environmental regulations and tax obligations. Production in this sector is also highly seasonal, concentrated during the dry months from November to June when soil moisture is low. This seasonality intensifies environmental pressures by aligning peak pollution and topsoil extraction with critical periods of the agricultural cycle, particularly the Boro season, which is Bangladesh's principal irrigated winter rice crop (Ahmed et al., 2022).

Remote-sensing approaches have been particularly valuable for tracking how brick kiln activity alters surrounding landscapes over space and time. Satellite-based indicators such as NDVI and the enhanced vegetation index (EVI) consistently show vegetation stress in areas located near kiln operations, with declines in NDVI often signaling early reductions in crop health. When these vegetation indexes are combined with crop growth models, researchers can better distinguish between the effects of normal climatic variation and those driven by human activity, thereby strengthening causal inference and informing more targeted and effective policy responses.

Ahmed et al. (2024) emphasize that climate and environmental risks are becoming increasingly significant drivers of food insecurity in Bangladesh, affecting agriculture not only through direct shocks to crop yields but also through broader processes of land-use change and ecological degradation. This observation is highly relevant to our study, which examines how brick-kiln operations and shifts in

vegetation conditions captured through NDVI, shape agricultural productivity and the resilience of vulnerable rural communities.

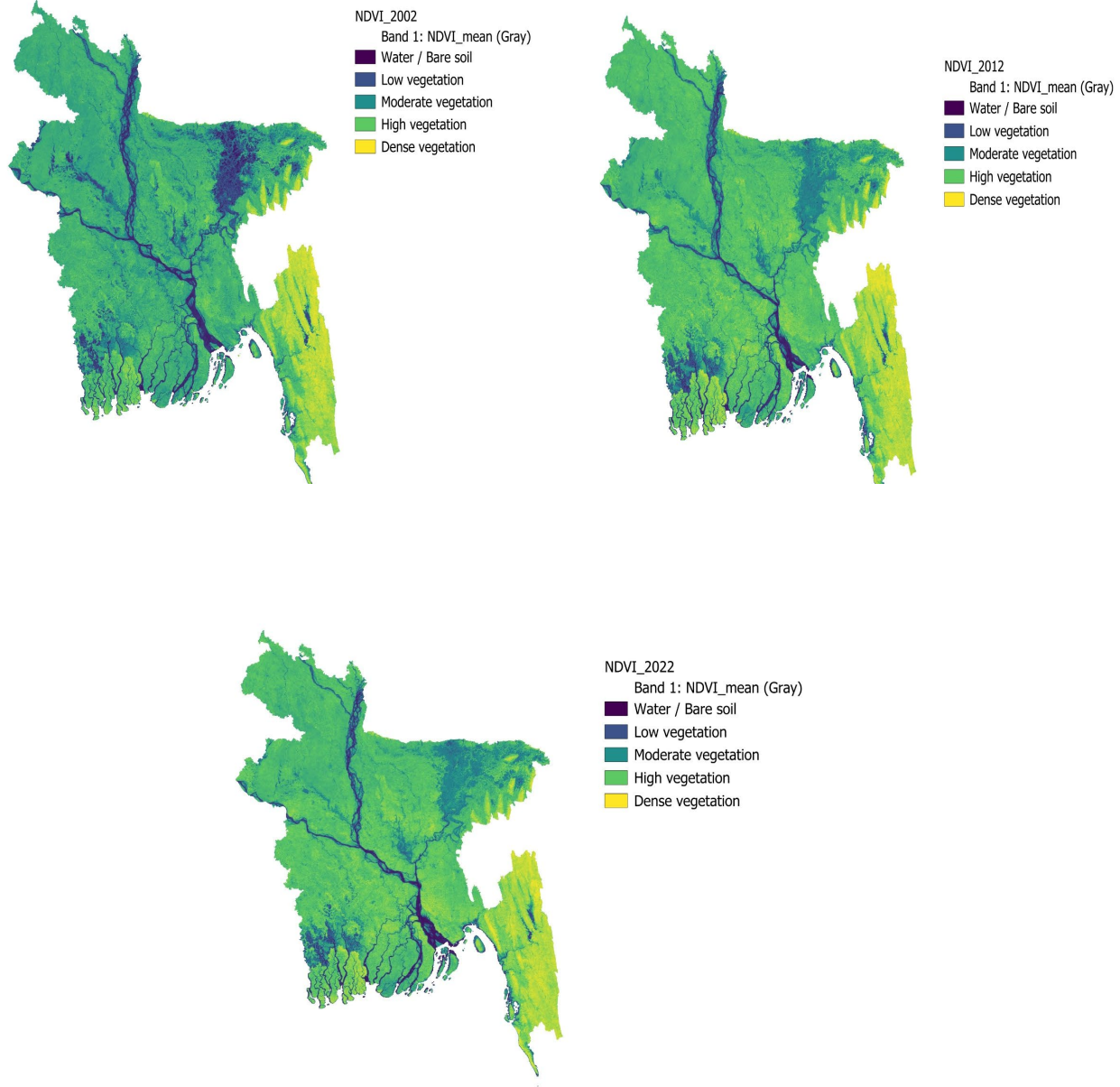
In summary, prior research and emerging empirical findings reveal the brick industry's dual role in Bangladesh, serving as an essential driver of construction and economic activity while simultaneously imposing substantial environmental costs. These underlying issues, including top-soil loss, air pollution, and reductions in crop productivity, are both considerable and potentially addressable. Experimental evidence shows that relatively simple operational improvements can meaningfully lower emissions and mitigate environmental damage (Brooks et al., 2025). Yet without strong institutional support and effective regulatory enforcement, inefficient production processes and unsustainable soil extraction are likely to persist, further threatening agricultural output and rural well-being. Confronting these challenges will require a coordinated policy strategy that integrates industrial upgrading, environmental governance, and agricultural protection to promote sustainable land management and long-term food security.

4. DATA

Satellite Data: MODIS

We use data from NASA's MODIS satellite, which provides 16-day composite NDVI values at a 250-meter spatial resolution. The NDVI measures greenness and vegetation health based on light reflectance in the red and near-infrared spectrum. The index ranges from -1 to 1, with higher values indicating denser vegetation. NDVI data are widely derived from satellite-based remote sensing platforms such as Landsat, MODIS, and Sentinel-2, each offering different spatial and temporal resolutions suitable for monitoring vegetation dynamics and agricultural productivity. Landsat provides high spatial resolution (30 meters) with a 16-day revisit cycle, Sentinel-2 offers very high spatial resolution (10 meters) with a 5-day revisit cycle, while MODIS provides moderate spatial resolution (250 meters) with high temporal frequency. These characteristics make MODIS particularly well-suited for long-term, large-scale vegetation monitoring, especially in data-scarce agricultural settings like Bangladesh (Figure 4.1).

Figure 4.1: NDVI maps of Bangladesh from 2002, 2012 and 2022



Source: Author's calculation from NASA MODIS.

NDVI represents photosynthetic activity and is widely used as a proxy for plant health. The index is calculated as:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

where NIR is near-infrared reflectance and RED is red-light reflectance. NDVI values are interpreted as follows:

Table 4.1 NDVI Ranges and Corresponding Land Cover Types

NDVI Range	Type of Land Cover
-1.00 to 0.00	Water, snow, ice, clouds, or barren surfaces
0.01 to 0.49	Sparse or moderate vegetation
0.50 to 0.69	Dense vegetation
0.70 to 0.99	Very dense and healthy vegetation

Source: NASA Earth Observatory. (2000). "Measuring Vegetation (NDVI & EVI)." Retrieved from: https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php

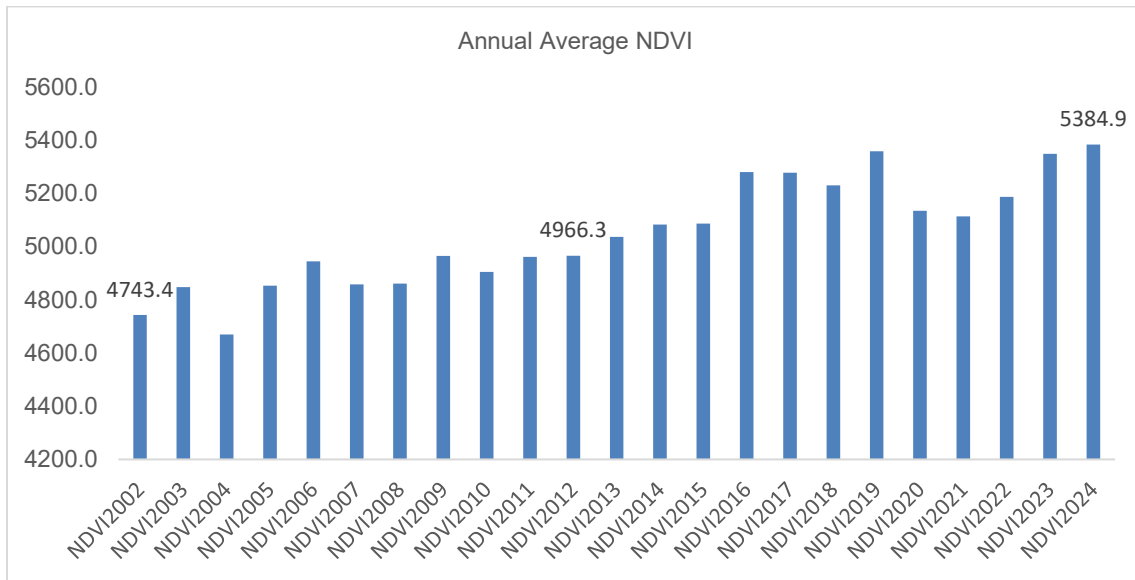
Here, NIR and RED represent reflectance in the near-infrared and red spectral bands, respectively (Rouse et al., 1974). NDVI values range theoretically from -1 to +1. Values close to zero or negative typically represent non-vegetated surfaces such as water, barren soil, or built-up areas, whereas values above 0.5 indicate dense and healthy vegetation (Tucker, 1979). NDVI is highly sensitive to chlorophyll concentration and photosynthetic activity, making it a powerful indicator of crop vigor. High NDVI values during the growing season signify healthy, actively photosynthesizing plants, while declines in NDVI signal stress due to drought, nutrient deficiency, or pest pressure. NDVI is also strongly correlated with above-ground biomass: dense vegetation leads to increased NIR reflectance and higher NDVI values. Because NDVI reflects both crop vigor and biomass accumulation, it serves as a robust proxy for crop yield. Numerous studies have demonstrated that NDVI values measured at critical phenological stages have the potential to be strong predictors of yield outcomes. Seasonal or annual NDVI averages are

therefore widely used as indicators of cumulative plant growth, particularly in smallholder-dominated regions where ground-based yield data are limited.

NDVI has been extensively validated as a reliable measure of agricultural productivity in South Asia. The ISRO operationally employs NDVI under its FASAL crop yield forecasting program (ISRO, 2012). In Bangladesh, Alam et al. (2019) developed a MODIS NDVI-based model for estimating Boro rice yields, finding a strong correlation with official yield statistics. Shanmugapriya et al. (2019) reviewed NDVI-based yield estimation applications in India and confirmed its utility for early warning and regional crop monitoring. Sahoo et al. (2024) further applied machine learning techniques to NDVI and climate data for forecasting Kharif rice yield gaps in Eastern India, achieving predictive accuracy with R^2 values exceeding 0.7. These findings collectively affirm NDVI's robustness as a proxy for yield under varying agroecological and climatic conditions.

Although NDVI may saturate at very high biomass levels, especially under dense canopies, this limitation can be mitigated through temporal averaging or complementary indexes such as the EVI and the soil-adjusted vegetation index (SAVI). In practice, NDVI's accessibility, cost-effectiveness, and strong yield correlation make it indispensable for long-term agricultural monitoring and environmental assessment in South Asia. Bangladesh's MODIS NDVI record extends back to 2002, enabling a two-decade assessment of vegetation dynamics. NDVI maps for 2002, 2012, and 2022 illustrate a gradual increase in average NDVI values nationwide. Between 2002 and 2024, the average NDVI across approximately 8,200 unions and municipalities rose by 13.5 percent, reflecting improvements in crop management, irrigation, and land use. Annual NDVI trends indicate a steady upward trajectory from 2002 to 2024, suggesting overall agricultural intensification and vegetation recovery (Figure 4.2).

Figure 4.2: Annual average NDVI at the union/municipality level from 2002 to 2024



Source: Author’s Estimation based on NASA MODIS data.

Histograms of average NDVI distribution show that most observations fall between NDVI values of 4,000 and 6,000, representing moderate to dense vegetation cover. Over time, the peak of the distribution has shifted upward, indicating improved vegetation health overall. However, the right tail has thinned slightly in industrial zones, suggesting localized vegetation stress due to kiln expansion and land conversion (Figure A4.1).

Three key stylized facts emerge from the NDVI analysis. First, NDVI values have increased nationally over the past two decades, reflecting improvements in irrigation, crop intensity, and agricultural management. Second, NDVI gains are uneven, that is, industrial zones and peri-urban areas show relative stagnation or decline, while agricultural heartlands exhibit sustained growth. Third, proximity to brick kilns corresponds with systematically lower NDVI, reinforcing evidence that industrial activities degrade vegetation health and agricultural productivity. In summary, NDVI offers a robust, cost-effective, and scalable means of quantifying agricultural productivity and environmental change in Bangladesh. Its strong correlations with crop vigor, biomass, and yield, combined with its sensitivity to environmental

stress, make it an indispensable tool for monitoring agricultural performance, detecting industrial impacts, and informing sustainable land-use policy.

Survey Data: BIHS 2018/19

Ground-truth agricultural data are sourced from the third round of the Bangladesh Integrated Household Survey (BIHS), conducted by the International Food Policy Research Institute (IFPRI) in 2018/19. The BIHS is a nationally representative panel dataset covering 6,500 rural households across 325 primary sampling units (villages), selected through a two-stage stratified sampling design. We extract plot-level production and yield data for paddy (rice), which is the dominant crop in Bangladesh. To align with the spatial resolution of NDVI data, we aggregate plot-level paddy production to the upazila level.

Secondary Data: BBS, Yearbook of Agricultural Statistics

We obtain rice yield data from the yearbook of agricultural statistics published by the Bureau of Statistics (BBS). We obtain rice yield estimates for all rice Boro, Aman, and Aus rice separately from this secondary source.

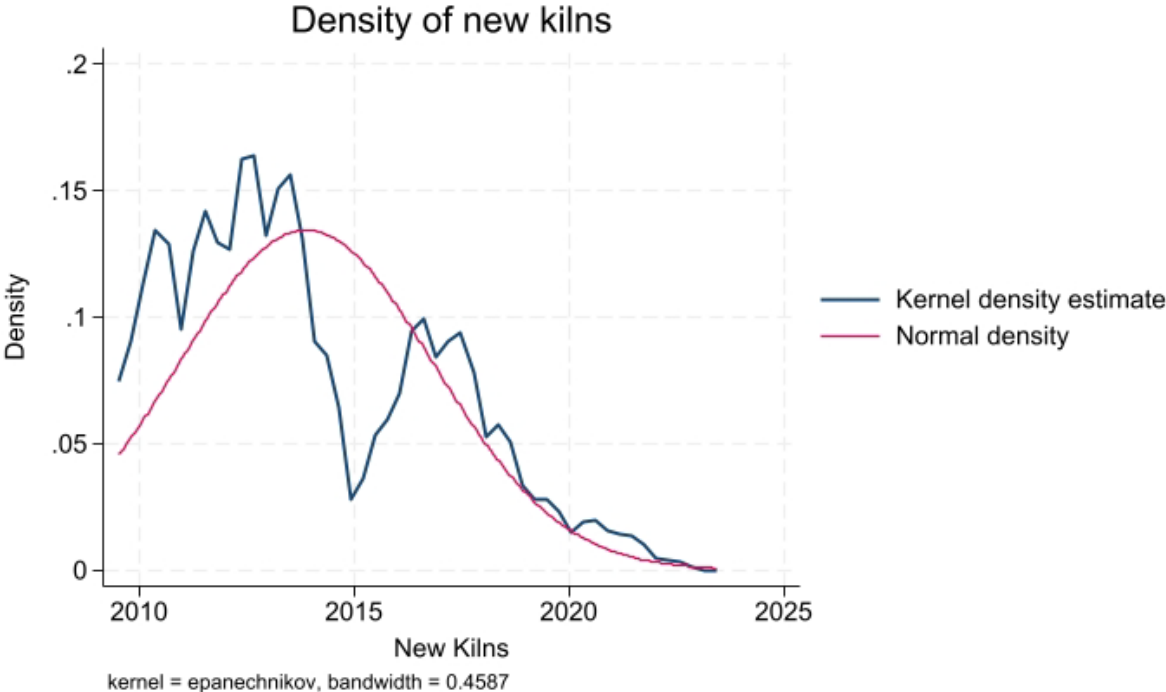
Brick Kiln Location Data

To analyze the spatial relationship between industrial expansion and agricultural productivity, this study constructs a comprehensive geospatial dataset of brick kiln locations across Bangladesh spanning the period from 2000 to 2025. We integrate multiple data sources, including remotely sensed satellite imagery, machine learning detection models, and government administrative records, to identify a total of 9,228 distinct clay brick kilns. The number of active kilns reached its peak in 2019 and has gradually declined since then, reflecting both cyclical economic dynamics and growing regulatory scrutiny.

For this paper we are using Thakrar et Al. (2025) dataset for kiln detection using machine learning techniques. For detailed methodology regarding kiln detection, please see [this paper](#).

Figure 4.3 presents the kernel density of kiln establishment between 2010 and 2023, showing that kiln openings peaked around 2013 and have steadily declined thereafter. The temporal pattern suggests that the sector underwent a period of rapid expansion between 2010 and 2015, after which the growth rate slowed.

Figure 4.3: Density of new kilns, 2010–2023



Source: Author’s estimation from Thakrar et al. (2025).

To examine long-term industrial dynamics, Figure 4.4 illustrates the evolution of the brick kiln industry in Bangladesh over the last two decades. The machine learning model detected kilns from 2000, and we observed steady growth since the start of detection of brick kilns since 2000.

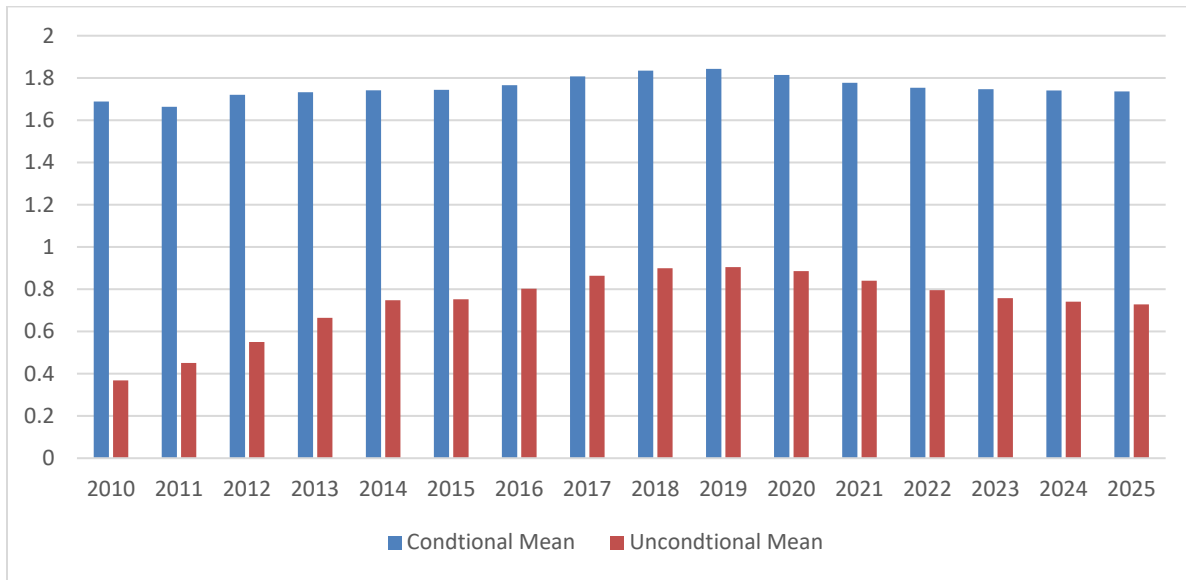
Figure 4.4: Evolution of brick kiln industry in Bangladesh



Source: Author’s estimation from Thakrar et al. (2025).

Our sample includes 9,228 unions and municipalities. We compute two measures of kiln exposure. The unconditional mean is the total number of active kilns divided by all unions, yielding a low national average because most unions have no kilns. The conditional mean restricts the denominator to only those unions that host at least one kiln, revealing that kiln-hosting unions typically contain between 1.7 and 1.8 kilns, whereas the unconditional mean contains between 0.4 to 0.9. The divergence between the two measures highlights the strong geographic clustering of brick kilns. This has important implications for our NDVI analysis: union-level average NDVI dilutes localized environmental damage, leading to modest but statistically significant treatment effects (Figure 4.5).

Figure 4.5: Average number of brick kilns per union/municipality in Bangladesh, 2010 to 2025



Source: Author's estimation Thakrar et al. (2025).

Figure A4.2 in the Appendix presents annual histograms of the distribution of active brick kilns per union in Bangladesh from 2000 to 2025, illustrating both the spatial concentration and temporal evolution of kiln activity. Across all years, the distributions exhibit a pronounced right skew, indicating that although most unions host few or no kilns, a small subset consistently contains disproportionately high numbers. The early 2000s show relatively low counts with limited dispersion, but from the mid-2000s to around 2017, the upper tail of the distribution lengthens substantially, reflecting rapid expansion and clustering of kilns in already active areas. This period is characterized by the emergence of unions with double-digit kiln counts, suggesting intensified industrial concentration. In the most recent years, the distributions remain skewed but appear somewhat more stable, with fewer extreme outliers than in the peak expansion period, potentially signaling regulatory effects, environmental pressures, or saturation in suitable locations. Overall, the figure highlights the persistent unevenness of kiln activity across unions and the dynamic growth followed by stabilization of the sector over the past two decades.

The spatial and temporal distribution of brick kilns across Bangladesh from 2000 to 2024 is presented in Figure A4.3. The maps illustrate the progressive densification of kilns along major transportation corridors, peri-urban regions, and fertile riverine zones, particularly in Dhaka, Gazipur, Narayanganj,

Comilla, Bogura, and Chittagong. Over time, kiln expansion has increasingly encroached on agriculturally productive land, reinforcing the need for integrated land-use planning. (Figure A4.3)

To contextualize the spatial distribution, we merge the kiln dataset with the Government of Bangladesh's (GoB) union-level geographic information services (GIS) administrative boundaries. We identify 9,228 kilns distributed across 2,580 of the total 8,202 unions/municipalities, averaging approximately 3.6 kilns per union. The remaining 5,622 unions (68.5 percent) exhibit no kiln presence, providing potential control areas for subsequent econometric analysis. This geographic coverage confirms that kiln activity is highly clustered, with significant implications for both localized environmental degradation and agricultural productivity.

Overall, this geospatial database provides the foundation for assessing the long-term and localized impacts of industrial land use on agricultural systems in Bangladesh. The integration of machine learning detection, satellite validation, and government administrative data represents one of the most comprehensive efforts to date in mapping industrial-environmental interactions in a developing country context.

5. EMPIRICAL STRATEGY

Cross Validation

We first cross validate the NDVI to understand how much it can explain agricultural productivity in the context of Bangladesh. For this purpose, we merge satellite data with other available secondary data such as IFPRI's BIHS 2018/19 and data from BBS yearbook of agricultural statistics. We compare NDVI with traditional agricultural productivity measures such as rice yield and total production of rice paddy.

Measuring Exposure to Kilns: Kiln Count within Union Boundaries

To assess the localized impact of brick kiln proliferation on agricultural productivity, this study employs a difference-in-differences (DiD) framework focusing on kiln count within union boundaries as the main treatment variable. The kiln count measure captures both the presence and intensity of industrial expansion by recording the cumulative number of new brick kilns established within each union boundary during the study period. This variable serves as a proxy for industrial activity that potentially exerts environmental pressure on agricultural land and vegetation health.

We define the treatment year ($gvar$) for each union as the first year in which at least one kiln was established. Unions that have not experienced kiln establishment throughout the study period are classified as untreated and assigned a $gvar$ value of zero. This coding strategy enables the comparison of changes in vegetation outcomes between treated and untreated unions over time, while accounting for staggered treatment timing across units.

The model is estimated using the Callaway and Sant'Anna (2021) DiD framework. This method extends traditional two-way fixed effects models to accommodate staggered adoption of treatment and treatment effect heterogeneity. The estimation uses the doubly robust inverse probability weighting (DRIPW) approach, which provides unbiased and consistent estimates even if either the outcome or treatment model is misspecified.

Formally, the empirical specification can be expressed as for two-way fixed effect model:

$$NDVI_{it} = \alpha_i + \lambda_t + \beta KilnCount_{it} + \varepsilon_{it}$$

Here, $NDVI_{it}$ represents the vegetation health index for union i in year t , $KilnCount_{it}$ is the cumulative number of kilns within the union boundary, α_i captures union-specific fixed effects, λ_t denotes year fixed effects, and ε_{it} is the error term. Union fixed effects control for time-invariant local characteristics such as soil fertility, land quality, and geographic location, while year fixed effects account for common shocks such as rainfall variation or national policy changes.

To quantify the temporal effects of continuous treatment intensity on agricultural productivity, we estimate a dynamic DiD model that allows for both lagged and anticipatory responses.

The dynamic continuous DiD model is specified as follows:

$$y_{ut} = \alpha_u + \delta d_t + \sum_L^1 \beta_l \Delta E_u^{t-l} + \sum_m^1 \theta_m \Delta E_u^{t+m} + \varepsilon_{ut}$$

Here, y_{ut} denotes the outcome for unit u at time t . In the context of this study, y_{ut} represents the NDVI as a proxy of overall agricultural productivity. The term α_u captures unit fixed effects that absorb time-invariant characteristics of each spatial unit, such as soil type, terrain, long-run climatic factors, and other persistent agro-ecological features. Time fixed effects, δd_t , control for shocks common across all units in period t , including seasonal weather patterns, national policy changes, or macroeconomic fluctuations. β_l capture contemporaneous and lagged effects, and θ_m test for pre-trends. The primary variable of interest is $\Delta E_{u,t}$, which measures the change in continuous exposure faced by unit u at time t . In this application, $\Delta E_{u,t}$ reflects changes in environmental exposure attributable to brick kilns (for example, changes in particulate matter concentration or proximity-based exposure indexes). Unlike binary treatment frameworks, the model exploits variation in the *intensity* of treatment. The first summation term, $\sum_{\ell=0}^L \beta_{\ell} \Delta E_{u,t-\ell}$ captures the contemporaneous and lagged impacts of exposure on agricultural

productivity. Coefficients β_ℓ reflect how exposure at different points in the past influences current NDVI, thereby allowing the model to uncover persistence or decay of treatment effects over time. For instance, β_0 denotes the immediate (same-period) effect, whereas β_ℓ captures the effect of the most distant lag considered.

To assess the validity of the parallel trends assumption and to detect potential anticipatory behavior, we include lead terms: $\sum_{m=1}^M \theta_m \Delta E_{u,t+m}$. The coefficient θ_m measures whether future changes in exposure are correlated with current outcomes. Statistically insignificant leads ($\theta_m \approx 0$) provide evidence that units were not on different pre-treatment trajectories, strengthening the identification strategy. Finally, ε_{ut} denotes idiosyncratic shocks varying across units and time. Standard errors are clustered at the appropriate spatial or administrative level to account for serial and spatial correlation in the residuals.

The empirical procedure proceeds as follows. The dataset is first merged by union-year to incorporate both kiln count and NDVI measures. The kiln count variable is defined as the cumulative total of new kilns up to each year, and the treatment variable $gvar$ records the first year of kiln establishment. Unions that have never hosted a kiln are retained as potential control units.

The resulting event-study plots reveal the trajectory of NDVI before and after the introduction of brick kilns within union boundaries. Stable and statistically insignificant coefficients prior to treatment provide evidence of parallel pre-trends, while post-treatment declines in NDVI indicate reductions in vegetation health due to kiln activity. The kiln count specification thus provides a granular measure of localized industrial exposure, enabling the identification of environmental externalities of brick kiln expansion within the administrative context of Bangladesh. By linking kiln presence directly to vegetation outcomes, this model captures both the spatial and temporal dimensions of industrial land-use change, offering robust insights into the consequences of unregulated industrial growth on agricultural sustainability.

6. RESULTS

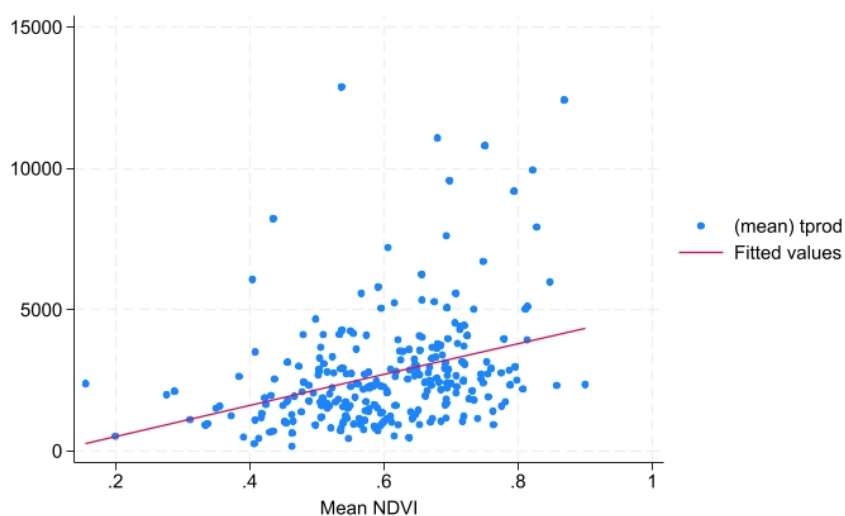
Cross Validation

For cross validation exercises, we use NDVI at two levels. First, we compute the mean annual NDVI for each upazila in Bangladesh over the 2017–2019 period. These values serve as our main explanatory variable for agricultural productivity. These data are then merged with the BIHS 2018/19 data to investigate level of association. To further investigate, we obtain NDVI at the district level from 2014 to 2024. We then merge this data with data from the BBS Yearbook of Agricultural Statistics for the same period to investigate the association further.

Descriptive Analysis

For the first part of analysis, we combine satellite data with survey data (BIHS 2018/19). Although this national rural survey is representative at the divisional level, this included data from 260 rice growing upazillas in Bangladesh. Using data from 260 upazilas, the correlation between NDVI and total paddy production is 0.3840, while the correlation with paddy yield is 0.2652. Both are statistically significant at the 0.01-percent level ($p = 0.0000$).

Figure 6.1: Relationship between mean NDVI and total paddy production



Source: Author's estimation using BIHS 2018/19 and NASA MODIS.

NDVI appears to correlate more strongly with total production than with yield.

Regression Results and Interpretation

For the second part of the analysis, we combine satellite data with rice yield estimates obtained from secondary sources (BBS Yearbook of Agricultural Statistics). We estimate log-log fixed effects regressions of rice yield on NDVI, controlling for unobserved heterogeneity at the upazila level. This section utilizes monthly rice yield data from the Yearbook of Agricultural Statistics, published by the BBS for fiscal years 2014 through 2024 (11 years). Results are presented separately for pooled rice data as well as by rice season (Aman, Aus, and Boro).

For the pooled sample, which aggregates all rice-growing seasons, the coefficient on the log of NDVI is 1.0752 and is statistically significant at the 1-percent level. Disaggregated estimates show that the association between NDVI and yield is strongest during the Aman season, with a coefficient of 1.1117. This is consistent with the seasonal dependence of Aman rice on rainfall and natural vegetation cycles, which NDVI is well-suited to capture. For the Aus season, the coefficient is 0.4767, which is positive but only marginally statistically significant ($p = 0.071$). In contrast, the Boro season, which relies heavily on irrigation and controlled farming practices, exhibits a smaller but statistically significant NDVI coefficient of 0.2292 (see Appendix Table A3 for details).

Overall, the results indicate that NDVI is a more reliable predictor of paddy yield in rainfed agricultural systems, particularly during the Aman season, than in seasons characterized by irrigation-dependent cultivation, such as Boro. The attenuated relationship observed in the Aus and Boro seasons may reflect a reduced sensitivity of yield outcomes to natural vegetation conditions in those contexts.

Two-way Fixed Effect Model

Before moving to our preferred specification of continuous and staggered DiD, we are presenting a simple two-way fixed effect model result to more easily interpret the impact. Table 6.1 reports the results from

the fixed-effects regression estimating the relationship between brick kiln concentration and local vegetation health, as measured by NDVI. The model includes union/municipality fixed effects to absorb all time-invariant spatial characteristics (for example, soil fertility, land use patterns, and elevation, among others), as well as year fixed effects to control for nationwide or time-specific shocks (for example, climatic variability, policy interventions, or satellite calibration changes). Standard errors are heteroskedasticity-robust and clustered at the union/municipality level.

The estimated coefficient on `kiln_count` is -7.304 , statistically significant at the $p < 0.01$ level. This negative and highly significant coefficient implies that each additional brick kiln within a union or municipality is associated with an average 7.3-unit decline in NDVI, holding other factors constant. The magnitude of the effect suggests that brick kiln activity is a substantial driver of vegetation degradation, consistent with the hypothesis that emissions and particulate pollution from kilns reduce photosynthetic activity and soil productivity in surrounding agricultural areas.

Overall, these findings provide empirical evidence that the expansion of brick kilns has significantly adverse impacts on local vegetation health in Bangladesh. The results underscore the environmental externalities associated with kiln concentration and highlight the importance of regulatory enforcement and the promotion of cleaner kiln technologies to mitigate land degradation and productivity loss.

Table 6.1 Two-way fixed effect model at the union/municipality level

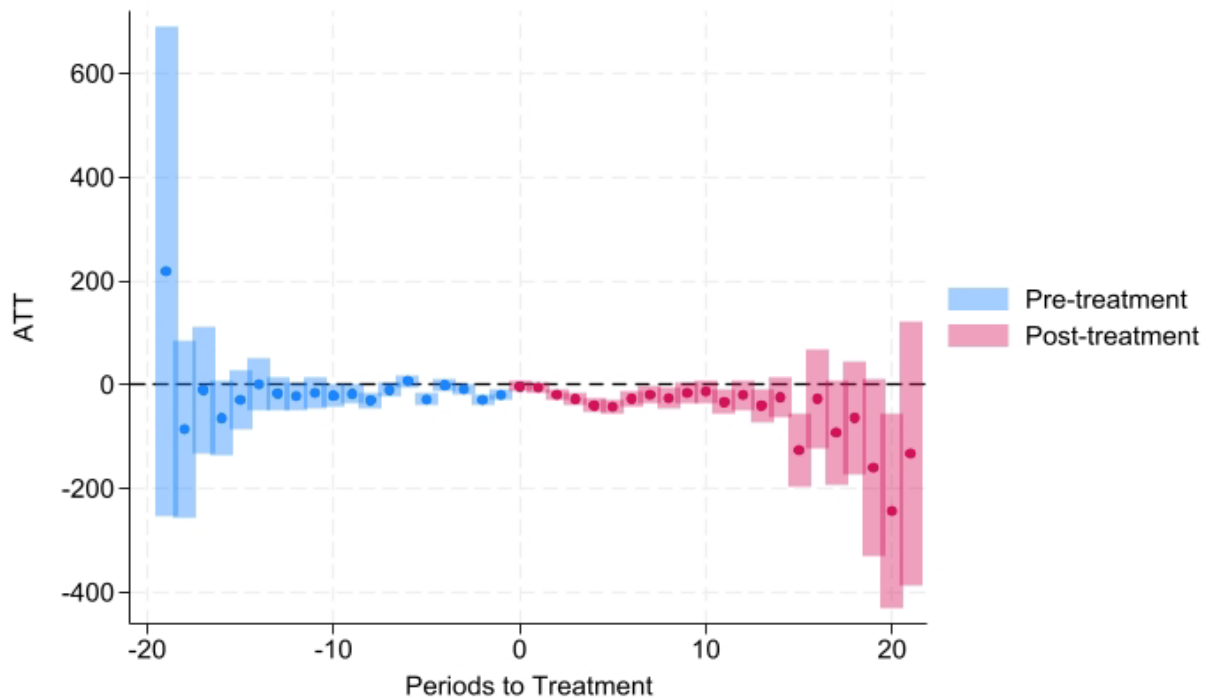
Effect	Estimate
Kiln count	-7.304*** (1.6667)
Intercept	5041.847** (1.148)

Notes: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Callaway–Sant’Anna Difference-in-Differences (CSDiD) and Event Study Results

Figure 6.2 and Table 6.2 present the dynamic treatment effects of brick kiln establishment on vegetation health, as measured by NDVI as a proxy variable to agricultural productivity. The estimates are derived from the Callaway and Sant’Anna (2021) DiD model, which accounts for staggered treatment adoption across unions. The event-study specification evaluates both the timing and persistence of the impact of kiln proliferation within union boundaries. We make one adjustment in the machine learning dataset of brick kiln detection: if a brick kiln is detected operating before the year 2010 and there is no observation for last before first variable in the dataset, we assume that those brick kilns have been operating since year of the brick kiln detection model, that is, 2000.

Figure 6.2: Event-study plot showing persistence decline of NDVI value post brick kilns establishment



Source: Authors' estimation.

Using the Callaway and Sant’Anna (2021) DiD framework at the union level, we find that NDVI declines immediately following the establishment of a brick kiln. The results show a clear temporal asymmetry between the pre-treatment and post-treatment periods. During the pre-treatment period, coefficients fluctuate around zero and remain statistically insignificant. The average pre-treatment effect (Pre_avg = -9.68, $p = 0.474$) confirms that there are no discernible differences in NDVI trends between treated and untreated unions before the first kiln establishment. This supports the parallel trends assumption, which underpins causal interpretation of post-treatment estimates.

In contrast, the post-treatment effects are consistently negative and statistically significant. The average post-treatment coefficient (Post_avg = -54.64) indicates that NDVI values decline substantially following kiln establishment, suggesting a notable deterioration in vegetation health. In economic terms, this is a decline of vegetation of almost 1 percent per union due to the marginal increase of a kiln from the average.

Overall, the event-study graph and coefficient estimate jointly demonstrate that brick kiln operations are associated with statistically significant and persistent declines in vegetation health at the union level. The negative average treatment effect of the treated (ATT) estimates increases in magnitude over time, suggesting that the environmental damage from kiln activity is both cumulative and long-lasting. The absence of pre-treatment differences enhances confidence in the causal interpretation of these effects. The estimated effect is economically meaningful: a marginal increase of one brick kiln at the union level in a given year is associated with approximately a 1-percent decline in NDVI. In many unions, kiln growth exceeds one unit per year, implying correspondingly larger productivity losses. Moreover, the effects are persistent and carry over into subsequent years rather than being transitory; we now clarify this interpretation explicitly in the manuscript.

We also try out another model where we curtail the dataset and use data from 2010 onwards. We observe some negative impact in the following years after kiln establishment. These results from this alternate scenario are illustrated in Figure A6.1 in the Appendix.

Table 6.2 CSDiD regression results

Effect	Estimate
Pre_avg	-9.677 (13.511)
Post_avg	-54.640** (18.330)

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

7. DISCUSSION AND POLICY IMPLICATIONS

The findings of this study reveal a clear trade-off between industrial expansion and agricultural sustainability in Bangladesh. While the brick manufacturing sector has played an indispensable role in meeting the country's growing demand for construction materials, its unregulated growth has imposed substantial environmental and agricultural costs. The proliferation of traditional brick kilns, often concentrated in peri-urban and agriculturally productive areas, has led to measurable declines in vegetation health, as captured through NDVI, and consequently, in crop productivity. These effects are not transient but persist and intensify over time, reflecting cumulative environmental degradation caused by sustained exposure to kiln-related pollutants and topsoil extraction. The event-study results presented in this paper clearly demonstrate a statistically significant and persistent decline in NDVI following kiln establishment, highlighting that industrial land use and agricultural land preservation are deeply interlinked policy domains.

One concern could be whether the process of topsoil use by brick kilns suggests the need for a natural structural transformation wherein the use topsoil is more productive in industrial base production compared to agriculture. While a full general equilibrium analysis is beyond the scope of this paper, we put forth the following argument: brick kilns in Bangladesh operate largely as an informal industry, and frequent violations of existing government guidelines and environmental regulations are well-documented. In particular, current regulations prohibit the use of fertile topsoil for brick production and restrict kiln operations within 1,000 meters of productive agricultural land. In practice, these rules are often weakly enforced. Importantly, the environmental impacts documented in this paper do not reflect an efficient structural transformation in which the reallocation of topsoil from agriculture to brick production yields higher aggregate productivity. Viable alternatives to topsoil extraction exist, including the use of subsoil layers, river silt, and soil from non-arable or degraded land, as well as cleaner kiln technologies. The persistence of topsoil extraction therefore reflects regulatory failure rather than technological

necessity. Given Bangladesh's severe land constraints, exacerbated by climate change, recurrent flooding, erosion, and rising soil salinity, the productive use of arable land remains critical for national food security. From this perspective, the observed productivity losses represent avoidable externalities rather than a trade-off inherent to development. Our results thus highlight the importance of effective regulation and land-use planning in mitigating environmental damage without constraining industrial activity.

Another relevant argument is whether air pollution caused by brick kilns is also having detrimental effects on crop productivity. Evidence on crop impacts is comparatively more limited and context dependent, in part because pollutant dispersion is influenced by wind direction, atmospheric conditions, and distance from emission sources. As a result, directly attributing observed vegetation declines to air pollution alone is empirically challenging in our setting. In this paper, our primary interpretation emphasizes land degradation through topsoil extraction as the dominant mechanism linking brick kiln activity to reduced agricultural productivity. Brick kilns operating near agricultural fields frequently remove fertile topsoil, which directly lowers soil organic matter, nutrient availability, and water retention capacity; mechanisms that are well established in agronomic research and operate independently of air quality.

The trade-offs between industrial output and agricultural sustainability therefore require a balanced and evidence-based policy response. Stricter spatial zoning regulations should be introduced to restrict kiln operations in high-yield agricultural zones and along riverbanks where topsoil extraction is most detrimental. Enforcement of existing emission control standards must be strengthened, accompanied by economic incentives for brick kiln owners to use silts from river or lower-level soils and replacing topsoil once the lower-level soil has been taken. This study sets the ground for a field experiment with kiln owners to train them on how not to use topsoil and instead use other options to reduce the impact on agricultural fields.

Furthermore, targeted agricultural restoration programs should be developed for areas surrounding former or inactive kiln sites. Such programs could include reforestation initiatives, soil fertility rehabilitation through organic amendments, and crop diversification schemes aimed at restoring ecosystem function and

productivity. Integrating geospatial monitoring tools like NDVI into local government planning frameworks can further help identify priority restoration zones and track recovery progress over time.

In conclusion, this study underscores that the unregulated growth of brick kilns in Bangladesh poses a significant threat to both agricultural productivity and environmental sustainability. Remote sensing evidence demonstrates that kiln proximity correlates with persistent vegetation decline, validating concerns over topsoil loss and air pollution impacts. However, the problem is not intractable. Through a combination of technological modernization, regulatory reform, and ecological restoration, Bangladesh can reconcile the competing demands of industrial growth and sustainable agriculture. The integration of satellite-based monitoring, data-driven zoning policies, and environmentally responsible production technologies offers a viable pathway toward a cleaner, more resilient, and food-secure future.

REFERENCES

- Ahmed, A. U., Bakhtiar, M. M., & Mahzab, M. (2024). Food Security and Nutrition in Bangladesh: Evidence-Based Strategies for Advancement. Dhaka: International Food Policy Research Institute, Bangladesh Country Office. Retrieved from https://bangladesh.ifpri.info/files/2024/11/IFPRI_Food-Security-in-Bangladesh_Report_November-2024.pdf
- Ahmed, A. U., Bakhtiar, M. M., Anowar, S., & Rahman, M. M. (2023). Public procurement of paddy in Bangladesh: Implications for policy. *The Bangladesh Development Studies*, 42(1/2), 1-30. <https://doi.org/10.57138/ZFHX2730>
- Ahmed, Raisuddin, ed.; Haggblade, Steven, ed.; and Chowdhury, Tawfiq-e-Elahi, ed. 2000. Out of the shadow of famine: Evolving food markets and food policy in Bangladesh. Baltimore, MD: Published for the International Food Policy Research Institute (IFPRI) by Johns Hopkins University Press. <https://hdl.handle.net/10568/156270>
- Biswas, D., Gurley, E. S., Rutherford, S., & Luby, S. P. (2018). The drivers and impacts of selling soil for brick making in Bangladesh. *Environmental Management*, 62(4), 792–802. <https://doi.org/10.1007/s00267-018-1072-z>
- Boyd, D. S., Perrat, B., Li, X., Jackson, B., Landman, T., Ling, F., Bales, K., Choi-Fitzpatrick, A., Goulding, J., Marsh, S., & Foody, G. M. (2021). Informing action for United Nations SDG target 8.7 and interdependent SDGs: Examining modern slavery from space. *Humanities & Social Sciences Communications*, 8, Article 111. <https://doi.org/10.1057/s41599-021-00792-z>
- Brooks, N., Biswas, D., Hossin, R., Yu, A., Saha, S., Saha, S., Saha, S. K., & Luby, S. P. (2023). Health consequences of small-scale industrial pollution: Evidence from the brick sector in Bangladesh. *World Development*, 170, 106318. <https://doi.org/10.1016/j.worlddev.2023.106318>
- Brooks, N., Biswas, D., Maithel, S., Miller, G., Mahajan, A., Uddin, M. R., Ahmed, S., Mahzab, M., Rahman, M., & Luby, S. P. (2024). Building blocks of change: The energy, health, and climate impacts of informal brick manufacturing in Bangladesh. *Energy Research and Social Science*, 7(6), 707-723. <https://doi.org/10.1016/j.erss.2024.103738>
- Brooks, N., Biswas, D., Maithel, S., Miller, G., Mahajan, A., Uddin, M. R., Ahmed, S., Mahzab, M., Rahman, M., & Luby, S. P. (2025). Reducing emissions and air pollution from informal brick kilns: Evidence from Bangladesh. *Science*, 388(6747), eadr7394. <https://doi.org/10.1126/science.adr7394>
- Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-differences with multiple time periods. *Journal of Econometrics*, 225(2), 200–230. <https://doi.org/10.1016/j.jeconom.2020.12.001>
- Calvão, T., & Palmeirim, J. M. (2004). Mapping Mediterranean scrub with satellite imagery: Biomass estimation and spectral behaviour. *International Journal of Remote Sensing*, 25(17-18), 3113-3126. <https://doi.org/10.1080/01431160310001654978>
- Climate and Clean Air Coalition. (2017). *National strategy for sustainable brick production in Bangladesh* (CCAC report). Retrieved December 23, 2025, from https://www.ccacoalition.org/sites/default/files/resources/2017_strategy-brick-production-bangladesh.pdf

Chen J (2007) Rapid urbanization in China: a real challenge to soil protection and food security. *Catena* 69(1):1–15. <https://doi.org/10.1016/j.catena.2006.04.019>

Directorate of Economics & Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. (2021, December 13). Forecasting Agricultural output using Space, Agro-meteorology and Land based observations (FASAL). Retrieved from <https://iegindia.org/projects/forecasting-agricultural-output-using-spaceagro-meterology-land-based-observation-fasal/>

Doraiswamy, P. C., Sinclair, T. R., Hollinger, S., & Akhmedov, B. (2005). Application of MODIS-derived parameters for regional crop yield assessment. *Remote Sensing of Environment*, 97(2), 192-202. <https://doi.org/10.1016/j.rse.2005.03.015>

Ferencz, C., Bognár, P., Lichtenberger, J., Hamar, D., Tarcsai, G., Timár, G., Molnár, G., Pásztor, S., Steinbach, P., Székely, B., Ferencz, O., & Ferencz-Árkos, I. (2004). Crop yield estimation by satellite remote sensing. *International Journal of Remote Sensing*, 25(17-18), 4113-4149. <https://doi.org/10.1080/01431160410001698870>

Gao, S., Chen, J., Zhang, R., & Li, Q. (2023). Evaluating the saturation effect of vegetation indices in forest canopies. *Remote Sensing of Environment*, 303, 113683. <https://doi.org/10.1016/j.rse.2023.113665>

Guttikunda, S. K., & Goel, R. (2013). Health impacts of particulate pollution in a megacity—Delhi, India. *Environmental Development*, 6, 8–20. <https://doi.org/10.1016/j.envdev.2012.12.002>

Guttikunda, S.K., Khaliqzaman, M. Health benefits of adapting cleaner brick manufacturing technologies in Dhaka, Bangladesh. *Air Qual Atmos Health* 7, 103–112 (2014). <https://doi.org/10.1007/s11869-013-0213-z>

Haque, M. I., Nahar, K., Kabir, M. H., & Salam, A. (2018). Particulate black carbon and gaseous emission from brick kilns in Greater Dhaka region, Bangladesh. *Air Quality, Atmosphere & Health*, 11(2018), 925–935. <https://doi.org/10.1007/s11869-018-0596-y>

Hossain, M. A., Zahid, A. M., Arifunnahar, M., & Siddique, M. N. A. (2019). Effect of brick kiln on arable land degradation, environmental pollution and consequences on livelihood of Bangladesh. *Journal of Science, Technology and Environment Informatics*, 06(02), 474-488. <https://doi.org/10.18801/jstei.060219.50>

Huang, S., Tang, L., Hupy, J. P., Wang, Y., & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of Forestry Research*, 32(1), 1–6. <https://doi.org/10.1007/s11676-020-01155-1>

Huete, A. R. (1988). A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*, 25(3), 295-309. [https://doi.org/10.1016/0034-4257\(88\)90106-X](https://doi.org/10.1016/0034-4257(88)90106-X)

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., & Ferreira, L. G. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment*, 83(1), 195–213. [https://doi.org/10.1016/S0034-4257\(02\)00096-2](https://doi.org/10.1016/S0034-4257(02)00096-2)

Imamul Huq SM, Md. Shoaib JU (2013) Soils and humans. In: *The soils of Bangladesh*. World Soils Book Series, vol 1. Springer, Dordrecht, pp 125–129. https://doi.org/10.1007/978-94-007-1128-0_13

- Lee, J., Brooks, N. R., Tajwar, F., Burke, M., Ermon, S., Lobell, D. B., Biswas, D., & Luby, S. P. (2021). Scalable deep learning to identify brick kilns and aid regulatory capacity. *Proceedings of the National Academy of Sciences of the United States of America*, 118(17), Article e2018863118. <https://doi.org/10.1073/pnas.2018863118>
- Lobell, D. B., Thau, D., Seifert, C., Engle, E., & (Additional authors). (2015). A scalable satellite-based crop yield mapper. *Remote Sensing of Environment*, 164. <https://doi.org/10.1016/j.rse.2015.04.021>
- Luby SP, Biswas D, Gurley ES, Hossain I (2015) Why highly polluting methods are used to manufacture bricks in Bangladesh. *Energy. Sustain Dev* 28:68–74. <https://doi.org/10.1016/j.esd.2015.07.003>
- Maaze, M. R., & Shrivastava, S. (2024). *Development and performance evaluation of recycled brick waste-based geopolymer brick for improved physico-mechanical, brick-bond and durability properties. Journal of Building Engineering*, 97, 110701. <https://doi.org/10.1016/j.jobe.2024.110701>
- Miller, G., Biswas, D., Mahajan, A., Singer Babiarz, K., Brooks, N. R., Brunner, J., Ashraf, S., Shane, J., Scarabosio, A., Maithel, S., Ahmed, S., Mahzab, M., Uddin, M. R., Rahman, M., & Luby, S. P. (2024). Productivity gains and work conditions in coercive labor markets: Experimental evidence from the Bangladesh brick sector (NBER Working Paper No. 32829). National Bureau of Economic Research. <https://doi.org/10.3386/w32829>
- Motalib, M., Lasco, R., Pacardo, E., Rebancos, C., & Dizon, J. (2015). Health impact of air pollution on Dhaka City by different technologies brick kilns. *International Journal of Technology Enhancements and Emerging Engineering Research*, 3(5), 127–132. Retrieved from <https://www.semanticscholar.org/paper/Health-Impact-Of-Air-Pollution-On-Dhaka-City-By-Motalib-Lasco/66cbb788aa15a0ecffd874aeb6270131b313e801>
- Prasad, A. K., Chai, L., Singh, R., & Kafatos, M. (2006). Crop yield estimation model for Iowa using remote sensing and surface parameters. *International Journal of Applied Earth Observation and Geoinformation*, 8(1), 26-33. <https://doi.org/10.1016/j.jag.2005.06.002>
- Rouse, J. W., Jr., Haas, R. H., Schell, J. A., & Deering, D. W. (1974, January 1). Monitoring vegetation systems in the Great Plains with ERTS (Third Earth Resources Technology Satellite-1 Symposium, Vol. 1, Sect. A, Paper No. A20). National Aeronautics and Space Administration, Goddard Space Flight Center. <https://ntrs.nasa.gov/citations/19740022614>
- Sahoo, S., Behera, S. K., Panigrahi, P. K., Dash, R. K., & Sahoo, A. K. (2024). Advanced prediction of rice yield gaps under climate uncertainty using machine learning techniques in Eastern India. *Environmental Advances*, 18, 100494. <https://doi.org/10.1016/j.jafr.2024.101424>
- Saritha, A., & Jangra, R. (2024). Industrialization effects on agriculture and health. *Anthropo-Indialogs*, 4(1), 31-37. <https://doi.org/10.47509/AI.2024.v04i01.03>
- M. S. Alam, K. A. Kalpoma, M. S. Karim, A. A. Sefat, and J. Kudoh. (2019) Boro rice yield estimation model using MODIS NDVI data for Bangladesh, in *Proc. IEEE Int. Geosci. Remote Sens. Symp. (IGARSS)*, 2019, pp. 7330–7333, doi: 10.1109/IGARSS.2019.8899084
- Sarker, A. H. M. R., Suza, M., & Røskaft, E. (2021). Impact of emissions from brick industries on soil properties, agricultural crops and home-gardens in Chittagong, Bangladesh. *Journal of Soil Science and Environmental Management*, 12(4), 159-172.

Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation*. Oxford: Oxford University Press.

Shanmugapriya, P., Rathika, S., Ramesh, T., & Janaki, P. (2019). Applications of remote sensing in agriculture – A review. *International Journal of Current Microbiology and Applied Sciences*, 8(1), 2270-2283. <https://doi.org/10.20546/ijcmas.2019.801.238>

Steven, M. D., Malthus, T. J., Baret, F., Xu, H., & Chopping, M. J. (2003). Intercalibration of vegetation indices from different sensor systems. *Remote Sensing of Environment*, 88(4), 412–422. <https://doi.org/10.1016/j.rse.2003.08.010>

Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, 225(2), 175–199. <https://doi.org/10.1016/j.jeconom.2020.09.006>

Thakrar, S. K., Boyd, D., Yu, X., Ahmed, S. R., & Mattsson, M. (2025). Mapping the health harm of Bangladeshi brick kilns. *EarthArXiv preprint*. <https://doi.org/10.31223/X5CM82>

Tian, Y., Yang, G., Wang, Z., Wang, H., Li, E., & Liang, Z. (2019). Apple detection during different growth stages in orchards using the improved YOLO-V3 model. *Computers and Electronics in Agriculture*, 157, 417–426. <https://doi.org/10.1016/j.compag.2019.01.012>

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8(2), 127–150. [https://doi.org/10.1016/0034-4257\(79\)90013-0](https://doi.org/10.1016/0034-4257(79)90013-0)

UNDP. (2015). Bangladesh Green Brick Project (IKEBMI): Mid-term Review. Prepared by Parnon Group. United Nations Development Programme. <https://info.undp.org/docs/pdc/Documents/BGD/20161028%20IKEBMI%20TE%20Final%20Report.pdf>

Wallace, J. F., Caccetta, P. A., & Kiiveri, H. T. (2004). Recent developments in analysis of spatial and temporal data for landscape qualities and monitoring. *Austral Ecology*, 29(1), 100-107. <https://doi.org/10.1111/j.1442-9993.2004.01356.x>

Weyant, C., Athalye, V., Ragavan, S., Rajarathnam, U., Lalchandani, D., Maithel, S., Baum, E., & Bond, T. C. (2014). Emissions from South Asian brick production. *Environmental Science & Technology*, 48(11), 6477–6483. <https://doi.org/10.1021/es500186g>

Zangana, S. D. A., & Yusof, N. F. F. M. (2024). Brick kiln emission variability and impact in environment and health. *Engineering, Technology & Applied Science Research*, 14(5), 17350–17356. <https://doi.org/10.48084/etasr.8598>

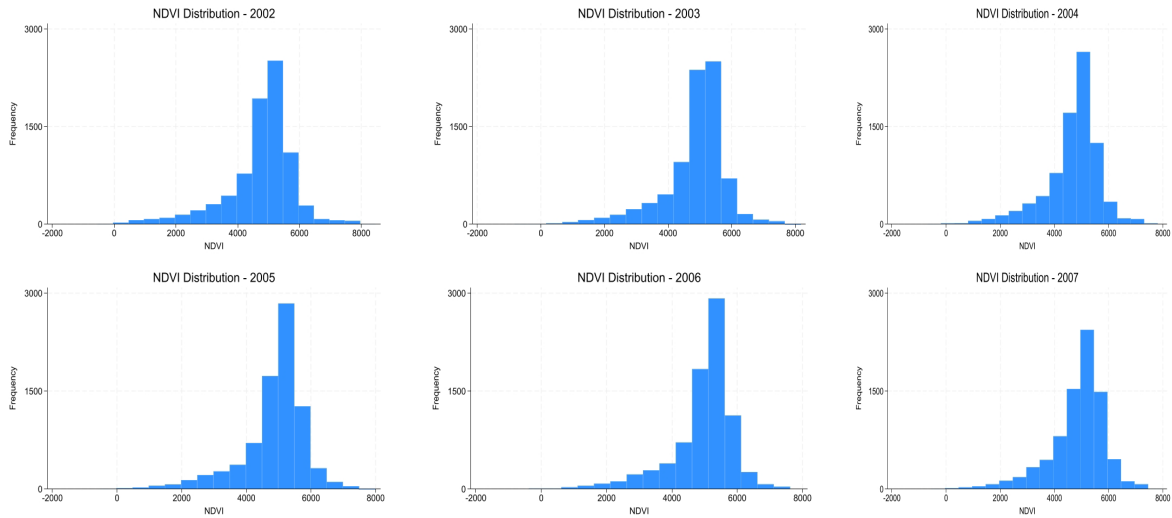
APPENDIX

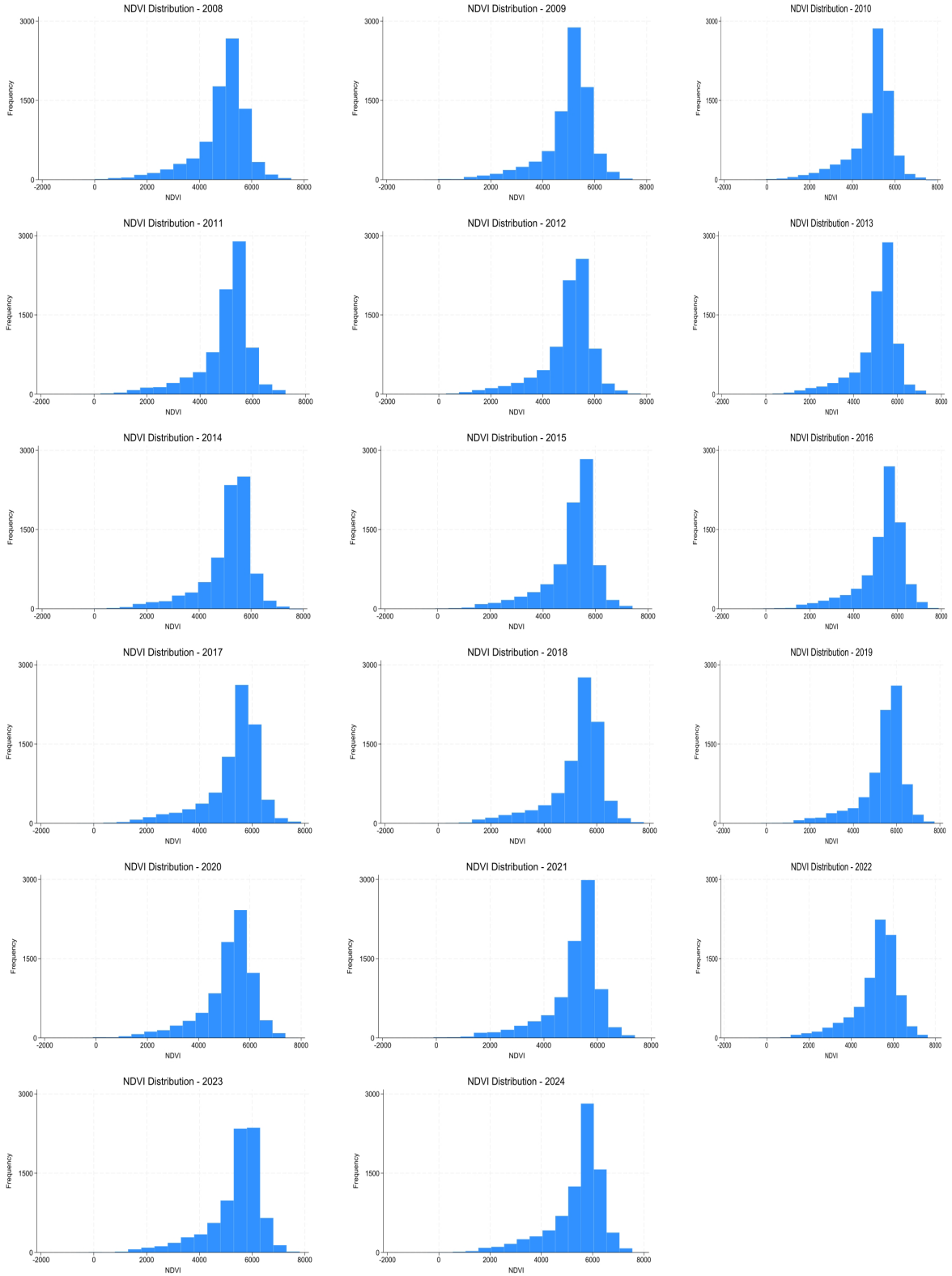
Table A1: Cross validation regression results

Effect	Estimate
All Rice	
ln_ndvi	1.0752*** (0.1418)
Intercept	-7.9773*** (1.2017)
Aman Rice	
ln_ndvi	1.1117*** (0.1655)
Intercept	-8.4713*** (1.3905)
Aus Rice	
ln_ndvi	0.4767* (0.2599)
Intercept	-3.2221 (2.2087)
Boro Rice	
ln_ndvi	0.2292*** (0.0604)
Intercept	-0.5543 (0.5127)

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

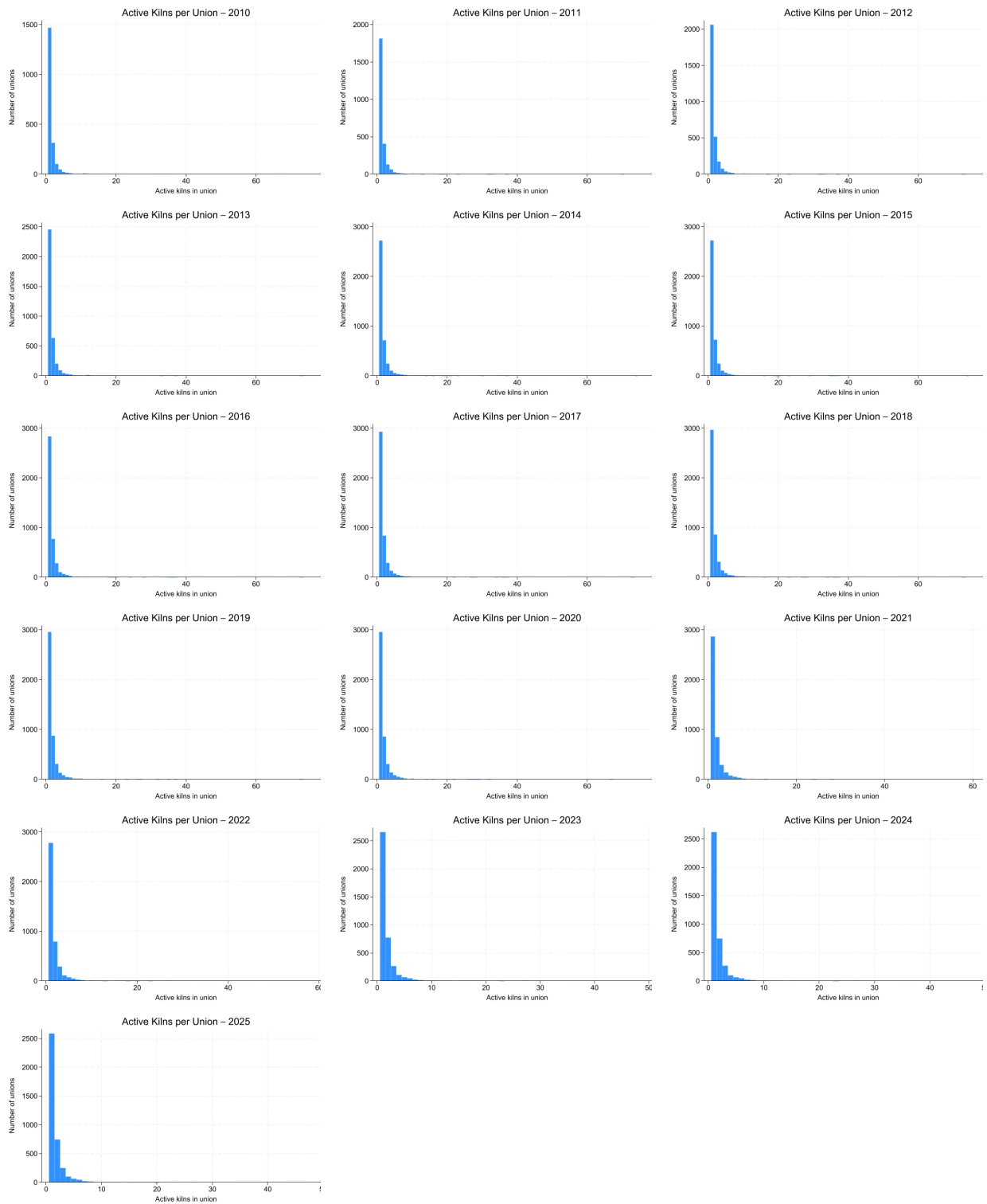
Figure A4.1: Average annual NDVI at union/municipality level (2002–2024)





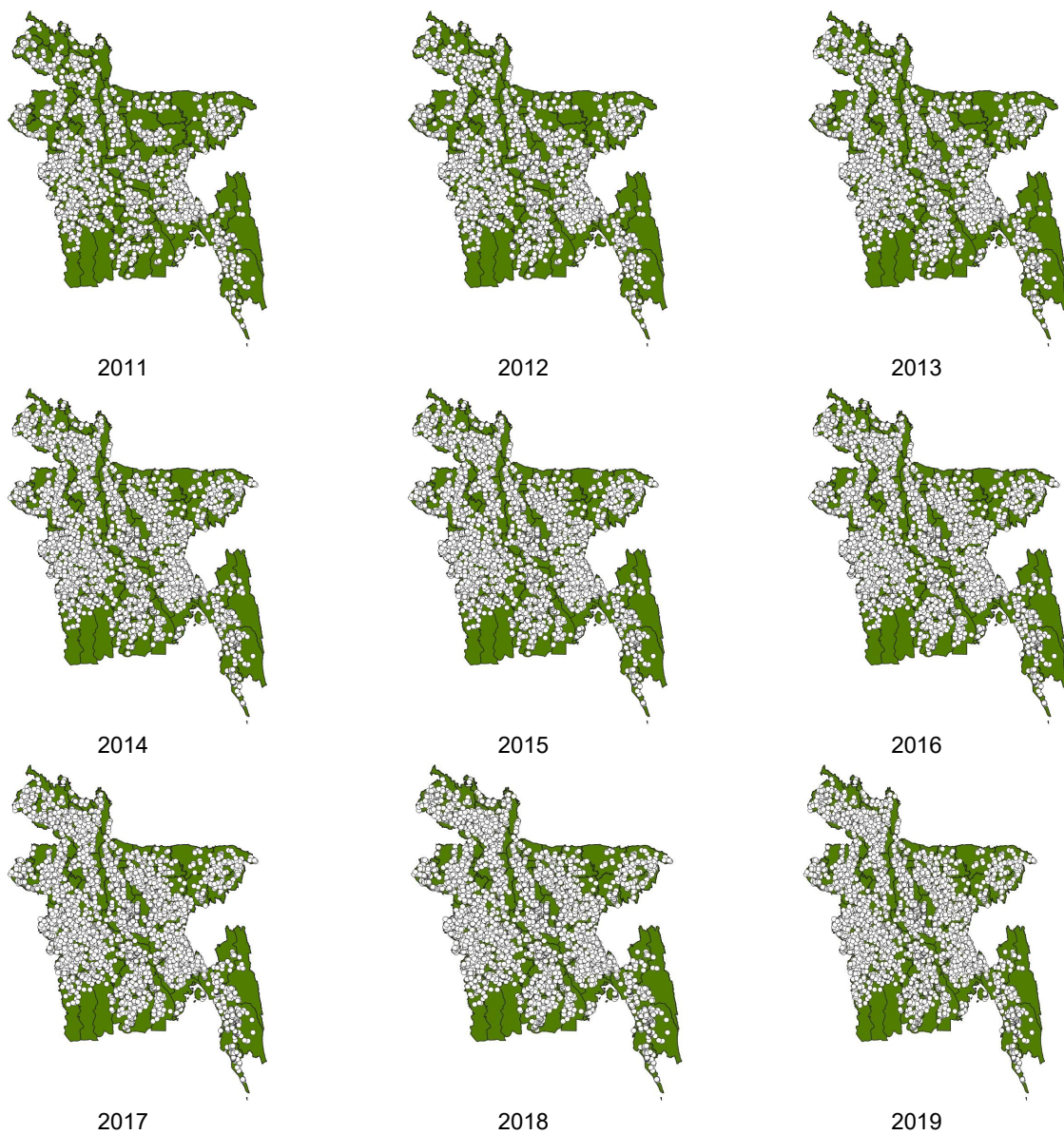
Source: Author's Estimation based on NASA MODIS data.

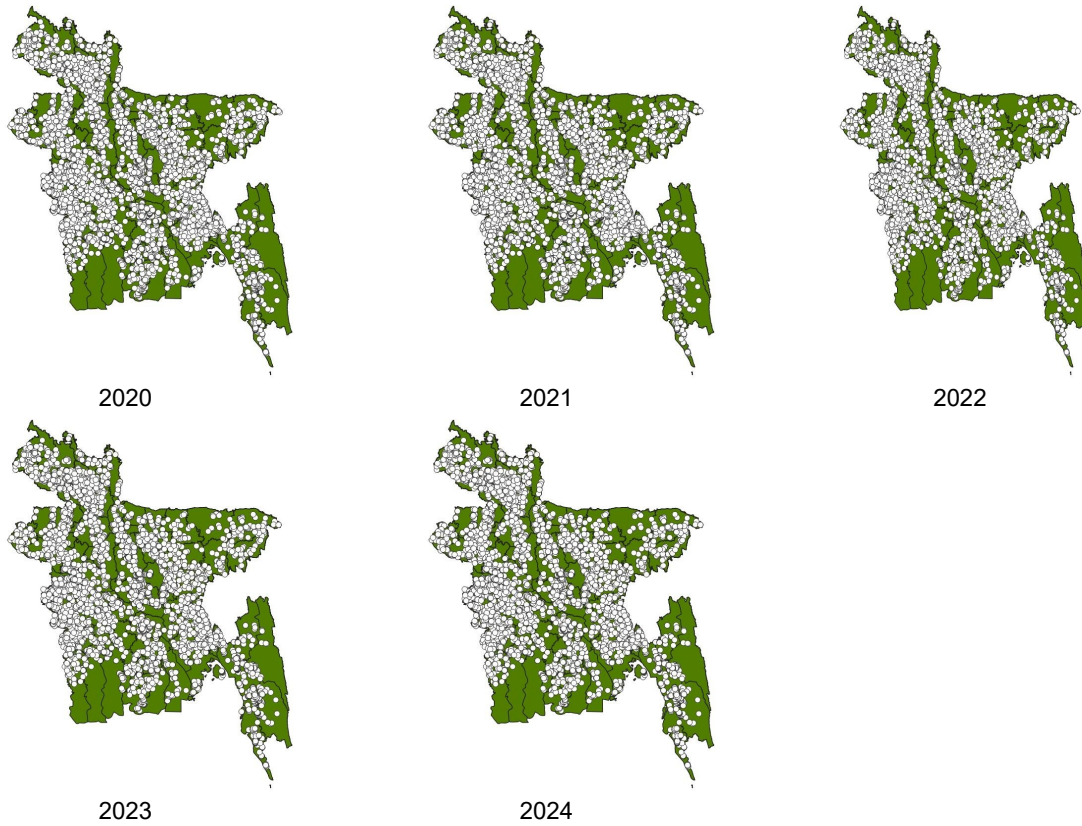
Figure A4.2: Distribution of active brick kilns per union/municipality in Bangladesh



Source: Authors' calculation.

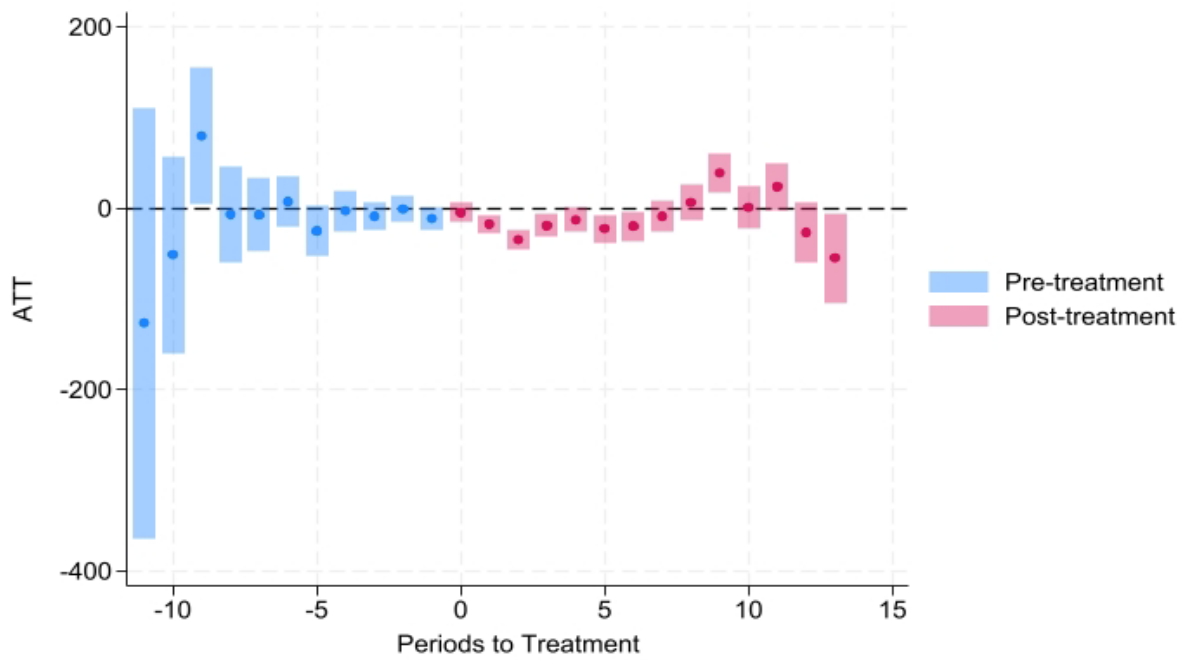
Figure A4.3: Spatial and temporal distribution of brick kilns across Bangladesh





Source: Authors' estimation.

Figure A6.1: Event-study plot using data since 2010 onwards



Source: Authors' estimation.

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IFPRI HEADQUARTERS

1201 Eye Street, NW

Washington, DC 20005 USA

Tel.: +1-202-862-5600

Fax: +1-202-862-5606

Email: ifpri@cgiar.org