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Community Pressure and Clean Technology in the Informal Sector: An Econometric Analysis of the Adoption of Propane by Traditional Mexican Brickmakers*

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In many developing countries the informal sector, comprised of low-technology unlicensed micro-enterprises, is a major source of pollution. Environmental management in this sector is exceptionally challenging. Though clean technologies offer a means of mitigating the problem, to our knowledge there has been no rigorous empirical research on why informal (or even small-scale) firms do and do not adopt them. As a first step toward filling this gap, this paper presents the results of an econometric analysis of the diffusion of propane among informal "traditional" brickmakers in Cd. Juárez, Mexico—a leading source of air pollution owing to their reliance on cheap, highly polluting fuels such as used tires and scrap wood. The two key policy implications of our analysis are that: (1) it is possible to successfully promote the adoption of a clean technology by intensely competitive informal firms even when the new technology significantly raises variable costs, and (2) community pressure applied by competing firms and private-sector local organizations can generate incentives for adoption.

1. INTRODUCTION

Notwithstanding a recent explosion of interest in Third World environmental issues, to date there has been very little research on the problem of pollution emitted by "informal" firms—low-technology micro-enterprises operating outside the purview of the state. Such firms have multiplied rapidly during the last several decades as a consequence of persistent population growth, rural–urban migration, and government efforts to tax and regulate. Today they constitute a key economic sector in most developing countries. In Africa and Latin America they typically employ over half of the nonagricultural labor force [32] and are responsible for 20 to 40% of GDP [7]. A significant percentage of informal firms are engaged in

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industry, including pollution intensive activities such as tanning, brick and tile making, automotive repair, wood finishing, metalworking, electroplating, and small-scale mining. For example, in Mexico, 38% of informal firms are classified as industrial [35]. What little research exists confirms that informal firms can be serious polluters (e.g., [7, 14, 34]). Given the sheer number of such firms in developing countries, their aggregate impact on the environment is likely to be significant.

But pollution control in the informal sector is exceptionally challenging, even by developing-country standards, for four reasons. First, by definition, informal firms have few preexisting ties to the state. Second, such firms are difficult to monitor since they are small, numerous, and geographically dispersed. Third, intensely competitive informal firms are under considerable pressure to cut costs regardless of the environmental impacts. And finally, informal firms sustain the poorest of the poor. As a consequence, they may appear to both regulators and the public as less appropriate targets for regulation than larger, wealthier firms. Given these constraints, conventional command and control regulation is likely to be problematic if not completely impractical. To be effective, environmental management in the informal sector will have to be innovative.

Recently, clean technologies—new technologies that mitigate environmental impacts without significantly raising production costs—have received a great deal of attention as a means of surmounting barriers to conventional environmental regulation in developing countries. The hope is that firms will adopt such technologies voluntarily or at least with minimal prodding, easing the burden on regulatory authorities. General endorsements of clean technologies are contained in both the seminal 1987 Brundtland Commission Report to the U.N. [37], and the equally influential 1992 World Bank Development Report on Development and the Environment [36], and a number of anecdotal studies have emerged in the last several years (e.g., [1, 23]). Yet, to our knowledge, there has been no rigorous research on why informal firms (or even small-scale firms) do and do not adopt clean technologies. The well-developed empirical and theoretical literature on the diffusion of small-scale cost-saving innovations in developing countries is certainly broadly relevant, but it does not have much to say about the regulation, externalities, and peculiar political-economy considerations that undoubtedly have a significant impact on the diffusion of clean technologies. From a policy perspective, this gap in the literature is lamentable. Even though efforts to promote clean technologies among informal sector firms are already underway, we have virtually no empirical research to guide policy.

As a first step toward filling this gap we present the results of an econometric analysis of the diffusion of propane among informal ‘‘traditional’’ brickmakers in Cd. Juárez, Mexico. Our overall aim is to identify the principal determinants of the adoption of propane in Cd. Juárez and to explore the implications for environmental management in developing countries.

The two key policy implications of our analysis are that: (1) it is possible to successfully promote the adoption of a clean technology by intensely competitive informal firms even when the new technology significantly raises variable costs, and (2) community pressure applied by competing firms and private-sector local organizations can generate incentives for adoption, presumably even in the absence of formal regulatory pressure.

The paper is organized as follows. Section 2 provides some background on traditional brickmaking in Cd. Juárez. Section 3 reviews the literature on the adoption of clean technologies and small-scale productivity-enhancing technologies. Section 4 describes analytical and econometric models. Section 5 discusses the data. Section 6 discusses our results. Finally, Section 7 summarizes and concludes.

2. BACKGROUND: TRADITIONAL BRICKMAKING IN CD. JUÁREZ

Principally fired with refuse such as used tires and scrap wood that is often impregnated with toxic varnishes, Cd. Juárez's approximately 300 traditional brick kilns are frequently cited as the third or fourth leading contributor to air pollution in both Cd. Juárez and its sister city, El Paso, Texas.[2] Though brick kilns are primarily associated with carbon monoxide and particulate emissions, depending on the fuels used, they also emit volatile organic compounds, nitrogen oxide, sulfur dioxide, heavy metals, and carbon dioxide, the most important greenhouse gas [19]. Traditional kiln emissions constitute an urgent environmental problem as air quality in Cd. Juárez and El Paso is the worst on the U.S.–Mexico border and among the worst in North America [26].[3]

In addition to contributing to citywide pollution, traditional kilns are a serious local health hazard to those living in and near Cd. Juárez's eight brickmaking *colonias*.[4] When brickmakers first squatted in these *colonias* 25 or 30 ago, all were situated on the outskirts of the city. Over time, however, most have been enveloped by urban sprawl. As a result, brick kilns were the most frequent subject of complaints (one in every four) to the Cd. Juárez municipal environmental authority in 1994 [9].

Traditional brickmaking in Cd. Juárez is an extremely labor-intensive, low-technology activity. The four main tasks—mixing earth and clay, molding the mixture into bricks, drying the bricks in the sun, and firing them in a primitive adobe kiln—are all performed by hand. It is also very small-scale and low-paying. On average, each kiln has a capacity of approximately 10,000 bricks, employs six workers, and generates profits on the order of $100 per month.[5] Socioeconomic conditions are poor. The majority of brickmakers live next to their kilns in primitive houses with no sewers or running water. On average, kiln owners have three years of schooling and approximately a quarter are illiterate [12].

Most of Cd. Juárez's brickmakers are associated with one of two rival political factions. The first comprises organizations affiliated with the nationally dominant Institutional Revolutionary Party (PRI).[6] The second faction is dominated by the

[2] See, for example, [19, 25]. Though widely used, this statistic is undocumented. According to the Texas Natural Resources Conservation Commission, no emissions inventory has ever been performed for Cd. Juárez.

[3] In 1995 the city of El Paso was classified by the U.S. Environmental Protection Agency as a "moderate" nonattainment area for both carbon monoxide and particulate matter, and El Paso county was classified as a "serious" nonattainment area for ozone [28].

[4] These *colonias* are: Anapra, División del Norte, Francisco Villa, Fronteriza Baja, Kilómetro 20, México 68, Satelite, and Senecu 2.

[5] This compares to the March 1996 monthly minimum wage in the north of Mexico of about $64 [4].

[6] The three principal PRI affiliates are the Federation of Mexican Workers (CTM), the National Federation of Citizens' Organizations (FNOC), and the PRI-affiliated Brickmakers' Union.

Committee for Popular Defense (CDP) linked to the national Worker's Party. The (CDP) has traditionally been opposed to the political establishment and has resisted all attempts to regulate brickmaking. In a July 1995 survey of 76 owners and managers of brick kilns in Cd. Juárez (described below), 44% belonged to a PRI affiliate, 18% to the CDP, and the remaining 38% were independent.

In the early 1990s, a binational multisector coalition led by a Cd. Juárez−based nonprofit organization, the *Federación Mexicana de Asociaciones Privadas* (FEMAP), began an effort to introduce clean-burning propane into the brickmaking *colonias* of Cd. Juárez (for a detailed history of the project, see Blackman and Bannister [8]). Faced with a daunting array of obstacles including brickmakers' financing constraints, their seeming indifference to the adverse health impacts of burning debris, strong competitive pressures to use cheap dirty fuels, and a virtual absence of regulatory pressure, the coalition put in place a number of inducements and sanctions aimed at encouraging adoption. Local propane companies provided free access to the equipment needed to burn propane.[7] Universities developed technical extension and health education courses. To improve enforcement of a widely ignored ban on the burning of debris, the municipal government of Cd. Juárez set up a ''peer-monitoring'' mechanism wherein police were dispatched in response to citizen complaints about specific kilns burning toxic materials. Violators were fined and sometimes jailed.[8] Finally, project organizers worked with leaders of local trade and community organizations to pressure brickmakers to adopt propane. In March 1993, the leaders of key brickmaker organizations were brought together to hammer out an agreement on clean fuels and to set a deadline for the adoption of propane. The PRI affiliates were, in general, quite cooperative, enforcing strict rules on permissible fuels in some brickyards. One important impetus for adoption developed autonomously as adoption proceeded—in an effort to avoid being undercut by competitors using cheap dirty fuels, those brickmakers who adopted pressured their competitors to switch as well.

Though adoption was frustratingly slow at first, by October 1993, an estimated 40 to 70% of brickmakers in Cd. Juárez were using propane, a significant achievement given the obstacles involved. Unfortunately, almost all of this progress has been reversed since 1994 due to nationwide reductions of longstanding Mexican subsidies on propane and a consequent dramatic increase in the price of propane relative to debris. Though relatively short-lived, this episode of adoption offers a rare opportunity to study clean technological change in the informal sector.

Note that the adoption of propane is best viewed as technological change rather than simple fuel switching because most brickmakers who adopted incurred substantial fixed costs in doing so and also made significant adjustments to the production process. Fixed costs consisted of transactions costs, learning costs, the costs of procuring a burner (the one piece of equipment that propane companies did not supply), and, for most adopters, the costs of modifying the kiln to enable it to withstand the intense heat generated by propane.[9] A common change in the

[7] In most cases the equipment was attached to a trailer that was moved from kiln to kiln as needed.

[8] Though enforcement during this period was relatively vigorous, it was never universally effective; at least 30% of brickmakers continued to burn debris throughout.

[9] Modifications generally consisted of reinforcing kiln walls, rebuilding the firebox with high-quality brick, and/or changing the height of the fire box. Fifty-four percent of the adopters in our sample made such modifications.

production process was a reduction in the number of laborers hired to help fire the kiln, as propane eliminates the need to continuously shovel fuel into the firebox.

3. THE LITERATURE

This section briefly reviews relevant findings from the thin academic literature on the adoption of clean technologies in developing countries, as well as related literature on the adoption of clean technologies in industrialized countries, and on the adoption of small-scale productivity-enhancing technologies in developing countries.

The literature identifies two determinants of technological change that are unique to clean technologies: regulatory pressure and awareness of the private health benefits of adoption. The link between formal regulatory pressure and clean technological change is well established in the theoretical literature (for a review, see [10]) and, recently, a number of researchers have found some empirical evidence for it (e.g., [18]). Even though financial and institutional constraints often preclude effective formal environmental regulation in developing countries [36], a growing body of recent research shows that community pressure—also known as ‘‘informal regulation’’—applied by private-sector groups such as neighborhood organizations, nongovernmental organizations, and trade unions can substitute for formal regulatory pressure. For example, Pargal and Wheeler [27] analyze data on releases of water pollution by Indonesian factories during a period when there was no effective national regulation for water pollution and find that lower releases were correlated with a set of proxies for community pressure including per capita income, education, and population density in the vicinity of the plant (see also [15]).

A second potential determinant of clean technological change is awareness of the private health benefits associated with adoption. For example, in a review of studies on the determinants of the adoption of improved cooking stoves in developing countries, Barnes *et al.* [5] found that adopters often perceived reduced exposure to smoke to be the principal advantage of new stoves. Similarly, research on the diffusion of low-chemical pest control technologies shows that farmers often view reduced exposure to chemicals as an important benefit of adoption (e.g., [3]).

The well-developed empirical and theoretical literature on the adoption of small-scale productivity-enhancing innovations in developing countries (for reviews, see [13] and [11]) identifies a number of determinants of adoption that are potentially relevant including: input prices, firm size, credit availability, and human capital. Obviously, firms that face different input prices will have different technological preferences. For example, firms with access to cheap labor may prefer relatively labor-intensive technologies (e.g., [17]).

The majority of the evidence indicates that large firms adopt many new technologies faster than small ones (e.g., [16]). The most obvious explanation is that adoption involves fixed costs that imply economies of scale. Fixed costs may arise from a capital indivisibility or from more subtle informational and transactions costs [11].

Considerable evidence suggests that lack of access to credit is a binding constraint on technological change for small firms (e.g., [21]) even when fixed pecuniary costs of adoption are not large (e.g., [6]).

Finally, there is a good deal of empirical evidence to support a positive correlation between adoption of new technologies, on the one hand, and human capital as proxied by either education, experience, or exposure to extension services, on the other (e.g., [22]).

4. MODEL

This section develops analytical and econometric models of a brickmaker's choice between firing technologies that formalize the discussion of the determinants of clean technological change in Section 3. We assume that each brickmaker chooses a firing technology and a vector of input quantities to minimize the discounted present value of the total cost of firing a kiln load of premolded bricks subject to a production function. Brickmakers choose between a clean technology and a dirty one indexed by $i \in (c, d)$. Time is indexed by $t = (0, 1, \ldots, \tau)$. Total costs are comprised of variable costs and fixed costs. Variable costs, paid by both adopters and nonadopters, are equal to the dot product of a vector of input quantities, $\mathbf{X}_{it}$, and a vector of input prices, $\mathbf{V}_{it}$. In addition, adopters must pay a one-time fixed cost of adoption which is broken down into two components: (1) nonpecuniary fixed transactions and learning costs, $T_{c0}(\cdot)$, and (2) pecuniary fixed costs, $F_{c0}(\cdot)$. Nonadopters obviously do not pay fixed adoption costs but must pay fixed perceived health costs, H_{dt}, and fixed regulatory costs, $R_{dt}(\cdot)$, in each period. All recurrent costs—H_{dt}, $R_{dt}(\cdot)$, and $\mathbf{X}_{it}\mathbf{V}_{it}$—are discounted using a subjective discount rate, θ.

Some of the fixed costs are functions of underlying brickmaker characteristics. Pecuniary fixed costs are assumed to be decreasing in wealth, "w_t," since poor brickmakers lack collateral that would enable them to finance investment at prime interest rates. In addition, pecuniary fixed costs are assumed to be increasing in output, "y_t," since larger kilns require more modification. Nonpecuniary fixed costs are assumed to be decreasing in human capital, "u_t," since more educated and experienced brickmakers learn the new technology more quickly. Finally, regulatory costs are assumed to be an increasing function of formal government regulatory pressure, "g_t," and community pressure, "o_t."

The restricted production function, $y_{it}(\mathbf{X}_{it}; u_t, k_t)$, is a twice differentiable, increasing concave function of input quantities holding constant levels of human capital and physical capital, "k_t."

Thus the brickmaker's optimization problem may be written as

$$\min_{(X_{it}, i)} \int_0^\tau [X_{it}V_{it} + H_{it} + R_{it}(g_t, o_t)] e^{-\theta t}\, dt + F_{i0}(y_0, w_0) + T_{i0}(u_0) \tag{1}$$

s.t.

$$y_t = y_i(\mathbf{X}_{it}; u_t, k_t), \qquad t = 0, 1, \ldots, \tau,$$

where, for nonadopters

$$F_{d0}(w_0, y_0) = T_{d0}(u_0) = 0,$$

and, for adopters,

$$H_{ct} = R_{ct}(g_t, o_t) = 0, \qquad t = 0, 1, \ldots, \tau.$$

The brickmaker will choose vectors of cost-minimizing input quantities for each period, that, in turn, imply restricted (variable) cost functions of the form

$$C_{it}(k_t, u_t, \mathbf{V}_{it}, y_t), \qquad i = (c, d), t = 0, 1, \ldots, \tau. \tag{2}$$

Thus, the present discounted value of minimized total costs for each technology may be written as

$$D_i(g_t, k_t, o_t, u_t, \mathbf{V}_{it}, w_0, y_t)$$
$$= \int_0^{\tau} [C_{it}(k_t, u_t, V_{it}, y_t) + H_{it} + R_{it}(g_t, o_t)] e^{-\theta t}\, dt + F_{i0}(y_0, w_0) + T_{i0}(u_0),$$
$$i = (c, d). \tag{3}$$

In order to write D_i as a function of period 0 costs, we assume that brickmakers know the intertemporal paths of the costs H_{ct}, R_{ct}, and C_{it}.[10] More specifically, we assume that the time path of each of these costs may be described by an equation of the form

$$R_{ct} = R_{c0} f_R(t),$$

where $f_R(t)$ is a bounded, nonnegative function of time. Then total minimized costs may be written as

$$\begin{aligned} D_i(g_0, H_{i0} k_0, o_0, u_0, \mathbf{V}_{i0}, w_0, y_0) &= S_{iC} C_{i0}(k_0, u_0, \mathbf{V}_{i0}, y_0) + S_R R_{i0}(g_0, o_0) \\ &\quad + S_H H_{i0} + F_{i0}(w_0, y_0) + T_{i0}(u_0), \qquad i = (c, d), \end{aligned} \tag{4}$$

where

$$S_{iC} = \int_0^{\tau} f_{Ci}(t) e^{-\theta t}\, dt, \qquad i = (c, d),$$

$$S_H = \int_0^{\tau} f_H(t) e^{-\theta t}\, dt,$$

$$S_R = \int_0^{\tau} f_R(t) e^{-\theta t}\, dt.$$

The brickmaker chooses between the two technologies by calculating the difference between the present discounted value of the minimized total costs associated

[10] We require a model in which D_i is a function of period 0 costs because we do not have a panel of data that would enable us to estimate a true intertemporal model. The assumption that brickmakers know the intertemporal path of costs is less restrictive than the alternative assumptions that yield the same result: (a) agents choose a technology by simply comparing the costs and benefits that accrue in period 0 (e.g., [22, 33]) or (b) costs are stationary, in which case agents' input demands are identical in each period and the intertemporal model collapses to a static one. We are grateful to Billy Pizer for discussions on this point.

with each, a quantity we shall call I^*, that is

$$I^* = D_d(g_0, H_{d0}k_0, o_0, u_0, \mathbf{V}_{d0}, y_0) - D_c(k_0, u_0, \mathbf{V}_{c0}, w_0, y_0). \quad (5)$$

The brickmaker will adopt as long as $I^* > 0$. Using Eq. (4), I^* may be written as

$$I^* = S_{dC}C_{d0}(k_0, u_0, \mathbf{V}_{d0}, y_0) - S_{cC}C_{c0}(k_0, u_0, \mathbf{V}_{c0}, y_0) + \{S_H H_{i0} + S_R R_{i0}(g_0, o_0) - F_{i0}(w_0, y_0) - T_{i0}(u_0)\}. \quad (6)$$

Our econometric model is a reduced form of Eq. (6).[11] We estimate

$$I_j^* = \beta_d C_{dj}^* - \beta_c C_{cj}^* + \mathbf{Z}_j \boldsymbol{\gamma} + \varepsilon_j, \quad (7)$$

where

j	indexes individual brickmaking firms
I_j^*	is an unobserved latent variable
C_{dj}^*	us firm j's true variable cost of using the dirty technology
C_{cj}^*	is firm j's true variable cost of using the clean technology
$\mathbf{Z}_j$	is a vector of firm-specific variables that influence fixed costs
β_i	is a parameter
γ	is a vector of parameters
ε_j	is an error term[12]

Though I_j^* is latent and unobserved, we do observe an indicator variable, I_j, which takes the value of 1 if the clean technology is adopted and 0 otherwise; that is, we observe

$$I_j = 1 \qquad \text{if } I_j^* > 0,$$
$$I_j = 0 \qquad \text{if } I_j^* \leq 0.$$

Note that the observed variable cost depends on whether the brickmaker has adopted; that is, we observe

$$C_{cj}^* \qquad \text{if } I_j^* > 0,$$
$$C_{dj}^* \qquad \text{if } I_j^* \leq 0,$$

but we never observe both C_{cj}^* and C_{dj}^*. Therefore, in order to generate the variable cost terms in Eq. (7) for the entire sample, we estimate variable cost

[11] Our model is similar to those used by Pitt and Sumodiningrat [31] and Shrestha and Gopalakrishnan [33].

[12] Note that in order to estimate the model with our data, we are forced to make a number of assumptions and abstractions. First, we implicitly assume that the discount factors, S_{iCj}, S_{Hj}, and S_{Rj}, and therefore discount rates, q_j, are constant across brickmakers. We note, however, that the literature suggests that discount rates may vary considerably across producers [29]. Second, we abstract entirely from uncertainty which is often a significant influence on investment decisions [30] and may have been a factor here given movements in propane prices. If uncertainty about propane prices did discourage adoption, then our model is misspecified since our measure of the stream of variable costs associated with the clean technology, C_{cj}^*, does not include the monetized utility costs of this uncertainty. As a result, β_c may be biased away from 0. Finally, we abstract from variations in producers' risk attitudes which may also have been significant [2].

functions for adopters and nonadopters. We employ a simple restricted Cobb−Douglas functional form:

$$C^*_{cj} = \alpha_c + \mathbf{P}_{cj}\boldsymbol{\partial}_c + \mathbf{K}_j\boldsymbol{\psi}_c + \phi_c Y_j + \eta_{cj}, \tag{8}$$

$$C^*_{dj} = \alpha_d + \mathbf{P}_{dj}\boldsymbol{\partial}_d + \mathbf{K}_j\boldsymbol{\psi}_d + \phi_d Y_j + \eta_{dj}, \tag{9}$$

where

$\mathbf{P}_{ij}$	is a row vector of logarithms of variable input prices for each firm, some of which depend on i, the index of c, d
$\mathbf{K}_j$	is a row vector of measures of fixed factors
Y_j	is the logarithm output
α_i	is a parameter
ϕ_i	is a parameter
$\boldsymbol{\partial}_i$	is a vector of parameters
$\boldsymbol{\psi}_i$	is a vector of parameters
η_{ij}	is an error term

Equations (7), (8), and (9) constitute a simultaneous equation model. A simple recursive approach—estimating Eqs. (8) and (9) using ordinary least squares, using the parameters to generate the variable cost terms on the right-hand side of the adoption equation, and, finally, estimating the adoption equation as a probit—will *not,* in general, yield consistent parameter estimates due to sample selection bias. Technically, selection bias exists if the expected values of the error terms in the cost regressions, conditional on the choice of technology, are nonzero, that is, if $E(\eta_{ij} \mid I_j = 1) \neq 0$. Intuitively, selection bias may arise because we do not observe both C^*_{cj} and C^*_{dj} for each brickmaker in the sample; we observe C^*_{cj} only for one subset of the sample (adopters) and C^*_{dj} only for a second subset (nonadopters). These subsets are not likely to be randomly constituted. Rather, the group of adopters may well possess certain *unobserved* characteristics such as managerial skills and political ties that predispose them to have relatively low costs no matter which technology they use. Therefore, in a simple recursive model, selection bias could generate a spurious correlation between variable cost and adoption.

To correct for possible selection bias, we use the two-stage estimation procedure proposed by Lee [20]. The object is to adjust the error terms of the cost functions so that they have zero means. In the first stage, we substitute Eqs. (8) and (9) into Eq. (7) to obtain a reduced-form adoption equation:

$$I^*_j = \mathbf{P}_j\boldsymbol{\lambda}_1 + \mathbf{K}_j\boldsymbol{\lambda}_2 + \lambda_3 Y_j + \mathbf{Z}_j\boldsymbol{\lambda}_4 + \upsilon_j, \tag{10}$$

where the λ's are parameters or vectors of parameters and υ_{j} is an error term. In the second stage we use OLS to estimate,

$$C_{cj} = \alpha_c + \mathbf{P}_{cj}\boldsymbol{\partial}_c + \mathbf{K}_j\boldsymbol{\psi}_c + \phi_c Y_j + \delta_c\left\{-n(p_j)/N(p_j)\right\} + \mu_{cj}, \tag{11}$$

$$C_{dj} = \alpha_d + \mathbf{P}_{dj}\boldsymbol{\partial}_d + \mathbf{K}_j\boldsymbol{\psi}_d + \phi_d Y_j + \delta_d\left\{n(p_j)/\left[1 - N(p_j)\right]\right\} + \mu_{dj}, \tag{12}$$

where $N(\cdot)$ is the cumulative distribution function of the standard normal, $n(\cdot)$ is its density function, p_j is the predicted value of the indicator variable in (10), and δ_i is a parameter. As long as the joint density of η_{cj}, η_{dj}, and υ_j is multivariate normal, these modified cost functions will have the property that $E(\mu_{ij} \mid I_j = 1) = E(\mu_{ij} \mid I_j = 0) = 0$ and will yield consistent parameter estimates. We use Eqs. (11) and (12) to generate the predicted cost terms. Finally, we estimate Eq. (7) as a simple probit.

5. DATA AND VARIABLES

We use data from an original July 1995 survey of the owners or managers of 95 traditional brick kilns in Cd. Juárez.[13] Nineteen records were later dropped because of missing information, leaving 76 complete records. Table I presents summary statistics for the complete sample as well as for subsamples of adopters ($n = 47$) and non-adopters ($n = 29$). Since by July 1995 virtually every brickmaker in Cd. Juárez who had been using propane had already reverted to debris (again, due to the elimination of subsidies on propane) the survey solicited recall data for a uniform "base" month—October 1993—judged to be the month during which most brickmakers in Cd. Juárez were using propane.

[13] The survey was administered by personal interview. The interviews were conducted by the two co-authors and four paid assistants. Eighty-nine percent of the respondents in our sample were kiln owners and the remainder were managers. We interviewed managers only when kilns had absentee owners and declined to interview hired workers when managers were absent. Because they were relatively inaccessible, we did not sample in three of the eight brickmaking *colonias* in Cd. Juárez—Anapra, Fronteriza Baja, and Senecu 2. According to the Municipal Environmental Authority, only 9% of the kilns in Cd. Juárez are located in these *colonias* [9].

TABLE I
Variables in Econometric Model

		Adopters ($n = 47$)		Nonadopters ($n = 29$)		All ($n = 76$)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
	Endogenous						
LPG	Adopt (1/0)	1	0	0	0	0.62	0.49
VC	Variable cost ($\$N$)	927.05	297.64	380.65	174.84	718.55	370.16
	Exogenous						
BKYRS	Experience (yrs.)	18.04	10.98	12.33	8.91	15.86	10.56
EDYRS	Education (yrs.)	3.54	2.87	2.69	2.75	3.22	2.84
GREG	Aware govt. regs. (1/0)	0.74	0.44	0.79	0.41	0.76	0.43
HEALTH	LPG "healthier" (1/0)	0.17	0.38	0.03	0.19	0.12	0.33
HOUSE	Owns house (1/0)	0.87	0.34	0.83	0.38	0.86	0.35
CAPKLN	Capac. kiln (1000 bricks)	10.62	3.10	8.38	2.44	9.76	3.05
LORGPRI	Member PRI affil. (1/0)	0.60	0.50	0.21	0.41	0.44	0.50
LD-SAT	*Colonia* Satelite (1/0)	0.32	0.47	0.03	0.19	0.21	0.41
LD-M68	*Colonia* México 68 (1/0)	0.28	0.45	0.52	0.51	0.37	0.49
LD-K20	*Colonia* Kilo. 20 (1/0)	0.17	0.38	0.41	0.50	0.26	0.44
LD-FV/DN	*Colonia* F.V./D.N. (1/0)	0.23	0.43	0.03	0.19	0.15	0.37
PL	Price labor ($\$N$/firing)	104.06	34.45	97.14	53.21	101.42	42.39
PFP	Price LPG ($\$N$/1000 l)	414.77	117.22	n/a	n/a	414.77	117.22
PFD	Price debris ($\$N$/tkld)	n/a	n/a	147.37	70.17	147.37	70.17
TRK	Owns truck (1/0)	0.85	0.36	0.66	0.48	0.78	0.42

To estimate cost functions we use data on six variables: output (CAPKLN); two variable inputs, labor (L) and fuel (F); a measure of physical capital, truck ownership (TRK); and two measures of human capital, years making bricks (BKYRS) and years of formal education (EDYRS). Output is measured as the average number of standard-size bricks produced per firing less breakage (output is equal to kiln capacity since the kiln is only fired when full). Therefore, inputs are measured in units per firing. Quantity of labor is measured as the total number of workers used to fire the kiln adjusted for the contribution of the owner. If the kiln is fired with family or nonpaid labor, wages are those that the owner reported he would have paid for hired labor. Wages are in pesos ($\$N$) per laborer per firing.[14] For propane, quantity is measured in thousands of liters per firing. Prices are in pesos per thousand liters. For debris, quantity data were poor as the common metric was a truckload of variable size. We used survey data on total cost of debris per firing and price per truckload to derive quantity measured in an arbitrary unit we call ‘truckloads’. Prices are in pesos per truckload.

To estimate the probit adoption function, we use data on 13 variables that are associated with fixed health, regulatory, and transactions costs in the manner hypothesized in the analytical model presented previously in Section 3. Recall that fixed regulatory costs for the dirty technology are hypothesized to depend on both formal regulatory pressure and community pressure and, as discussed in Section 2, both types of pressure seem to have had some real impact. Unfortunately, finding a good exogenous firm-specific measure of formal regulatory pressure proved difficult. The most easily observed measure, incidences of enforcement, is obviously correlated with adoption since nonadopters are more likely to have experienced such incidences. We use a dichotomous variable that indicates simple knowledge of the existence of laws banning certain types of fuel (GREG).

Our proxy for community pressure, a dichotomous variable indicating membership in a PRI affiliated local organization (LORGPRI), purports to capture the pressure that PRI affiliates applied on their members to adopt propane. Recall that 44% of the brickmakers in our sample belonged to PRI-affiliated neighborhood and trade organizations which actively cooperated with efforts to promote the adoption of propane, in some cases enforcing strict rules on permissible fuels.

To proxy for perceived fixed health costs associated with burning debris, we use a dichotomous variable (HEALTH) indicating an affirmative response to the question, ‘‘Is burning propane healthier than burning debris?’’

Recall that, in the analytical model, fixed pecuniary transactions costs associated with adoption of the clean technology are a function of firm size and wealth, while non-pecuniary fixed transactions costs are a function of human capital. We use kiln capacity (CAPKLN) to proxy for firm size. To measure wealth, we use a dummy variable for home ownership (HOUSE). We use the same measures of human capital in the adoption regression as in the cost functions: years making bricks (BKYRS) and years of formal education (EDYRS).

[14] Note that most of the tasks involved in brickmaking other than firing—molding bricks, loading and unloading the kiln, and transporting bricks—are performed by hired laborers who are paid standard piece rates. As a result, there is very little variation in the per brick costs of these tasks across firms. Moreover, these tasks are functionally independent from firing. For these reasons, we assume that the cost function is separable between firing and the ‘‘piece rate tasks’’ and disregard the latter. Thus, the cost function gives the variable costs of firing, holding all other costs constant.

Finally, we control for fixed location effects in a separate model using location dummies for *colonia* Satelite (LD-SAT), *colonia* México 68 (LD-M68), *colonia* Kilómetro 20 (LD-K20), and an amalgamation of two small neighboring *colonias*, Francisco Villa and División del Norte (LD-FV/DN).

6. RESULTS

Table II presents the OLS selectivity corrected estimates of the parameters of the cost functions. Recall that the selectivity term is constructed from the residuals of a reduced-form probit (Eq. (10)) and, as a result, depends on the specification of the adoption equation. Therefore, we report cost function parameter estimates for each of our two adoption models.

For adopters, regression results are consistent across both models. Estimated coefficients for both input prices are significantly different from 0 at the 1% level and have the expected sign. None of the coefficients on either the output or the capital measures is significantly different from 0. The selectivity variable is significant in model 2.

For nonadopters, the estimated coefficient for labor prices is significantly different from 0 at the 1% level and has the expected sign in both models. However, the coefficient for fuel prices is not significantly different from 0 in either model. The most likely explanation is that, having been imputed from total costs, debris prices

TABLE II

Cost Function Estimates Corrected for Selection Bias

		Adopter		Nonadopter	
	Variable	Model 1	Model 2	Model 1	Model 2
	Intercept	−0.463	−0.015	2.445	2.722
		(1.135)	(1.108)	(2.023)	(2.210)
PL	Ln price labor	0.357***	0.385***	0.871***	0.821***
		(0.097)	(0.093)	(0.108)	(0.116)
PF	Ln price fuel	0.643***	0.615***	0.129	0.179
		(0.097)	(0.093)	(0.108)	(0.116)
CAPKLN	Ln output	0.177	0.137	−0.153	−0.188
		(0.122)	(0.118)	(0.222)	(0.243)
EDYRS	Education	0.014	0.014	0.009	0.005
		(0.015)	(0.014)	(0.023)	(0.025)
BKYRS	Experience	0.002	−0.001	0.008	0.008
		(0.004)	(0.004)	(0.007)	(0.008)
TRK	Owns truck	0.058	0.075	0.007	0.003
		(0.097)	(0.093)	(0.136)	(0.149)
$-n(p_j)/N(p_j)$ or	Selectivity	0.00005	0.02560*	0.035*	0.006
$n(p_j)/[1-N(p_j)]$	term	(0.00182)	(0.01313)	(0.018)	(0.013)
	Sample size	47	47	29	29
	F value	5.667	6.839	4.060	3.003
	Adj. R^2	0.378	0.432	0.396	0.300

***Significant at 1% level two-tailed test.
**Significant at 5% level two-tailed test.
*Significant at 10% level two-tailed test.

TABLE III
Average Predicted Variable Costs of Using Propane and Debris per 1000 Bricks ($*N*)*

	October 1993	July 1995 (imputed)
Propane	98.56	147.59
Debris	46.32	51.97
Ratio	2.13	2.84

n = 76.
*Average for models 1 and 2.

were measured with error.[15] None of the coefficients on the output or capital measures is significantly different from 0. The coefficient for selectivity variable is significantly different from 0 in model 1.

The cost functions confirm evidence indicating that propane was considerably more costly to use than debris. For the two models, the average ratio of the mean predicted variable cost of firing with propane to the mean predicted variable cost of firing with debris is 2.13 (see Table III). Evidently, any savings in labor costs that accrued to propane users were swamped by the higher energy costs.

Table IV reports the results of the two probit adoption models. Of our proxies for nonpecuniary transactions costs associated with adoption—years of experience (BKYRS) and years of education (EDYRS)—the coefficient on the former has the expected sign and is significantly different from 0 at the 1% level in both models, and the coefficient on the latter has the expected sign and is significantly different from 0 at the 5% level in the second model.[16] Thus more experienced brickmakers and more highly educated ones were more likely to adopt.

The coefficients on our proxies for pecuniary transactions costs associated with adoption—house ownership (HOUSE) and kiln size (CAPKLN)—are insignificant in both models. This result is not surprising. Other studies have found that wealth and firm size are correlated with adoption when adoption entails substantial fixed pecuniary costs that large wealthy firms can pay more easily than small poor firms. But in the present case, local community groups heavily subsidized the fixed pecuniary costs of adoption by providing free propane equipment, greatly reducing the advantages conferred by size and wealth.[17]

The coefficient on our proxy for the perceived fixed health costs associated with burning debris (HEALTH) has the expected sign and is significantly different from 0 at the 10% level in both models. Though suggestive, this result should be interpreted cautiously for two reasons. First, only 8 of the 47 adopters in our

[15] Measurement error would also explain why estimated cost shares for fuel seem to be biased downwards: The estimates are 13% and 18% while the actual average cost share is 57% percent.

[16] The insignificance of years of education in model 1 which does not control for location effects suggests that this variable is a good predictor of adoption within *colonias* but not across them.

[17] Note that our finding that wealth is not a significant predictor of adoption is robust to our choice of a wealth proxy. Our data set includes dummy variables indicating whether each brickmaker owns a television, a fan, a car, and a truck, and whether each has an alternative source of income. When substituted for HOUSE in the adoption regressions, none of these dummy variables were significantly correlated with adoption.

TABLE IV
Probit Adoption Function Estimates

	Variable	Model 1	Model 2
	Intercept	−2.476**	−0.698
		(1.121)	(1.459)
BKYRS	Experience	0.052***	0.056***
		(0.020)	(0.022)
EDYRS	Education	0.090	0.197**
		(0.070)	(0.093)
HEALTH	LPG "healthier"	1.293*	1.302*
		(0.766)	(0.812)
HOUSE	Owns house	0.375	0.066
		(0.540)	(0.668)
GREG	Aware city regulations	−0.655	−0.433
		(0.454)	(0.536)
CAPKLN	Capacity of kiln	0.095	0.095
		(0.082)	(0.099)
PVCLP	Predicted cost LPG	0.026	0.028
	($*N* 100)	(0.138)	(0.170)
PVCD	Predicted cost debris	0.076	−0.091
	($*N* 100)	(0.175)	(0.233)
LORGPRI	Member PRI affiliate	0.908**	0.481
		(0.414)	0.502
LD-SAT	*Colonia* Satelite		0.033
			(1.045)
LD-M68	*Colonia* México 68		−1.916**
			(0.817)
LD-K20	*Colonia* Kilo. 20		−1.383**
			(0.796)
	Sample size	76	76
	Log likelihood	−35.421	−29.267

***Significant at 1% level two-tailed test.
**Significant at 5% level two-tailed test.
*Significant at 10% level two-tailed test.

sample believed that firing with propane was healthier than firing with debris, so that this belief cannot have played a role in the adoption decisions of most brickmakers. Second, this result does not necessarily imply that brickmakers who believed that burning propane was relatively healthy adopted propane as a result. The causation may have run in the opposite direction: adopters may have concluded that propane was healthier than debris after they adopted.

The coefficients on our predicted variable costs terms are not significantly different from 0 in either model. We strongly suspect that at bottom this result stems from the fact that, though our price and quantity data are undoubtedly noisy, *true* cross-sectional variation in factor prices and factor productivities was limited because factor markets within Cd. Juárez were competitive and simple firing technologies were more or less uniform across brickmakers. As a result, the ratio of the per-brick variable costs associated with the two technologies was approximately 2 to 1 for all brickmakers. Hence, cross-sectional differences in variable costs did not drive the pattern of adoption observed in October 1993. Rather, this pattern was shaped by cross-sectional differences in fixed costs, namely, regulatory costs, perceived health costs, learning costs, and transactions costs.[18]

Given the evident lack of true cross-sectional variation in variable costs, our cross-sectional analysis cannot tell us much about the sensitivity of adoption to changes in variable costs. However, we can get a rough idea of this sensitivity by noting that in July 1995, by which time propane had disappeared from the brickyards of Cd. Juárez, the ratio of the per-brick variable costs of using propane versus debris was 25% higher than it had been in late 1993 when the majority of brickmakers were using propane (see Table III).[19] Thus, the 2 to 1 ratio of per-brick variable costs that existed in October 1993 was probably approximately the maximum that was politically sustainable.

The coefficient on our proxy for the formal regulatory costs associated with burning debris (GREG) is not significantly different from 0 in either model. We suspect that the data for GREG were corrupted by measurement error. Though almost one quarter of our survey respondents claimed to have been ignorant of any formal regulation regarding permissible fuels, leading us to believe that GREG would be a good proxy for formal regulatory pressure, there are indications that a number of these respondents were feigning ignorance, perhaps because they were hesitant to admit awareness of rules that had been violated. If this is, in fact, what happened (i.e., if virtually the entire sample was aware of government regulation), then GREG, even if accurately measured, would not be a particularly good proxy for formal regulation.

Finally, in model 1, our proxy for the informal regulatory costs associated with burning debris (LORGPRI) is significantly different from 0 at the 5% level. This suggests that community pressure brought to bear by PRI-affiliated local organizations played an important role in brickmakers' adoption decisions.

But alternative explanations are possible. Since membership in PRI-affiliated local organizations is correlated with location (see Table V), LORGPRI may proxy for location-specific effects that promote adoption. To test this hypothesis, we introduce location dummies in model 2. In this new model, the coefficient on LORGPRI is not significantly different from 0 but the coefficients on two of the three location dummies are. This suggests that location-specific effects were, in fact, important.

What exactly were these location-specific effects? One candidate is localized information dissemination, long a principal focus of technology diffusion research (e.g., Mansfield [24]). Put more concretely, the spatial concentration of adoption may have stemmed from the fact that brickmakers in *colonias* where a select few adopted early on were able to acquire information about the new technology from their neighbors at relatively low cost and were therefore apt to adopt themselves.

A second possibility is that the spatial concentration of adoption arose from a type of community pressure that is not captured by LORGPRI: the pressure to

[18] Note that this finding does not imply that *intertemporal* changes in variable costs had no effect on brickmakers' adoption decisions—they obviously did—only that *cross-sectional* variation in variable costs does not explain which brickmakers had adopted in October 1993 and which had not.

[19] We are grateful to an anonymous referee for suggesting this comparison. For 1995 factor quantities, we used 1993 values. For 1995 debris and labor prices, we used actual survey data on 1995 prices. For 1995 propane prices, we used 1993 values adjusted by a growth factor based on a propane price series that FEMAP has provided. Finally, we assumed that kiln capacity, years of education, years of brickmaking experience, and number of trucks are the 1993 levels.

TABLE V
Survey Respondents, Percentage Adopters, and Percentage PRI Affiliate Members by *Colonia*

Colonia	Survey respondents	Percentage adopters	Percentage PRI affiliate members
México 68	28	46**	36
Kilómetro 20	20	40*	20*
Satelite	16	58	58**
F. Villa/D.d. Norte	12	92*	42
All	76	62	43

$n = 76$.
*Significantly different from sample mean at 5% level.
**Significantly different from sample mean at 10% level.

switch to propane that adopters placed on all nonadopters—regardless of their political affiliation—to avoid being undercut by brickmakers using cheap dirty fuels. The intensity of this pressure would have been location-specific since the proportion of adopters differed markedly across *colonias* (see Table V).

A third possibility is that community pressure applied by local organizations did actually drive the spatial pattern of adoption, but that location dummies capture this effect better than LORGPRI. This could happen if, in *colonias* like Francisco Villa that were dominated by PRI affiliates, PRI leaders were able to induce brickmakers of all political persuasions to adopt.[20]

Ultimately, our data do not allow us to disentangle the impacts of localized information dissemination and community pressure in the econometric analysis. However, additional survey data support the hypothesis that community pressure was, in fact, an important, if not a critical, determinant of adoption. Twenty-five percent of the adopters we surveyed identified "outside pressure" as the "most important" factor affecting their decision to adopt, as high a percentage as chose any other factor, while only 9% picked "information provided by various parties" (see Table VI). In addition, 64% of the 48 local organization members we surveyed said that a local organization (not necessarily their own) had an influence on their current (July 1995) choice of fuels, and a third of these respondents volunteered the information that the local organization prohibited the use of dirty fuels such as tires and plastics. We would expect that, in October 1993 at the height of the propane initiative, pressures applied by local organizations to burn clean fuels would have been stronger and more pervasive.

7. CONCLUSION

To sum up briefly, our econometric results indicate that, first, on average, the variable cost of burning propane was over two times greater than the variable cost of burning debris in October 1993. Second, the adoption of propane was correlated

[20]Access to propane equipment did not differ significantly across *colonias*, and is therefore not likely to have driven the spatial concentration of adoption. Our survey data suggest that access to equipment was universal; every adopter in our sample acknowledged using free equipment and no nonadopters cited lack of access to equipment as having played a role in their decision not to adopt.

TABLE VI
Seven Factors Affecting Adoption: Percentage of Adopters Identifying Each as "Most Important"

Factor	Percent
Outside pressure	25
Good for environment	25
Access to free LPG equipment	21
Info. provided by city *et al.*	9
LPG is more convenient	8
LPG suppliers extended credit	6
Other	7
	100%

$n = 44$.

with the brickmakers' human capital, awareness of the health costs of burning debris, location, and (most likely) exposure to community pressure. And, finally, for the reasons discussed previously, we observed no significant correlation between adoption and our measures of the brickmakers' wealth, firm size, exposure to government regulation, and variable costs. What are the policy implications of these findings?

One important implication is that it is possible to successfully promote the adoption of a clean technology by intensely competitive informal firms even when the new technology significantly increases variable costs and imposes considerable one-time fixed costs. In Cd. Juárez, this success was the result of an organized effort to simultaneously lower the fixed costs of adoption and raise the costs of nonadoption by supplying equipment, training, and education free of charge, and by ratcheting up both formal and informal penalties for continuing to burn debris.

Our finding that the adoption of propane is likely to have been correlated with the intensity of community pressure extends a growing body of recent research that shows that even in countries where financial and institutional constraints preclude effective public-sector monitoring and enforcement, community pressure can take up at least some of the slack. Most of the existing research concerns large-scale polluters and some authors (e.g., [1]) have suggested that since small-scale firms have a relatively low profile and are generally viewed more sympathetically than large firms, they are not likely to be susceptible to community pressure. Our findings suggest otherwise.

Ironically, one reason that community pressure may work in the informal sector has to do with the intense competition among small-scale firms. In Cd. Juárez, adopters were at a competitive disadvantage compared to nonadopters. Therefore, they had an incentive to ensure that, at very least, neighbors and fellow union members switched to propane as well. This suggests that, in general, if enough informal firms can be convinced by hook or crook to adopt a clean technology, eventually competition will ensure that diffusion becomes self-perpetuating, even if the clean technology is cost increasing.

Several qualifications regarding community pressure in the informal sector are in order. First, as discussed previously, since we are not able to disentangle the impacts of location-specific information effects from community pressure our results must be interpreted cautiously. Second, our results should not be interpreted as evidence that community pressure can be effective absent public sector support since in Cd. Juárez the municipal government was instrumental in providing both carrots and sticks that led PRI affiliated organizations to cooperate with the propane effort. Third, in our case study, effective community pressure depended largely on the fact that neighbors could easily observe violations because they could see or smell emissions from burning debris. Other types of informal sector pollution, such as the dumping of waste oil into sewers by mechanics is not as easy to detect.

Finally, our finding that the adoption of propane was correlated with human capital and was weakly correlated with the perception that burning debris is relatively unhealthy echoes the conclusions of other studies of technological change in developing countries and suggests that training and education, in particular the dissemination of information about the health risks associated with dirty technologies, can be an effective means of promoting adoption.

APPENDIX: NOTATION

Analytical Model

c	clean technology
d	dirty technology
$f_{iC}(t)$	time path of variable costs of technology i
$f_R(t)$	time path of regulatory costs
$f_H(t)$	time path of health costs
g_t	formal regulatory pressure
i	index of technologies
k_t	physical capital
o_t	community pressure
t	index of time
u_t	human capital
w_t	wealth
y_t	output
$y_{it}(\cdot)$	restricted production function
$C_{it}(\cdot)$	minimized variable cost of technology i
$D_i(\cdot)$	minimized p.d.v. of total cost of technology i
$F_{it}(\cdot)$	pecuniary fixed adoption cost
H_{it}	fixed perceived health costs
I^*	difference between the minimized p.d.v. of total cost of each technology
$R_{it}(\cdot)$	fixed regulatory costs
S_{iC}	discount factor for minimized variable costs of technology i
S_R	discount factor for regulatory costs
S_H	discount factor for health costs

$T_{it}(\cdot)$	nonpecuniary fixed transactions and learning costs
$\mathbf{V}_{it}$	vector of input prices
$\mathbf{X}_{it}$	vector of input quantities
$\mathbf{X}^*_{it}(\cdot)$	vector of factor demands for technology i
θ	discount rate
τ	time horizon

Econometric Model

$n(\cdot)$	standard normal probability distribution function
p_j	predicted probability of adoption from reduced-form adoption regression for firm j
j	index of individual brickmaking firms
C^*_{ij}	logarithm of firm j's true variable cost of using technology i
$N(\cdot)$	standard normal cumulative distribution function
I^*_j	true difference between the minimized p.d.v. total cost of the two technologies to firm j (unobserved)
I_j	indicator variable equal to 1 if firm j adopts and 0 if it does not
$\mathbf{K}_j$	vector of measures of fixed factors for firm j
$\mathbf{P}_{ij}$	vector of logarithms of variable input prices for firm j, some of which depend on i
Y_j	logarithm of output for firm j
$\mathbf{Z}_j$	vector of variables that influence fixed adoption costs for firm j
α_i	parameter (intercept of technology i cost function)
β_i	parameters (coefficients on variable cost terms in adoption regression)
$\boldsymbol{\gamma}$	vector of parameters (coefficients on variables that influence fixed costs in adoption regression)
$\boldsymbol{\partial}_i$	vector of parameters (coefficients on prices in technology i cost function)
ε_j	error term for firm j (adoption regression)
η_{ij}	error term for firm j (technology i cost function)
$\boldsymbol{\lambda}_1, \boldsymbol{\lambda}_2, \lambda_3, \boldsymbol{\lambda}_4$	parameter or vectors of parameters (coefficients of terms in reduced-form adoption regression)
μ_{ij}	error term for firm j (selectivity corrected technology i cost function)
δ_i	parameter (coefficient on selectivity term in technology i cost function)
υ_j	error term for firm j (reduced from adoption regression)
ϕ_i	parameter (coefficient on output in technology i cost function)
$\boldsymbol{\psi}_i$	vector of parameters (coefficients on measures of fixed factors in technology i cost function)

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