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Why highly polluting methods are used to manufacture bricks in Bangladesh

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ABSTRACT

Brick kilns in Bangladesh use inefficient coal burning technology that generates substantial air pollution. We investigated the incentives of stakeholders in brick manufacturing in Bangladesh to help inform strategies to reduce this pollution. A team of Bangladeshi anthropologists conducted in-depth interviews with brick buyers, kiln owners, and Department of Environment employees. Brick buyers reported that bricks manufactured in traditional kilns worked well for most construction purposes and cost 40% less than bricks manufactured in more modern, less polluting, kilns. Brick kiln owners favored approaches with rapid high return on a modest investment. They preferred kilns that operate only during the dry season, allowing them to use cheaper low-lying flood plain land and inexpensive seasonal labor. The Department of Environment employees reported that many kilns violate environmental regulations but shortages of equipment and manpower combined with political connections of kiln owners undermine enforcement. The system of brick manufacturing in Bangladesh is an economic equilibrium with the manufacture of inexpensive bricks supplying the demand for construction materials but at high cost to the environment and health of the population. Low-cost changes to improve kiln efficiency and reduce emissions could help move toward a more socially desirable equilibrium.

Introduction

An estimated 5000 brick kilns operate across Bangladesh (World Bank, 2011) including approximately 1000 surrounding Dhaka, the capital city (Guttikunda et al., 2013). These brick kilns contribute substantially to poor air quality and poor community health in Dhaka and throughout Bangladesh. During the dry season, the season when they operate, brick kilns contribute 30%–50% of the <2.5 micron particulate matter (PM 2.5) in the air in cities near where they operate (Begum et al., 2011; Guttikunda, 2009; Hossain et al., 2007). These small particulate products of combustion are especially dangerous to human health because they are absorbed deep in the lungs (Squadrito et al., 2001) and are associated with cardiovascular and respiratory disease (Dominici et al., 2006) and mortality (Laden et al., 2000; Lepeule et al., 2012). Different modeling approaches estimate that the air pollution generated by brick kilns results in between 530 and 5000 premature adult deaths annually in Dhaka alone (Croitoru and Sarraf, 2012; Guttikunda, 2008, 2009). A study conducted in the Mirpur neighborhood of Dhaka found that during the dry season when brick kilns operate, ambient air contributed more to indoor PM 2.5 levels than did type of cooking stove (Gurley et al., 2013), and higher levels of PM 2.5 in households was associated with earlier onset of the first episode of acute lower respiratory infection among young children (Gurley et al., 2014). Lower respiratory infection is the leading cause of death among children in Bangladesh (NIPORT, 2013) and the youngest children are at the highest risk of death (Walker et al., 2013).

Manufacturing bricks using highly polluting kilns is common not only in Bangladesh but is widespread across India (Bhanarkar et al., 2002; Heierli, 2008; Pangtey et al., 2004), Nepal (Joshi and Dudani, 2008; Raut, 2003), Pakistan (Tahir et al., 2010), China (Lei et al., 2011; Zhang et al., 2007), and even Mexico (Blackman et al., 2006). Brick kilns are an important source of atmospheric black carbon (Reddy and Venkataraman, 2002; Weyant et al., 2014) which contributes disproportionately to global warming and by depositing on Himalayan glaciers reducing reflection of sunlight and increasing glacial melting (Menon et al., 2002; Ramanathan and Carmichael, 2008).

Bricks are central to construction in Bangladesh. Approaches to construction that substitute concrete for bricks increase costs because Bangladesh has to import limestone or clinker, essential raw material for making cement (Alam et al., 2009; Harder, 2008) since, to date, the identified limestone deposits within Bangladesh are too deep to mine profitably (Akhtar, 2005; Mohan and Dutta, 2006). Moreover, even when cement is imported, because there are limited stones naturally

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available in Bangladesh, pieces of fired bricks constitute the most common coarse aggregate for making concrete (Rashid et al., 2009). Indeed, brick aggregates produce concrete with higher strength than concrete made with stones (Rashid et al., 2009; Uddin, 2013).

Within Bangladesh, civil society and journalists have raised concerns about the environmental and health impacts of the use of highly polluting kilns to make bricks, but despite the promulgation of several brick kiln regulations (Table 1) and efforts to introduce various cleaner technologies, 91% of all bricks manufactured in Bangladesh are manufactured using highly polluting fixed chimney kilns (World Bank, 2011). Five percent of bricks in Bangladesh are manufactured in Hoffman style kilns (World Bank, 2011). Hoffman kilns have a fixed roof which contributes to energy efficiency and, if the owner has sufficient land to store unfired bricks, permits operation during the rainy season (Gomes and Hossain, 2003; Hossain et al., 2007). Hoffman kilns include a fan, which requires electricity, but provides a constant draught. The cleanest Hoffman kilns use natural gas for fuel, though most in Bangladesh burn coal. Hybrid Hoffman kilns are a lower cost variant of the Hoffman kiln that have thinner kiln walls, are constructed with regular bricks rather than lower thermal conductivity firebricks, and have no cover over the kiln (Hossain et al., 2007). Although zigzag kilns accounted for fewer than 1% of bricks manufactured in Bangladesh in 2009 (World Bank, 2011), the Government of Bangladesh has promoted using zigzag kilns as an alternative to fixed chimney kilns. In a zigzag kiln, the airflow through the kiln is directed by arranging the bricks in a series of zigzags and a draught fan helps move heated air more thoroughly through the bricks (Gomes and Hossain, 2003; Hossain et al., 2007). The efficiency of a zigzag kiln is heavily dependent upon appropriate design, construction, and operation (Hossain et al., 2007; World Bank, 2011).

Not only in Bangladesh, but in low-income countries generally, limited government capacity for monitoring and enforcement hinders implementing strategies that have been successfully deployed in high-income countries to control harmful emissions from industrial plants (Blackman and Harrington, 2000). Nevertheless, even in the setting of weak enforcement, many industrial plants located in low-income countries take substantive steps to abate pollution, often even meeting strict high-income country standards (Dasgupta et al., 2000; Hettige et al., 1996). Factors associated with active investment in pollution abatement by low-income country industrial firms include demands by the surrounding community, demands which are more effective when the community is less impoverished, when the pollution is visible, when the plants are more profitable and when the firm is not owned by the government (Hettige et al., 1996; Pargal et al., 1997).

To help design strategies to encourage brick-manufacturing processes that produce less damage to human health and the environment, we sought to understand the incentives that maintain the current equilibrium that produces low-price bricks in Bangladesh but generates high environmental and human health costs.

Methods

Because we were interested in mapping the incentives of the various operators throughout the system of brick production and use we deployed in-depth qualitative methods to explicate the perspective and worldview of the study subjects (Manning, 1997). Although closed-ended multiple-choice questions simplify mathematical summary of responses, such questions assume that study respondents share the researchers' cognitive framing. We wanted to avoid our preconceptions blinding us to our participant's viewpoint.

We conducted the study in two districts, Dhaka and Jessore, between November 2012 and March 2013 (Fig. 1). Although Dhaka was the main study site and has the largest number of brick kilns in the country, we selected one other city to look for differences in incentives for brick making.

Study population

A team of Bangladeshi anthropologists (led by DB) used standard qualitative methods to conduct in-depth interviews (DiCicco-Bloom and Crabtree, 2006) with brick buyers to explore their perspective on brick manufacturing in Bangladesh. The anthropologists targeted buyers who purchased many bricks, but also specifically included different types of buyers, including wholesalers, retailers, developers, and end users, to understand the perspective of various purchasers.

The anthropologists identified brick kiln owners for interviewing by using the anthropologists' own social networks and following recommendations from officials from the Bangladesh Brick Manufacturing Owners Association (BBMOA). Following the interviews, several brick kiln owners also provided contact information of additional kiln owners who would be willing to participate.

The study team met with the director general of the Department of Environment, Ministry of Environment and Forests of the Government of Bangladesh. The team requested information on the number and level of employees who were responsible for assessing compliance and enforcement of regulations of brick kilns and they requested access to frontline inspectors for interviews. The anthropologists interviewed all the employees available during the time of data collection of the Department of Environment in the Dhaka and Jessore offices who were responsible for enforcement of brick kiln regulations.

Data collection

The anthropologists conducted in-depth interviews with brick buyers, brick kiln owners, and government employees (Table 2). The anthropologists asked the brick buyers from whom they purchased bricks and their perspective regarding more environmentally friendly bricks.

Table 1
Government of Bangladesh brick kiln regulations and enforcement.

Year	Policy, law, regulation	Content[a]	Situation reported by study respondents
1989	Brick Burning (Regulation) Act	Kilns required license; firewood banned as fuel	Firewood is used less commonly
2001	Revision of Brick Burning (Regulation) Act	Kilns not allowed to be within 3 km of urban areas, residential areas gardens, or government forest reserves	Not enforced
2002	Revision of Brick Burning Rules	37 m fixed chimney kilns required	Many kilns switched to fixed chimney kilns. Older-style kilns with shorter chimneys no longer published in government reports, but approximately 500 operating
2007	Government of Bangladesh Notification	Environmental clearance certificates would not be renewed if kiln did not shift from coal to alternative fuel and improved technologies by 2010	Not enforced
2010	Government of Bangladesh Notification	Fixed chimney kilns banned by Dec 2012	Postponed

[a] From World Bank (2011).

Fig. 1. Field sites.

During interviews with brick kiln owners, the anthropologists explored the business of making bricks using fixed chimney kilns and selling the bricks in Bangladesh. They asked about financial flows, the kiln owners' relationship with government authorities, familiarity with laws that govern brick kilns, attitudes toward the pollution caused by kilns, and the reputation of brick kiln owners.

The anthropologists asked the government employees about the organizational structure of the office, their formal responsibility, the resources available for inspecting brick kilns, the process and timelines for inspections, their knowledge of and attitude toward regulations aimed at limiting environmental damage caused by brick kilns in Bangladesh and what they saw as barriers to implementing these regulations.

The anthropologists also visited 8 brick kilns to observe the brick-manufacturing process. These included 4 fixed chimney kilns (3 in Dhaka and 1 in Jessore) and 4 zigzag kilns (3 in Dhaka and 1 in Jessore). We oversampled zigzag kilns because the Department of Environment was encouraging kiln owners to adopt this technology at the time of the study.

Data analysis

Most interviews were audio recorded. When participants did not want conversations recorded, the anthropologists took detailed handwritten notes and, after completing the interview, expanded the handwritten notes. The anthropologists conducted all interviews and group discussions in Bengali, transcribed the recorded interviews and group discussions verbatim, and then summarized the interviews and group discussions (McLellan et al., 2003). While preparing summaries, the anthropologists translated the interviews into English. The anthropologists reviewed all the interviews and group discussions and manually coded them, looked for relationships between codes, and then grouped them accordingly to summarize the findings from interviews (Leech and Onwuegbuzie, 2007).

Table 2
Total sample size.

Target groups/data collection tools	In-depth interviews	
	Dhaka	Jessore
Brick kiln owners	15	5
Brick buyers	27	5
Government employees	8	1

Human subjects

The anthropology team explained the study to each of the study participants and took written informed consent. The study protocol was approved by the Ethical Review Committee of the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b).

Results

Brick buyer's perspective

Buyers described several types of bricks. The largest proportion of bricks on the market is *Bangla* bricks which are bricks that are molded by hand and fired in traditional kilns. Bricks that are fired in the center of the kiln are thoroughly fired, have the best strength, and are classified as grade A bricks. Kiln owners estimated that 50–55% of bricks fired in a fixed chimney kiln are grade A bricks. Buyers generally used these bricks for building walls. Approximately 10% of bricks are fired above and below the optimal center firing zone of the fixed chimney kilns, and are classified as B grade bricks. Purchasers commonly used grade B bricks to build outside boundary walls, foot paths, and courtyards. Grade C bricks, which constitute about 5% of production, are very low quality and are generally purchased by low-income households to use as flooring in animal sheds or in their home. Heavily fired bricks, especially those that are over-fired, are usually broken up into smaller pieces referred to as pickets. Pickets, which constitute 15–20% of the production of a fixed chimney kiln, substitute for stones, which are largely unavailable in Bangladesh. A layer of pickets underlies nearly all paved roads in Bangladesh. In addition, buyers mix pickets with cement to form concrete used throughout building construction.

Bricks that are machine molded and fired in a Hybrid Hoffman kiln have more consistent quality and shape and are referred to as auto bricks. Builders of custom homes in high-income neighborhoods and well-funded commercial buildings purchase auto bricks. "Ceramic" bricks is the name used for the highest-quality brick manufactured in Bangladesh. These are machine molded, are perforated with air spaces, exact in size, well fired, attractive, and have good strength. Builders use these bricks for beautification on the front of their most elegant projects. One purchaser explained, "We have different types of projects; such as diamond, golden, silver and rose. Generally, we use machine made bricks for diamond category apartment complexes which is very costly. Otherwise, we use 'bangla bricks' for other projects."

At the time of these interviews, brick purchasers reported the price per brick was 6–7 taka (US$0.07–US$0.08) for Grade A and 4.5–5 taka for Grade B (US$ 0.05–US$ 0.06); *bangla* bricks, 8.5–12 taka (US$ 0.10–US$ 0.14) for auto bricks and 18–20 taka (US$ 0.21–US$ 0.24) for "ceramic" bricks.

Both *bangla* bricks and auto bricks may be high quality. Most purchasers assessed the quality of bricks by evaluating their shape, size, and color. Bright red color indicated good quality. Other common assessments for brick quality include pressing their fingernail into the brick and seeing if it left an impression. If so, this was a low-quality brick. When purchasers struck two bricks against each other, a ringing sound indicated a high-quality, thoroughly fired brick.

Larger construction companies were interested in more thorough assessments of brick quality, because brick quality contributed importantly to customer satisfaction. They were interested in the salinity of soil used in making the brick and the water absorption capacity of the bricks. Soil salinity of fired bricks can lead to unsightly crystals forming on the brick surface. The water absorption capacity of the brick was evaluated by submerging the brick under water for 5–6 hours. If the brick absorbed more than 20% of its weight in water then it was considered a low-quality brick. Most large purchasers assessed the soil salinity and water absorption of bricks themselves, but some construction companies sent bricks to a laboratory for evaluation.

Some construction companies reported that they have purchased bricks from the same kiln owners for several years. Purchasers reported that they received a high-quality product at a good price and were spared the effort of visiting the brick kiln and assessing brick quality with each purchase. Some brick kiln owners even allowed their regular customers to purchase bricks on credit. One respondent said, “Normally we purchase bricks from a particular area, because of our familiarity with them. In the case of dealing with any new brick field, we have to visit that brick field regularly and have to assure the quality.”

The primary interest of brick buyers was securing bricks of appropriate quality for their project at a low price. Although brick buyers recognized that brick manufacturing generated substantial air pollution, environmental consequences were not a consideration in their brick purchases. They explained that there was a large need for new construction and considered bricks an essential building material. One purchaser said, “We, the consumers, are not liable for air pollution contributed by brick kilns. Our duty is to build houses and we need bricks to construct them. This is not our duty to observe which kiln is responsible for air pollution.” Brick buyers thought it was the government's responsibility to ensure that brick kilns were not generating excessive pollution.

Kiln owners' perspective

Most brick manufacturers preferred fixed chimney kilns. This technology has low capital costs. Brick kilns are not recognized as an industry in Bangladesh because they do not provide year-round employment and do not hold substantial fixed assets. Most fixed chimney brick kiln owners could not obtain industrial financing because their business was located on rented land and so did not have sufficient fixed assets to offer as collateral to banks. When loans were offered to kiln owners, they were at high interest. Brick kiln owners reported that banks charged them 15–17% annual interest for a 12-month loan. To raise the capital to build and operate a kiln, several Bangladeshi investors/businessman commonly pooled resources to open the kiln. Among our study informants, 2–10 investors pooled resources for each kiln.

Kiln owners reported that fixed chimney kilns returned their investment much faster than would be possible with other manufacturing approaches. They reported paying $100,000 to $125,000 in initial investment with $190,000–$250,000 per year in annual operating costs. They reported recovering their initial investment within 2–3 years. Kiln owners reported strong market demand for bricks fired in fixed chimney kilns. Over 80% of interviewed kiln owners had sold out their entire production inventory before the next season.

Fixed chimney kilns manufacture bricks during the dry season. This 6 months of kiln operation provides a perfect complement to agricultural laborers who find less work in the dry season. Operating only during the dry season also permits construction of kilns on floodplain lands, that is, lands that flood during the annual rainy season. Fixed chimney kiln owners reported using an average of 2.5 hectares (ha) including 0.8 ha for the kiln and 1.7 ha to dry green bricks before firing. Kiln owners near Dhaka reported that floodplain land costs between $100,000 and $300,000 per ha compared with a median $1,500,000 per ha for high land that does not flood. Floodplain land can be rented for $1500–$1850 per ha per season. By contrast, high land that does not flood during the rainy season rents for $8100–$14,000 per ha per season. The initial capital required to construct a fixed chimney kiln is low enough and the time required to recover the initial investment is fast enough that it is profitable to build a fixed chimney kiln on land rented through the widely available typical 5-year lease. Land tenancy is often contentious in Bangladesh. The owner of a fixed chimney kiln had much less capital at risk compared with the owner of a Hoffman kiln. Renting floodplain land also permitted kiln owners to hire inexpensive boats to carry soil and coal during the rainy season at much lower costs than land transport.

Kiln owners reported many additional advantages of fixed chimney kilns. Knowledge on how to build and operate the kilns was widespread. The only skilled position was the fireman, the person who adds the coal to the kiln, and even people with this experience were widely available. A fixed chimney kiln firing hand-molded bricks does not require electricity and so faces no loss of productivity when electricity is unavailable. Owners do not need to pay the cost of backup generators. Kiln owners also reported enjoying not having to work running the kiln during 6 months each year.

Owners explained that zigzag kilns were more expensive than standard fixed chimney kilns, and fewer people knew how to construct them. They reported that zigzag kilns cost approximately $190,000 to build new or $62,500 to upgrade an existing fixed chimney kiln to a zigzag kiln. Zigzag kilns require an electrical fan to pull the flue gas through the longer pathway. Because electricity is unavailable in many places and even when available does not run continuously, kiln owners require a diesel-powered electricity generator which requires extra investment and running costs. Owners also noted that a zigzag kiln required more laborers who were trained to work in zigzag kilns and so could demand more wages, which further increased operational costs.

The primary interest expressed by brick kiln owners was generating rapid substantial return on their investment. Brick kiln owners noted that since combustion creates pollution, it was an inevitable part of manufacturing bricks and so concluded that it was not their responsibility. They noted that fixed chimney kilns generated less pollution compared to the older Bull's trench kiln technology. All kiln owners reported using firewood to start the fire in the kiln at the beginning of the season and used coal as the principal fuel through the bulk of the season though three kiln owners reported using both firewood and coal during the year.

Department of Environment employees' perspective

The Department of Environment is part of the Ministry of Environment and Forests of the Government of Bangladesh. The head office is in Dhaka. There are 6 regional offices and 21 district offices among the 64 districts of Bangladesh. Each district level office has a post for an inspector who is responsible for inspecting environmental hazards including air pollution from brick kilns, industry, and vehicles; water pollution from industry; noise pollution from both industry and vehicles; and pollution from waste management. The Jessore District Office had posts for 2 inspectors, but at the time of the evaluation both posts were vacant. Indeed, 7 of the 11 posts in the Department of Environment at the Jessore District Office were vacant at the time of the evaluation. Respondents noted that salaries for government positions were lower than at private firms and technical positions, like chemists, were often vacant in the Department of Environment. District level inspectors had no enforcement authority. They report environmental hazards to the regional or central office who could enforce environmental regulation.

Upon receiving a reported violation by a brick kiln, the enforcement committee at the divisional or central level called brick kiln owners to the Department of Environment office and interrogated them regarding the evidence generated by the inspector. Enforcement options available to Department of Environment officials include giving the kiln owners a warning or a fine, referring them to the courts for prosecution, seizing materials, or demolishing the kiln(s).

Although the Department of Environment has the responsibility nationally for environmental enforcement, each district has a deputy commissioner who is drawn from the Bangladesh Civil Service and reports to the cabinet division which reports directly to the prime minister. The deputy commissioner has general authority for control of government activities in the district. Permits to construct brick kilns are issued by the deputy commissioner of the district, and the deputy commissioner's office also has a magistrate and the authority to enforce environmental policies.

The Department of Environment employees reported lacking the essential resources to effectively enforce regulations (Table 1). There was only a single vehicle dedicated to enforcement at the central office. They did not have a bulldozer to destroy illegal kilns. They did not have their own equipment for testing air quality. The chemists who were qualified to collect environmental samples worked in another department and were often unavailable in response to requests from the enforcement division.

They noted that, at times, the deputy commissioner's office issued a license for a brick kiln that was not compliant with the Government of Bangladesh brick kiln regulations (Table 1). The central office personnel reported that brick kiln owners often had connections to politically powerful people and that local Department of Environment employees accepted bribes in return for not reporting violations. They reported that the police were generally uninterested in enforcing environmental regulation and would refuse if the kiln owner had political connections. The staff reported that Bull's trench kilns were banned in 2002 and were no longer mentioned in any official Department of Environment report but that there were hundreds operating in many areas. One respondent noted, “I don't know details, but if there is no illegal transaction then how could these illegal brick kilns be operated?” Respondents from both the field and central office reported fear of losing their jobs if they took any action against someone with political power. They reported that sometimes the deputy commissioner did not cooperate with the enforcement staff to support an enforcement action, but because the deputy commissioner was a politically powerful person, they could not confront him. They reported trying to persuade brick kiln owners to comply without taking legal action by explaining what the regulations were and their importance for preserving the environment.

One of the brick kiln owners reported that a few years earlier there was a senior officer in the Department of Environment who had worked vigorously for the improvement of the brick sector and the environment including enforcement of regulations, but he was transferred out of this responsibility. The brick kiln owner said, “We don’t know why he has been transferred but we can assume that it was because he was a very strict officer. This is why some political figure requested the Ministry transfer him.”

Discussion

Although there have been several calls for transformation of the brick manufacturing sector in Bangladesh to larger, cleaner kilns (Croitoru and Sarraf, 2012; World Bank, 2011), these cleaner kilns produce a small minority of the total bricks on the market. Financial models developed by the World Bank suggest that over a 20-year timeframe, a modern Hoffman kiln selling higher-grade bricks can generate a per brick profit that is 9% higher than from a fixed chimney kiln (Croitoru and Sarraf, 2012), but the present study explains the strong economic incentives that underlay the current system of brick manufacturing. There is a strong demand for low-cost bricks with a much smaller market for expensive bricks. The cost of production for bricks fired in small seasonal fixed chimney kilns is substantially less than for bricks fired through a more modern Hoffman kiln that can produce bricks with less pollution per brick. This difference in cost of production is unlikely to change until labor becomes much more expensive because of the underlying lower costs for floodplain versus high land and for the construction of fixed chimney kilns compared with more efficient kilns. The shorter time required to achieve profitability and the high return on a more modest investment provides strong incentives for investment in traditional seasonal kilns.

Historically, the Bangladesh Department of Environment has not enforced regulations to reduce emissions from brick kilns (Table 1). Although firewood was banned as a fuel for brick manufacturing in 1989 and a 2007 Government of Bangladesh notification specified that environmental clearance certificates would not be renewed after 2010 unless brick kilns adopted alternative fuels rather than coal, each of the brick kiln owners interviewed for this study reported using firewood at least to start the kiln and coal as fuel. In 2001, the Government of Bangladesh amended the Brick Burning Regulation Act to prohibit the construction of brick kilns within 3 km of an urban area, but kilns are frequently located near residential communities (Nazneen, 2012). In 2002, the Government of Bangladesh introduced a rule banning older-style Bull's trench kilns that did not have at least a 37 m fixed chimney. While the older-style kilns are no longer mentioned in Government of Bangladesh reports, during this investigation, Department of Environment employees noted that there were hundreds of older-style Bull's trench kilns with shorter chimneys operating in Bangladesh.

The present investigation suggests that the Bangladesh Department of Environment is unable to enforce regulations for several reasons. First, the structure of the government where the deputy commissioner, who reports directly to political authority, issues the license to operate a brick kiln undermines the authority of the Department of Environment. The Department of Environment lacks bureaucratic autonomy and has little opportunity to develop technical expertise and a broad trusted reputation that would protect it from political influences (Carpenter, 2001). Indeed, the incentives of employees within the Department of Environment are not aligned with the public interest of breathing clean air. Employees received financial payments and career advancements in return for supporting the short-term financial gain of brick kiln owners at the expense of public welfare. The current financial incentives, institutional lines of authority and historical failure of enforcement of brick kiln regulation suggests that new regulations are unlikely to change the current equilibrium of producing low-cost bricks at a high cost to public health.

Although we did not interview political leaders for their perspective as part of this study, political leaders in Bangladesh generally support the financial interests of well-connected business owners, because such business owners provide financial support to politicians (Sobhan, 2004; Zafarullah and Siddiquee, 2001).

How do we break from the current equilibrium where each actor—brick purchasers, kiln owners, Department of Environment officials, and politicians—has no incentive to act differently? Weak institutional governance has long been recognized by political science scholars studying in Bangladesh (Ara and Khan, 2006; Khan, 2003; Zafarullah and Huque, 2001). Efforts to improve governance so that government action is more aligned with the public welfare rather than the interests of the politically connected elite is a laudable long-term goal but is unlikely to bring change quickly to the brick manufacturing sector. One specific step that could improve governance would be empowering the Department of Environment, rather than the deputy commissioner, with the authority to issue brick kiln licenses. In addition, increasing the technical capacity of the Department of Environment and policies and practices that encourage departmental leadership to retain skilled personnel, rather than frequently transferring staff, could strengthen the institution's capacity to support the public interest. Using limited government capacity and funds to train brick kiln managers in improved environmental management may be more effective and less corruptible than attempting to enforce punitive regulation (Dasgupta et al., 2000).

Technological innovation could help move the current equilibrium toward a healthier alternative. Improving the combustion efficiency of seasonal kilns could markedly reduce air pollution while simultaneously reducing coal consumption and improving kiln owner profitability. Potential strategies include improving the process of adding coal to the kilns either through automation or instituting smaller coal spoons so that combustion is more complete and/or pulverizing coal and mixing it with clay (Hossain et al., 2007). Mixing coal with clay internalizes the fuel. At high temperature in the kiln, the coal still combusts, but the heat is efficiently captured within the clay matrix and little particulate matter is produced (Heierli, 2008). Hollow or perforated bricks, that is, bricks with air space, require less coal to fire and when used for wall construction provide better insulation and so decrease demand for air conditioning (Heierli, 2008). Hollow bricks are currently manufactured using mechanical molders and fired in tunnel kilns. Adapting techniques for hollow brick manufacturing to seasonal kilns and marketing the value of hollow bricks to consumers could reduce the pollution generated per brick.

A properly constructed zigzag kiln improves heat transfer between fired bricks and "green" bricks before firing and so burns less coal per brick produced and generates less particulate matter than a fixed chimney kiln (Lalchandani et al., 2013; Maithel et al., 2012). Brick kiln owners noted that, in contrast to fixed chimney kilns, few people in Bangladesh knew how to properly construct a fuel efficient zigzag kiln. They also noted that zigzag kilns require an electrically powered fan to draw the air through the longer flue gas pathway. Such a fan with a backup diesel generator to keep the kiln running through frequent power outages requires additional upfront and operating costs. Engineers in India, however, have demonstrated that with proper chimney and kiln design, sufficient natural draft can be generated in a zigzag kiln without the need for an auxiliary fan (Lalchandani and Maithel, 2013; Lalchandani et al., 2013). These natural draft zigzag kilns generate more grade A bricks and less air pollution than a fixed chimney kiln. Converting a fixed chimney kiln to a natural draft zigzag kiln requires an investment on the order of $40,000, but this investment can be recouped within one season of operation because of reduced coal costs and the increased proportion of grade A bricks (Lalchandani et al., 2013).

Thus, there are several strategies to improve kiln efficiency that would save coal and money for the owners and reduce air pollution. The command-and-control strategy used by the Department of the Environment has been unsuccessful, but modest efforts to support technical improvements in kiln efficiency would generate large social benefits. Indeed, the large public health burden from air pollution justifies public investment to reduce this burden. A well-run public–private partnership could provide high-quality training to kiln owners and employees and offer loans for these improvements that would be repaid within one to two seasons through savings on coal expenditures.

The harmful impact on the environment could also be reduced by technologies that remove harmful elements from the kiln exhaust. The approaches used in high-income countries are effective (Franco and Diaz, 2009; Meij and te Winkel, 2004) but are prohibitively expensive for small brick producers in Bangladesh. Lower-cost low-maintenance approaches optimized for the context may provide a cost-effective improvement over the current situation though they would need to add little to the marginal cost of production in order to be affordable and acceptable to small business owners (Hettige et al., 1996). If these innovations are low cost and highly visible, kiln owners could be encouraged to adopt them both through formal regulatory requirements and through pressure from local residents and civil society groups. If an affordable treatment of exhaust were developed and endorsed by the government as a strategy for compliance with regulations, a public website of all brick kilns in the country using photographs to identify whether or not exhaust was being treated could empower civil society and the Department of Environment to encourage compliance.

There are important limitations to this study. As is typical for qualitative studies, the small number of study subjects was not selected using a method to ensure that they were statistically representative of all members of their group so there is a risk that their perspectives may not be representative of the larger group. The goal of qualitative research is to explore the perspective of study subjects in-depth. The perspectives that emerged provided a coherent and consistent explanation of observed behavior and suggest a basic model for how incentives interact. Social desirability bias may have resulted in underreporting illicit behavior. However, since several of the respondents mentioned these illicit activities, they likely affect system incentives and performance, even if their prevalence is imprecisely defined.

Taken together, these data suggest that in Bangladesh, the current equilibrium of low-priced bricks with high externalities to environment and health results from the structure of the underlying incentives of stakeholders. Although this assessment focused on Bangladesh, similar incentives are likely at the root of highly polluting brick-manufacturing industries across South Asia (Raut, 2003; Reddy and Venkataraman, 2002; Tahir et al., 2010). Transitioning these long-standing equilibria to alternative equilibria that produce less damage to health and the environment will require new approaches.

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