Clean Technological Change in Developing-Country Industrial Clusters: Mexican Leather Tanning

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Abstract

In many developing country cities, clusters of small and medium enterprises create severe pollution problems. Because conventional regulatory approaches are typically ineffective in such situations, policy responses have increasingly focused on promoting voluntary clean technological change. Yet the data and analysis needed to guide such efforts are scarce. This paper uses original firm-level survey data on a cluster of small- and medium-scale leather tanneries in León, Guanajuato—Mexico's leather capital—to econometrically identify the factors that drive the adoption of two clean tanning technologies. Using a multivariate probit model to estimate a system of seemingly unrelated regressions, we find—in contrast to conventional wisdom—that neither firm size nor regulatory pressure is positively correlated with adoption. Rather, the key driver of adoption is the firm's human capital, the same factor that often explains conventional productivity-enhancing technological change. We also find that a private-sector trade association is an important sources of technical information about clean technologies.

Key Words: clean technology, developing country, small and medium enterprises, Mexico, multivariate probit

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1. Introduction

In developing countries, small and medium enterprises (SMEs) typically dominate certain pollution-intensive economic sectors. As a result, they are often leading contributors to environmental degradation. For example, in Ecuador, where 80% of the industrial labor force is employed in firms with ten or fewer workers, SMEs are responsible for over 90% of total water pollution associated with vehicle repair and the manufacture of furniture, iron goods, processed foods, pulp and paper, and textiles (Lanjouw 1997). SMEs create particularly severe environmental problems when they are geographically clustered. For example, emissions of particulate matter from a collection of 350 small-scale brick kilns in Ciudad Juárez, Mexico, cause over a dozen cases of premature mortality and hundreds of cases of respiratory illness annually, damages valued at $20-90 million (Blackman et al. 2000).

Unfortunately, conventional regulatory instruments are generally ineffective in dealing with such problems. Clusters of SMEs large enough to create pressing pollution problems usually have the political power to deflect efforts by local authorities to enforce environmental regulations. Also, the political will needed for enforcement is often weakened by the perception that, as a leading employer of the poor, SMEs fulfill an important distributional function. Politics aside, enforcing environmental regulations in industrial clusters is difficult because SMEs are

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exceptionally numerous and because many are “informal,” that is, virtually anonymous to the state (Blackman 2000).

Given these constraints on conventional regulation, a promising strategy for controlling SME pollution is to promote the adoption of clean technologies that prevent pollution and either reduce production costs or do not raise them significantly. The hope is that firms will adopt clean technologies voluntarily or at least with minimal prodding. This approach has received considerable attention as a means of surmounting all manner of barriers to conventional environmental regulation in developing countries (United Nations 2002; World Bank 1992 and 1998; World Commission on Environment and Development 1987).

Notwithstanding widespread enthusiasm for clean technologies in policy circles, there has been little empirical research on why developing country firms—and SMEs in particular—do and do not adopt them. Such research can help stakeholders design polices to promote clean technologies. The literature on the diffusion of cost-saving innovations among SMEs in developing countries is broadly relevant, but it does not have much to say about the regulation, externalities, and peculiar political-economy considerations that affect the diffusion of clean technologies. One reason for the lack of research in this area is that hard data on clean technology adoption are scarce.

This paper uses original firm-level survey data on a sample of 145 small- and medium-scale leather tanneries in León, Guanajuato (Mexico), to econometrically identify the determinants of the adoption of two clean tanning technologies. León is an archetype of a city where clean technological change represents the best hope for controlling emissions from a SME industrial cluster. The city’s leather tanneries have severe environmental impacts and attempts to mitigate the problem using command-and-control regulation have repeatedly failed. Recently however, a significant percentage of León’s tanneries have voluntarily adopted clean technologies. Ours is the first attempt to explain this phenomenon and distill policy prescriptions.

This paper makes two contributions to the literature. First, as discussed above, it fills a gap in the literature (reviewed in Section 3 below) on the determinants of clean technological change in developing countries. Contrary to this literature, we find that that neither firm size nor top-down regulatory pressure are positively correlated with adoption. Rather, a key driver of adoption is the firm's human capital, the same factor that often explains conventional productivity-enhancing technological change. Also, we find that a private-sector trade association is a critical source of technical information about clean technologies.

Second, this paper sheds light on a broader concern in the literature about whether and how private-sector institutions can be used to help improve environmental performance in countries where public-sector regulatory institutions are weak. Proponents of this approach argue that community associations and non-governmental organizations can bring political pressure to bear. In addition, trade associations and business contacts can provide technical assistance in pollution control (World Bank 1999). We find evidence for the second mechanism, but not the first.

In terms of methodology, this paper belongs to the relatively thin empirical literature on the adoption of multiple complementary—as opposed to mutually exclusive—technologies. We review this literature in Section 3 below. We use a multivariate probit model to estimate a system of seemingly unrelated adoption equations.

The remainder of the paper is organized as follows. The next section provides background on leather tanning in León. Section 3 briefly reviews the literature. Section 4 develops our econometric model. Section 5 discusses data. Section 6 presents our results, and the last section offers our conclusions.

2. Background

2.1. Efforts to regulate leather tanning in León

The city of León in north-central Mexico produces about two-thirds of the country's leather. Almost all of it is used in shoemaking, León's other hallmark industry. Although exact numbers are not known, local regulators estimate that León is home to approximately 1,200 tanneries. At least three-quarters of these tanneries are small-scale, employing fewer than 20 workers, and about a quarter are unregistered and informal (Villalobos 1999).

Historically, León's tanneries have dumped untreated effluents directly into municipal sewers that then deposit them into the Gómez River, a tributary of the Turbio. The main pollutants from tanneries are salt (used to preserve raw hides), various chemical compounds of sulfur (used to de-hair hides), chromium III—commonly known as chrome—(used to render hides biologically inert), dissolved and suspended solids, and solid wastes impregnated with tanning chemicals. The pollution has contaminated surface and groundwater and has damaged irrigated agricultural land. A 1987 study found chromium VI—a highly toxic by-product of chromium III—in three-quarters of the city's drinking water wells (Hernández 1987). León's water pollution problems attracted international attention in 1994 after a die-off of tens of thousands of migratory aquatic birds wintering in a local reservoir contaminated by the city's wastewater (Commission for Environmental Cooperation 1995).

Regulations governing tannery pollution have been on the books for decades. Among other things, they require tanneries to register with environmental authorities, install sedimentation tanks and water gauges, handle most solid wastes as hazardous materials, and—most important—pre-treat wastewater so that daily concentrations of various pollutants do not exceed set standards. For the most part, however, these regulations are simply not enforced. By all accounts, the main reason is that leather tanneries are a mainstay of the local economy and therefore enjoy considerable political power.

Concerted efforts to truly control tannery pollution in León began in July 1987 when tannery representatives signed a voluntary agreement to comply with written regulations within four years. But when it became apparent in 1991 that the tanners had not taken any action aside from installing crude sedimentation tanks desperately needed to prevent sewers from clogging, the agreement was renegotiated.[1] In October 1991 a new voluntary agreement essentially granted tanners a second three-year grace period. It also committed the city of León to build both a common effluent treatment plant for biological (but not chemical) wastes and a facility for

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[1] Sedimentation tanks are the only end-of-pipe abatement devices commonly used in León. These inexpensive, low-technology concrete barriers enable suspended solids to settle out of waste streams. To prevent the city's sewers from clogging, the municipal water authority (SAPAL) has strictly enforced regulations requiring sedimentation tanks since the late 1980s.

handling solid and hazardous wastes. By the end of this second grace period, these facilities had not been built, and tanneries had made no progress in reducing discharges. A third voluntary agreement was negotiated in June 1995 and a fourth in March 1997. None of these efforts produced any concrete progress in treating tannery industrial wastes.

For the most part, public-sector ineffectiveness in using top-down pressures to force compliance with environmental regulations has been matched by private-sector disinterest in and resistance to such strategies. Interviews and focus groups with a wide variety of stakeholders in León—including environmental advocates, tanners, politicians, and regulators—indicated that environmental advocacy groups and neighborhood organizations have not placed significant overt pressure on tanners to improve their environmental performance.

Surprisingly, the one exception in this regard has been the Cámara de la Industria de Curtiduria del Estado de Guanajuato (CICUR), the principal trade organization representing León's tanners. Notwithstanding its continued opposition to promulgating and enforcing pollution control regulations, CICUR has encouraged—and on occasion even pressured—its members to cut pollution. In addition, it has promoted clean technological change in meetings and trade publications (*Dinámica de la Curtiduría*, various years).

Given that León's tanneries have yet to install end-of-pipe treatment facilities needed to comply with emissions standards, to date the most significant progress in controlling tannery emissions has resulted from the voluntary adoption of clean tanning technologies which are not specifically required by law. The next section provides background on these technologies, as well as a brief overview of the process of leather tanning.

2.2. Clean tanning technologies

Leather tanning consists of two meta-processes: wet blue production and finishing. The former involves removing unwanted substances (salt, flesh, hair, and grease) from a cured raw hide, trimming it, treating it to impart the desired grain and stretch, and finally soaking it in a chrome bath to prevent decomposition.[2] Finishing involves splitting, shaving, re-tanning and dying the wet blue. The wet blue process and finishing process are technologically and economically separable and many tanneries in León specialize in one or the other.

The wet blue process is far more polluting than finishing, generating 90% of the water pollution associated with leather tanning. Two substages of this process are particularly dirty: de-hairing in which raw hides are soaked in a bath of lime and sodium sulfide to dissolve hair and flesh and chrome tanning in which hides are soaked in a chrome bath to render them biologically inert.[3]

Both of the clean technologies we consider are associated with chrome tanning (for technical details, see UNEP 1991). The technologies are:

1. Precipitation. Using alkalis to precipitate out the chrome in the tanning bath, collecting the resultant sludge and processing it with sulfuric acid to recover the chrome. This process can be done either by letting the sludge form overnight in a holding tank or by using a device called a filter press. Some adopters contract out the sludge processing stage to chemical supply companies.
2. Recycling. Reusing the contents of the chrome bath instead of discharging them into the sewer after a single use. The recycled bath must be tested and its chemical composition readjusted prior to reuse. Recycling only requires fixed investments in a holding tank, a pump, and a filtering system to remove suspended solids—usually a simple wire mesh screen.

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[2] The resulting semifinished hide is called a wet blue because the chrome bath imparts a bluish tint.

[3] A small percentage of tanneries in León use an alternative to chrome tanning called “vegetable tanning” that involves soaking hides in tree bark extracts. This process produces low-grade leather used primarily as shoe soles. Our survey sample does not include any tanneries that use this process.

Both recycling and—to a lesser extent—precipitation are reputed to reduce variable production costs by cutting the use of chrome, the most expensive chemical input in the wet blue process. According to UNEP (1991), the payback period for recycling is less than one year (see also Thorstensen 1997).

3. Literature and modeling approach

Among the determinants of technological change discussed in the literature, at least one—regulatory pressure—is unique to clean technologies. The link between formal regulatory pressure and clean technological change is well established in the theoretical literature (e.g., Millman and Prince 1989), and a number of researchers have found empirical evidence for it (e.g., Kerr and Newell 2003). As noted above, even though financial and institutional constraints often preclude effective formal environmental regulation in developing countries, a growing body of recent research shows that "informal regulation" (also known as "community pressure") applied by private-sector groups such as neighborhood associations, trade unions and non-governmental organizations, can substitute for formal regulatory pressure (World Bank 1999). For example, Blackman and Bannister (1998) examined a city-wide effort to persuade small-scale brickmakers in Ciudad Juárez (Mexico) to voluntarily substitute clean-burning propane for dirty traditional fuels such as used tires and scrap wood. They found that a key determinant of propane adoption was the extent to which brickmakers were exposed to pressure from local trade unions and neighborhood organizations.

The literature identifies a number of non-regulatory determinants of technology adoption that are potentially relevant (for a review, see Jaffe, Newell, and Stavins 2003). Of these, informational factors have probably attracted the most attention. The key idea is that in order to adopt new technologies, firms must first acquire the requisite technical and economic information—a costly enterprise. Information acquisition may be passive, with firms absorbing information via day-to-day contact with business associates (Mansfield 1968), or it may be active, with firms engaging in training and technical extension programs. In either case, information acquisition is greatly facilitated and accelerated by the firm's pre-existing stock of human capital—that is, the education and training of the management and staff. Therefore, empirical studies of technology adoption typically find that firms more human capital are more likely to adopt new technologies, all other things being equal.

Other drivers of adoption that have received considerable attention in the literature include input prices, firm size, and credit availability. 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. The majority of the evidence indicates that large firms adopt new technologies faster than small ones. The most obvious explanation is that adoption involves fixed costs that imply economies of scale. Fixed costs may arise from capital indivisibilities or from more subtle informational and transactions costs. Finally, considerable evidence suggests that lack of access to credit is a binding constraint on technology adoption for small firms, even when fixed pecuniary costs of adoption are not large.

A variety of econometric approaches have been used to model the adoption of multiple complementary technologies. One is to group technologies into packages and to assume firms make a single decision about whether or not to adopt the entire package (Rauniyar 1998; Rahm and Huffman 1984). A second is to assume firms make independent decisions about each technology (Fletcher and Terza 1986). Both of these options rely on univariate probit or logit models. A third approach is to use Poisson count models to explain the number of technologies firms adopt (Ramírez and Shultz 2000). All three approaches have drawbacks. The “packages” and count model approaches do not shed light on differences in decisionmaking across individual technologies. The “independent decisions” approach ignores jointness in firms’ decisions to adopt such technologies. For example, it ignores the fact that unobservable firm characteristics such as management skill can affect adoption decisions for several technologies. In such situations, error terms in single equation models for the different technologies will be correlated, and as a result, these models will be inefficient.

A fourth approach is to use multivariate probit models to estimate a system of seemingly unrelated adoption equations, that is, equations linked only by correlations among the disturbance terms (Greene 2000, 614, 856–857).[4] Two variants of this approach are possible. One is to develop a list of all possible combinations of the technologies in question, and to specify a separate adoption equation for each of these "technology plans." A second variant is to specify a conventional adoption equation for each technology (e.g., Wozniak 1984). An advantage of the first variant is that it reflects an underlying choice model in which firms explicitly consider the complementarities among different technologies. However, for our purposes, the second variant is more appropriate because it generates results that are more useful from a policy perspective. For example, given two technologies A and B, the technology plan variant would indicate which regressors are correlated with adopting technology A but not B, which regressors are correlated with adopting technologies B but not A, and which are correlated with adopting both A and B. The simpler model, on the other hand, would indicate which regressors are correlated with adopting technology A and which are correlated with adopting B—information that has much clearer policy implications. Indeed, the literature that has used the technology plan variant typically does so in the context of a two-stage procedure where the first stage adoption model is not of interest in and of itself, but mainly serves to correct for selection bias in a second stage regression (e.g., Wu and Babcock 1998; Khanna 2001). Also, for relatively small data sets like ours, the technology plan approach presents practical difficulties due to small numbers of observations in each plan.

4. Model

To formalize the foregoing discussion of the determinants of clean technological change, this section presents a model of a tannery's decisions to adopt the two technologies discussed in Section 2. We specify separate equations for each decision, in effect assuming the tannery

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[4] Note that of the remaining commonly used choice models, multinomial probit and logit models are not applicable here because they deal with a single decision among two or more alternatives, whereas we are concerned with several decisions between two alternatives. Nested logit models are not applicable because they require specification of a sequential nesting structure for firms' adoption decisions. No obvious structure exists for the technologies considered here.

decides whether or not to adopt each innovation individually. However, as discussed above, we estimate the two equations as a system of seemingly unrelated regressions to account for any correlation in the error terms.

For each of the innovations discussed in Section 2, we assume that tanners choose between two technological alternatives indexed by $i \in (c,d)$: a new clean technology and an old dirty one. The tanner selects the technology that maximizes the present discounted value of total profit generated by producing wet blues, Π_i. Total profit in each time period $t = (0,1, \ldots \tau)$ is equal to revenues less costs. Revenues, in turn, are equal to the product of price and quantity, $N_{it} = p_t q_{it}$. Costs are comprised of four separate elements: production costs, $C_i(\bullet)$, environmental regulatory costs, $R_{it}(\bullet)$, one-time pecuniary fixed costs associated with adopting the clean technology, $F_{c0}(\bullet)$, and one-time non-pecuniary fixed information costs associated with adoption, $T_{c0}(\bullet)$. Several of these costs depend on the tanner's technology choice. Environmental regulatory costs (e.g., the costs of fines and social sanctions) are lower for adopters than for non-adopters and non-adopters obviously do not pay fixed adoption costs. In addition, production costs may be different for adopters versus non-adopters. Revenues and the two recurrent costs are discounted using a subjective discount rate, θ.

Each of the four components of costs are functions of underlying tannery characteristics. Production costs are increasing in input prices, $\mathbf{v}_{it}$, (where $\mathbf{v}_{it}$ is a vector) and are decreasing in both human capital, u_t, and the scale of the plant, y_t. Regulatory costs are an increasing function of formal government regulatory pressure, g_t, and informal community pressure, o_t. Pecuniary fixed costs are increasing in the price the tannery pays for physical capital, r_t. In addition, for one of the clean technologies (recycling) pecuniary fixed costs are increasing in firm scale, y_t, since firms with more tanning drums need to purchase more equipment. Non-pecuniary fixed costs are decreasing in human capital, u_t, since tanneries with better trained staff learn the new technology more quickly. We assume that the cost function is a twice-differentiable, increasing convex function of output holding constant input prices, human capital, and firm scale.

Thus, for each of the two innovations, the tanner's optimization problem may be written

$$\max_{(q_{it},i)} \Pi_i = \int_0^{\tau} [N_{it} - C_{it}(q_{it}; \mathbf{v}_{it}, u_t, y_t) - R_{it}(g_t, o_t)] e^{-\theta t} dt - F_{i0}(y_0, r_0) - T_{i0}(u_0)$$

$i = (c,d);\ (t = 0, 1, \ldots \tau)$ (1)

where for non-adopters,

$F_{d0}(y_0,r_0) = T_{d0}(u_0) = 0.$

The tanner chooses whether or not to adopt the clean technology by comparing the maximum profit that can be obtained from the clean technology and the dirty technology. More specifically, for each technology, the tanner first chooses a stream of output quantities, q_{it}^* for $t = (0, 1, \ldots \tau)$ so as to maximize the present discounted value of profit, and then compares maximized profit for the two technologies. We assume that the price of output p_t and the recurrent costs C_{it} and R_{it} are (bounded non-negative) functions of time and period zero prices and costs only so that tanners can foresee the intertemporal paths of prices and costs. This enables us to express Π_i as a function of period zero tannery characteristics.[5]

$\Pi_i(g_0,o_0,r_0, u_0,\mathbf{v}_{i0},y_0) i = (c,d).$(2)

Hence, the tanner chooses between the two technologies by calculating,

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[5] This feature is needed because our econometric model relies on a single cross-section of survey data instead of a panel. The assumption that tanners foresee future prices and costs is less restrictive than alternative assumptions that imply profits are a function of period zero tannery characteristics only: (a) tanners make their technology choices by simply comparing the profits that accrue in period zero (a common assumption in the literature), or (b) costs and prices do not change over time, in which case tanners' output decisions are identical in each period and the intertemporal model collapses to a static one.

$$I^* = \Pi_c(g_0,o_0,r_0, u_0,\mathbf{v}_{i0},y_0) - \Pi_d(g_0,o_0, \mathbf{v}_{i0},y_0).(3)$$

The tanner will adopt as long as $I^* > 0$.

Using this framework, it is straightforward to show that, all other things equal, a tannery is more likely to adopt the clean technology the lower its cost of capital, the more human capital it has, the more intense its exposure to formal and informal regulatory pressure, and the higher are the prices it pays for inputs used more intensively in the dirty technology than the clean one. Firm scale has an ambiguous impact on the probability of adoption. On one hand, it enables tanners to spread fixed costs over a greater number of units of output. But on the other hand, it necessitates higher fixed pecuniary adoption costs since set up costs are higher in relatively large tanneries.

To model the tanners' technology choices econometrically, we estimate the following system of equations[6]

$$I_j^* = \mathbf{C}\ \kappa \ + \mathbf{R}_j\gamma_j + \mathbf{F}\ \phi \ + \mathbf{T}_j\varphi_j + e_j \quad j = (1,2,3)(4)$$

where:

j	indexes the two clean technologies (precipitation and recycling)
I^*_j	is the net benefit or cost of adoption, an unobserved latent variable
$\mathbf{C}_j$	is a vector of firm-specific variables that influence production costs

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[6] Note that in order to be able to estimate the model with our data, we are forced to make a number of assumptions and abstractions. For instance, we abstract entirely from uncertainty that is often a significant influence on investment decisions (Pindyk 1991). Also, we abstract from variations in producers' risk attitudes which may also have been significant (Antle 1987).

$\mathbf{R}_j$	is a vector of firm-specific variables that influence regulatory costs
$\mathbf{F}_j$	is a vector of firm-specific variables that influence pecuniary fixed adoption costs
$\mathbf{T}_j$	is a vector of firm-specific variables that influence non-pecuniary fixed adoption costs
$\kappa, \gamma, \phi, \psi$	are vectors of parameters, and
e_j	is a stochastic error term.

The stochastic error terms are assumed to be jointly distributed multivariate normal random variables such that

$$E[e_1] = E[e_2] = 0$$

$$Var[e_1] = Var[e_2] = 1$$

$$Cov[e_1, e_2] = \rho_{12.}$$

The observable dichotomous choice variables are

$$I_j = 1 \text{ if } I^*_j > 0, \text{ and}$$

$$I_j = 0 \text{ otherwise.}$$

The two seemingly unrelated regressions in (4) constitute a multivariate probit model.

5. Data and variables

Our data are drawn from an original survey of owners and managers of 164 León tanneries. The survey was administered in person by a team of enumerators during the winter of 2000. Nineteen surveys were eliminated from the sample due to missing or inconsistent responses, leaving a total of 145 complete records.

To estimate equation (4), we use data on two dependent variables along with seven independent variables associated with costs in the manner hypothesized in the analytical model. Table 1 lists these variables and presents summary statistics for the full sample of 145 tanneries, as well as for subsamples of adopters and non-adopters for each technology.

We include two independent variables related to production costs: the natural logarithm of the price of labor (P_LABOR) and the natural logarithm of the number of wet blues produced per week (F_SIZE), a measure of the scale of the firm. Following the convention in Mexico, our survey distinguished between four different classes of labor—*obreros, técnicos, supervisores,* and others. We use the price of *obreros* because obreros account for the lion's share of workers and labor costs in leather tanneries and because our data are most complete for this variable.[7]

As for the determinants of regulatory costs, our proxy for the intensity of formal regulatory pressure is the number of visits per year by SAPAL, the local water authority charged with enforcing certain regulatory requirements (R_VISITS). SAPAL schedules regular monthly visits to León's tanneries to ensure sedimentation tanks are being cleaned. This cleaning is

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[7] On average, for the tanneries in our sample, *obreros* account for approximately 85% of the total number of workers and approximately 77% of total labor costs.

Table 1. Variables in econometric models: sample means (standard deviations)

Variable			**Full sample**		**Subsamples**			
					Precipitation		Recycling	
Proxy for:	Name	Description			adopters	non-ads.	adopters	non-ads.
			(n=145)		(n=29)	(n=116)	(n=28)	(n=117)
I^*	PC_ADOPT	Adopted precipitation of chrome?†	0.20	(0.40)	1.00	0.00	0.39	0.15
I^*	RC_ADOPT	Adopted recycling of chrome bath?†	0.19	(0.40)	0.38	0.15	1.00	0.00
C(v)	P_LABOR	Ln price labor	6.31	(0.35)	6.23	6.33	6.22	6.33
C(y), F(y)	F_SIZE	Ln no. wet blues produced/week	5.40	(1.17)	5.49	5.38	5.25	5.44
R(g)	R_VISITS	Visits per year by SAPAL	9.79	(3.98)	10.21	9.69	10.68	9.58
R(o), T(u)	CICUR	Member CICUR?†	0.89	(0.31)	0.93	0.88	0.93	0.88
F(r)	CREDIT	Credit apps. rejected 1990-2000?†	0.08	(0.28)	0.07	0.09	0.07	0.09
F(r)	OWNER	Own (vs. rent) plant?†	0.57	(0.50)	0.59	0.57	0.64	0.56
T(u)	H_CAPITL	Number professionals on staff	1.62	(4.97)	3.34	1.19	3.54	1.16

† dichotomous dummy variable

needed to prevent city sewers from clogging. According to focus groups, although SAPAL neither increases nor decreases the frequency of its visits in response to the environmental performance of specific tanneries, given the number of tanneries in León, some slip through the cracks. As the summary statistics for R_VISITS indicate, some of the tanneries in our sample needed to prevent city sewers from clogging. According to focus groups, although SAPAL neither increases nor decreases the frequency of its visits in response to the environmental were visited less than once per month, an indication that they were subjected to relatively lax formal regulatory pressure. Our proxy for informal regulatory pressure is a dummy variable indicating whether or not the tannery belongs to CICUR, the tannery trade association that has promoted clean technologies (CICUR). This variable may also proxy for human capital since, as noted in Section 2.1, trade union members may have easier access to technical information and assistance.

As for the determinants of fixed pecuniary adoption costs, our proxy for the cost of capital is a dummy variable that identifies tanneries that were not able to get any loans from formal banks between 1990 and 2000 because their applications were rejected (CREDIT). We also include a dummy variable identifying tanneries that own (versus rent) their plants (OWNER). Renters pay a higher effective price for new equipment since it is costly for them to recover investments in equipment when they switch locations.

As for the determinants of non-pecuniary fixed information costs associated with adoption, our measure human capital is the number of employees in the tannery with a bachelor’s degree (*licenciatura*) in engineering or chemistry or a technical degree (*carrera técnica*) in tanning (H_CAPITL).

Finally, note that in preliminary specifications, we included dummy variables for each tannery’s location in León. We divided the city of León into 12 sectors by aggregating *colonias* (neighborhoods included in all addresses) so as to account for natural barriers such as large roads, rivers, and railroad lines. We hypothesized that location dummies might proxy for information costs: if demonstration effects are important, firms in sectors where tanneries are “thick on the ground” may pay lower information costs than relatively isolated firms. In addition, we hypothesized that location dummies might proxy for regulatory pressure: one might expect monitoring and enforcement to be more intense in some sectors than in others. However, none of the location dummies were correlated with adoption in any of our models. Therefore, we omit them to preserve degrees of freedom.

6. Results

Table 2 presents regression results for the multivariate probit model and for the two single equation probit models. Intuitively, *rho*—the coefficient of correlation between the disturbances for the two equations (listed at the bottom of the table)— measures the correlation between the outcomes for the two equations after the influences of the regressors have been accounted for. *Rho* is positive and significant at the 10% level. Thus, the same omitted factors apparently drive the adoption of the two chrome-saving technologies. Note, however, that qualitatively, the results from the single equation probit models are quite close to those for the multivariate probit model, a result that likely stems from the fact that few of the insignificant regressors in the single equation models are borderline significant.

We turn now to the multivariate probit results for each subset of regressors. With regard to the production cost variables, the most striking result is that F_SIZE, the proxy for firm scale, is insignificant in the precipitation equation and is negative and significant at the 10% level in the recycling equation. Evidently, economies of scale associated with the two clean technologies are not important and/or are counterbalanced by disincentives to adopt due to the magnitude of fixed adoption costs. P_LABOR, the price of labor, is insignificant in both equations—a result that suggests that differences in labor costs are not driving cross-sectional patterns of adoption, either because the two technologies have relatively minor impacts on labor usage or because, as Table 1 indicates, there is relatively little variation in the price of labor.

Neither of the variables that pertain to regulatory pressure are significant. R_VISITS, the proxy for formal regulatory pressure and CICUR, the proxy for informal regulatory pressure, are insignificant in both equations. As for the determinants of the fixed pecuniary costs of adoption, neither CREDIT nor OWNER are significant in either adoption equation.

Of all the regressors, the one associated with the costs of acquiring the information needed to use the technologies—i.e., the non-pecuniary fixed adoption costs—appears to be the most important. H_CAPITL, the number of trained environmental specialists on staff at the tannery, is positive and significant at the 5% level in the precipitation equation and at the 10% level in the recycling equation.

Survey data not used in the econometric analysis both support and embellish the conclusion that factors related to information acquisition are the key drivers of clean technology adoption. For each technology, Table 3 presents non-adopters' most important reasons for not adopting. In both cases, the plurality of non-adopters said the key reason was a lack of relevant technical information.

Table 2. Regression results

	Single equation probits		**Multivariate Probit**	
Variable	**Precipit.**	**Recycle**	**Precipit.**	**Recycle**
Constant	1.201	1.494	0.931	1.154
	(2.333)	(2.364)	(2.293)	(2.343)
P_LABOR	-0.443	-0.437	-0.394	-0.362
	(0.344)	(0.347)	(0.337)	(0.343)
F_SIZE	-0.040	-0.214*	-0.042	-0.223*
	(0.127)	(0.128)	(0.126)	(0.127)
R_VISITS	0.030	0.072	0.030	0.067
	(0.036)	(0.045)	(0.036)	(0.044)
CICUR	0.655	0.585	0.640	0.563
	(0.511)	(0.538)	(0.505)	(0.531)
CREDIT	-0.005	-0.176	-0.043	-0.158
	(0.447)	(0.478)	(0.454)	(0.479)
OWNER	-0.095	0.121	-0.096	0.109
	(0.252)	(0.264)	(0.252)	(0.264)
H_CAPITL	0.065**	0.105***	0.064**	0.104***
	(0.032)	(0.039)	(0.031)	(0.039)
ρ	N/a	N/a	0.300*	
			(0.170)	
Log Likelihood	-68.310	-63.307	-130.231	

* significant at 10% level

** significant at 5% level

*** significant at 1% level

(standard errors in parentheses)

Table 3. Most important reason for not adopting technology: percentage non-adopters' responses in each category*

Reason	Precipitation (n=80)	Recycling (n=103)
Lack tech. info.	45	37
Uncertainty	5	10
Fixed costs	21	24
Variable costs	5	5
Ruins quality	9	9
Other	15	16

*responses missing for some of the records included in regression analysis

Table 4 shows how long the survey respondents had been aware of each technology. In each case, less than a third had been aware more than four years. Thus, although they have been in use in other countries for decades, these two clean technologies are new to tanners in León and, as a result, information about them is evidently relatively scarce.

Table 4. Years since respondent first became aware of technology: percentage responses in each category (n = 145)

Years	Precipitation	Recycling
0	24	9
Less than 5	43	54
5 – 9	18	23
10 – 14	9	11
15 – 20	4	1
More than 20	1	1

Table 5 presents data on how the adopters in our sample first became aware of each technology. For enzymes, almost half of adopters learned about the technology from chemical supply companies. For the two other technologies, the plurality of adopters first heard about the technology from CICUR, the tannery trade union.

Table 5. How respondent first became aware of technology: percentage responses in each category*

Source	Precipitation (n=109)	Recycling (n=131)
Tanner	16	21
Input supplier	14	8
CICUR	27	35
CIATEC	17	12
Other	26	23
Do not recall	2	0

*responses missing for some of the records

7. Conclusion

By way of conclusion, we consider the implications of our results for policy. We begin with the negative results. We found no evidence that top-down regulatory pressure applied by either public-sector or private-sector institutions had an impact on the adoption of clean technologies by our sample tanneries, a finding that runs counter to the literature's emphasis on the importance of regulatory pressure as a driver of clean technological change. That formal regulatory pressure is not important in León is not all that surprising given such regulation is relatively weak. That informal regulatory pressure is not important is somewhat more surprising.

Two factors may explain this finding. One has to do with the nature of the pollution in question. While emissions from industrial sources of air pollution are relatively easy to detect and also impact some neighborhoods disproportionately, damages from individual tanneries (odors aside) are not easy to detect and are not concentrated around the source. Tannery effluents are discharged into common sewers where they are mixed with effluents from other sources before being deposited in a river miles away. Thus, it is difficult for private-sector organizations such as neighborhood organizations to identify particularly dirty tanneries, and moreover, they have little incentive to do so. A second explanation for the lack of top-down informal regulatory pressure has to do with the political economy of León. As discussed above, tanneries are a leading employer and powerful political force in the city and are able to derail efforts to enforce environmental regulations. Unfortunately, neither one of these two factors is likely to be unique to our case study: one would expect them to be present in most large clusters of water polluters.

In addition to the insignificance of regulatory pressure, a second important negative result is that, surprisingly, firm size is not positively correlated with the probability of adoption. This finding suggests that efforts to promote clean tanning technologies should be as successful among the SMEs that dominate industrial clusters as they are among large firms.

Our key positive result is that factors related to information acquisition appear to be driving the adoption of clean tanning technologies in León. This implies that clean technological change can be hastened by training tannery personnel. Strategies for accomplishing this goal include developing and distributing non-technical, easily accessible brochures, organizing seminars and training sessions, modifying curricula at technical schools that educate plant engineers and managers, and financing demonstration projects. Our survey data indicate that in León, one of the principal purveyors of technical information has been the tannery trade association. Hence, working with and through such institutions may be the most effective and efficient means of implementing these information-dissemination strategies. Given chronic constraints on public-sector funding for promoting clean technologies in developing countries, this is welcome news. Also encouraging is the fact that learning and demonstration effects are typically cumulative and self-perpetuating. As more firms adopt, the rate of adoption should accelerate, at least until some threshold is reached. One would expect this dynamic to occur even in the absence of subsidies to technical training.

Finally, we briefly recast this discussion to emphasize its relevance to the debate about whether and how private-sector institutions can help to “green” industry in countries where public-sector regulatory institutions are weak. On one hand, our results suggest that the ability of private-sector institutions like neighborhood associations to use sanctions or threats of sanctions—that is, “sticks”—to accomplish this goal is limited. Such approaches are only likely to be feasible in specific political and geophysical settings. But on the other hand, our findings suggest that the private-sector institutions can play a key role in facilitating improved environmental performance through less coercive means, namely by providing “carrots” such as technical assistance.

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