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Are the costs of pollution abatement lower in Central and Eastern Europe? Evidence from Lithuania

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ABSTRACT. It is often claimed that pollution reductions can be achieved at lower cost in Central and Eastern Europe and the former Soviet Union, because more possibilities exist to update production processes and reduce waste. To date, however, there has been little or no systematic evaluation of what the costs actually are in these countries. The main purpose of this paper is to partially fill this research gap using firm-level data from Lithuania. Abatement cost estimates for key air pollutants are presented based on investments made in Lithuania during 1993–4. The paper also attempts to estimate the demand for pollution directly using data on pollution charges from 1994. Using both methods, it is shown that for at least some key pollutants marginal and average abatement costs are probably substantially lower in Lithuania than in western countries.

1. Introduction

Following the opening of Central and Eastern Europe (CEE) and the former Soviet Union (FSU) to outside examination an oft debated issue, at least among those involved with environmental policy development, has been whether emissions of key pollutants can really be reduced at a lower cost than in the West.[1] Perhaps this issue was first raised by Hughes (1993), but it has also been echoed in the policy literature (e.g., Environment for Europe, 1994, II-5), as well as implied in the regional pollution prevention literature (e.g., Dobes, 1995; World Environment Center, 1995a, 1995b). The idea behind such claims is that production technologies

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[1] The term 'west' is meant to refer to countries of the European Union, European Economic Area, United States, and Canada and does not imply any divide between western, eastern, and central Europe. Indeed, most countries in Central and Eastern Europe are actively seeking membership in the European Union.

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in CEE and the FSU are substantially less efficient than in the west and therefore have higher emissions per unit of output. Large environmental gains can therefore be had by focusing on changes in production processes that reduce waste, produce better products, or both.[2] Indeed, the story goes, end-of-pipe controls in many cases can be left for the future because these gains are likely to be so large.

To date, however, there has been little or no systematic evaluation of what the costs actually are in CEE and FSU countries. The goal of this paper is to partially fill this research gap by presenting two sets of air pollution abatement cost estimates based on firm-level data from Lithuania. The first measure focuses on the costs and environmental results of investments made in Lithuania during 1993–4. These estimates are termed 'long-run' costs, because the capital stock is varied. I also attempt to assess the short-run costs by estimating the demand for pollution directly using data on pollution charges from 1994. Using both methods, it is shown that for at least some key pollutants marginal abatement costs are probably substantially lower in Lithuania than in western countries.

This question is of interest primarily because knowing the costs of abatement is very important for policy making. Perhaps the most important application is for setting pollution charge rates to achieve particular goals. As discussed in Vincent and Farrow (1997), most countries in the CEE and FSU have made pollution charges important and even key parts of their environmental policy systems.[3] How to calibrate charges is therefore a major issue. Nevertheless, it is difficult to find even one careful study of the demand for pollution in any country in the region, and rates are normally set on purely political grounds. Despite this lack of analysis, it has often been observed that rates are 'too low' in the region. Rarely, however, has the question of 'too low to achieve what?' that is so closely linked with the need for abatement cost estimation, been effectively answered.

A relatively new reason why abatement cost estimation is useful for policy making is related to the goal of integration with the European Union. Many CEE countries are in the process of approximating their environmental legislation with the EU and it is likely that substantial and even fundamental changes will be required at the plant level as a result of this process. It is expected that the necessary investments will be very expensive, and several studies are underway to estimate these costs.[4] To date, however, no baseline cost estimates have been established, and

[2] Typically such measures are referred to as 'win–win', because emissions are reduced at the same time companies make changes that are neither profitable from the start or pay back very quickly.

[3] In this paper a pollution charge is defined as a charge levied on the actual or reported emissions (in tons per year) of a particular pollutant. Extensive discussions of the implementation of pollution charge systems in Central and Eastern Europe and the former Soviet Union can be found in *Controlling Pollution in Transition Economies: Theories and Methods*, Randall Bluffstone and Bruce A. Larson, eds., 1997, Edward Elgar.

[4] One preliminary estimate has put the total costs of changes in the environmental sector at ECU 12 billion (Environmental Policy Europe, 1997).

therefore the costs that are truly attributable to EU integration are likely to remain somewhat of a mystery.

The paucity of abatement cost studies in the region is not surprising, because estimating the demand for pollution based on observed behavior is certainly less than straightforward. Indeed, marginal abatement cost functions are ideally firm-specific, though in reality except for a few industries with well-known technologies, constructing even a partial set of firm-specific abatement cost functions is very difficult. Economy-wide abatement cost functions made up of single points on individual firms' costs curves are therefore the best one can realistically expect, but achieving even this simpler goal has proved difficult because abatement measures are quite difficult to define.

The standard method is for abatement costs to be defined and estimated using engineering models that restrict the set of abatement options to end-of-pipe controls. When it is possible to test such approaches, however, it is often found they have overstated costs. For example, at the time of development of a pollution charge on NO_x emissions introduced in Sweden in 1992, average abatement costs were estimated at SEK 40 (approximately $5.50) per kilogram. The actual cost turned out to be less than one-quarter of that figure, resulting in substantial *over*-compliance (Swedish Ministry of Environment and Natural Resources, 1994). Similarly, a sulfur charge introduced in Sweden in 1991 yielded revenues only half the predicted level, again suggesting abatement costs were over-estimated (Nystrom, 1996). In the European countries in transition, estimates of SO_2 abatement costs in Poland have been proposed (again, based on engineering models) that are several times higher than those estimated for the US (Berbeka, 1995).

A very general definition of abatement measures that includes more than end-of-pipe controls is certainly needed in the CEE and FSU if one believes that most 'environmental' investments are not end-of-pipe measures at all, but instead are integral parts of enterprise restructuring (Sachs, 1995). If environmental change is linked to the essentials of economic change, it also means that a wide variety of abatement options must exist in the economy, implying that identifying an 'environmental' investment is difficult. With environmental costs potentially so wrapped up with basic business changes, firms themselves—even assuming they are able to identify and assign costs to measures they have taken—probably will have difficulty estimating the environmental effects their actions have induced.

Even if least-cost abatement methods are clear, calculations of costs are still problematic, because measures often affect more than one pollutant simultaneously. For example, regulators may define a project as affecting SO_2, but in reality other pollutants are also significantly reduced.

These issues of definition and joint costs have to some extent been recognized and addressed in the literature. With World Bank support, for example, significant empirical work has been conducted both in the US and in developing countries. Using the US Commerce Department Pollution Abatement Cost and Expenditures (PACE) survey, Hartman *et al.* (1994) estimated costs of air pollution reductions based on observed variation in emissions, firm characteristics, and the level of investments in control equipment. Average abatement costs (converted to 1995 dollars) for sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulates were estimated at $143, $100, and $91 per ton respectively. Dasgupta *et al.* (1996) also estimated marginal costs of reducing water pollutants in China, and found they are surprisingly low, as low as a few cents per ton for BOD, COD, and suspended solids. The burgeoning literature on the productivity effects of environmental regulation takes the approach even further by completely avoiding the problem of defining pollution abatement costs (e.g., Barbera and McConnell, 1986; Gray, 1987; Gray and Shadbegian, 1995; Jaffe *et al.*, 1994).[5]

This paper attempts to add to this body of literature. To provide some background, the next section briefly overviews the regulatory system in Lithuania, briefly discusses the data used and gives some preliminary results. Section 3 presents an analytical model of polluter behavior within that regulatory framework, section 4 defines the variables used in the empirical analysis, and section 5 presents the results. Section 6 concludes the paper.

2. Overview of the Lithuanian environmental regulatory system and some preliminary results

Lithuania became independent from the Soviet Union in 1990. Economic transformation has been underway since that time and by 1996 the economy had been transformed from one based on agriculture, mining, and manufacturing to one with a substantial service sector.[6] A consequence of this transformation has been a sharp decline in industrial output. Many industrial firms are reported to be operating on the verge of bankruptcy, and a substantial percentage of manufacturing firms are known to be producing at only a fraction of pre-1989 levels. In 1994, for example, 75 per cent of the enterprises analyzed in this paper were producing at least 30 per cent below and 50 per cent were at less than half of pre-independence levels.[7] These economic changes have certainly been good for the environment. Air quality substantially improved since the introduction of market reforms. Emissions of sulfur dioxide, nitrogen dioxide, carbon monoxide, and dust all fell by at least two-

[5] It should be noted that these results are not useful for setting pollution charge rates, because they are expressed in terms of productivity units and costs are not attributable to particular pollutants. Indeed, I am not aware of any study that derived cost curves for particular pollutants with heterogeneous industries that even remotely resembled the marginal abatement cost functions found in most textbooks.

[6] An important part of this increase in services is banking, but capital markets are still extremely thin in Lithuania and virtually all environmental investment capital is internally generated.

[7] As was noted by Fischer *et al.* (1996) Lithuanian GDP fell by 61 per cent during the period 1989–94, a decline that occurred even as most of the economy was privatized. As of 1996, only 25 per cent of firms were under state control (Gray, 1996). In the sample of firms examined in this paper, the average percentage of stock owned by the state was 20.1 per cent. The median was substantially lower at 8.0 per cent.

thirds between 1989 and 1996 (Ministry of Environmental Protection, 1997).

Environmental protection is the responsibility of the Ministry of Environmental Protection and environmental inspectors who are the primary agents of the Ministry's 55 regional departments. The regulatory system, as in most CEE and FSU countries, combines facility-level permits and pollution charges levied on reported emissions monitored through periodic spot-checks.[8] The most important section of a permit is an annual facility limit that specifies the target emissions of each permitted pollutant in tons per year. Limits are renewed every five years, but are changed infrequently.

Good environmental performance is defined as emitting at or below this limit, which is abbreviated in Lithuanian as DLT. These limits are set in the case of air pollution to divide up a total air pollution load among all enterprises in a region such that ambient air quality goals are met.[9] If firms emit over their limits, they are subject to substantially higher charge rates. Firms that are judged to have no hope of meeting their DLT limits can apply for more lenient LLT limits if they also agree to carry out plans to achieve DLT levels within agreed periods of time. Among air polluters, approximately one-third of all polluters have LLT limits (Semeniene *et al.*, 1997).

Limits are tailor-made for each facility. They are set not only based on estimated environmental effects, but are also calibrated to account for differing sizes of facilities, types of products, vintages, production technologies used, and qualities of existing end-of-pipe controls. They therefore encapsulate a large amount of technical information into one number.

The pollution charge rate structure that is linked to these limits is quite complicated. There are a total of 151 *base* rates defined for different pollutants, but the total charge *rates* owed are functions of the type of limit and the ratio of a facility's emissions to that limit. Firms that are over their limits pay a substantially higher rate for all emissions. Because different polluters are assigned different limits, this structure means that different polluters pay different rates for emissions of the same pollutants.

The air pollutants examined in this paper are sulfur dioxide, nitrogen dioxide, carbon monoxide, manganese, and dust.[10] Data are cross-sectional

[8] In the sample used in this paper, air polluters were checked on average every 6.3 months.

[9] This mapping of enterprise emissions into ambient concentrations is done using dispersion models. As of 1996, ambient limits had been developed for approximately 800 pollutants. Of these, 151 substances had pollution charge rates. Semeniene *et al.* (1997) provide a discussion of the details of the system in Lithuania.

[10] In the Lithuanian system, six categories of dust are charged. The main category is called organic and inorganic dust. This type of dust, along with any of the other five specialized categories that are charged at the same base rate, is what is analyzed here. Included in separate categories are dusts from coal, cement, limestone, gypsum, clay, talc, mica.

Table 1. *Charge rates and annual payments for pollutants analyzed in this paper (1994)*

Air pollutant	*Mean charge rate ($US/ton)*[a]	*Mean annual charges paid ($US/annum)*	*Median annual charges paid ($US/annum)*	*Number of facilities in sample*
Sulfur dioxide	$12.05	$4,665.25	$24.90	102
Nitrogen dioxide	$21.75	$1,086.45	$24.33	127
Dust	$10.58	$111.40	$11.90	83
Manganese	$4,345	$22.51	$7.57	56
Carbon monoxide	$0.675	$65.44	$3.14	115

Source: Author's calculations.
Note: [a] Mean and median charge rates are similar.

and come from a 366-enterprise random sample of all point-source air and water polluters reporting emissions to the Ministry of Environmental Protection in 1994. Official data included emissions, charges paid, permit types, and annual facility limits. This sample of polluters was then surveyed in three areas: firm characteristics, current and expected future pollution reduction activities, and sources of information regarding pollution reduction options.[11]

As table 1 suggests, charge rates for key pollutants are quite low. For example, Lithuanian charge rates for sulfur dioxide, nitrogen dioxide, and dust were only 15–25 per cent of those levied in Poland (Anderson and Fiedor, 1997).[12] The charge in Sweden that is applied to nitrogen oxide emissions by power plants is over 500 times that found in Lithuania. Also as shown in table 1, the annual charges paid by firms are generally low. Only one reason is low charge rates, however, because the distribution of emission is also highly skewed, with many small and relatively few medium and large polluters.[13]

But as shown in table 2, these payments do not necessarily correspond with those the legislation says should be paid. Stated otherwise, just because a firm is supposed to pay a particular rate does not mean it actually pays it. There is a certain lack of formalism in enforcing environmental laws in Lithuania, and one example of this tendency is that charge rates paid often deviated from those specified in the law. Both over- and undercharging were typical for all types of facilities, but perhaps not

[11] Survey of 750 firms titled 'Waste Minimization and Resource Saving in Lithuanian Industry', conducted by Leonardas Rinkevicius. The survey forms were hand-delivered and introduced to senior staff in each enterprise by trained enumerators and pickup times were arranged directly with these individuals. The enumerators returned to enterprises at appointed times, checked the survey forms for completeness and contradictions, and recorded the names of enterprises and respondents before accepting the survey forms.

[12] It should be noted that a real doubling of charge rates occurred on 1 July 1995 when full inflation indexing was adopted.

[13] Such a skewed distribution makes the median a much better measure of central tendency. A 'normal' firm therefore typically pays *very* low charges.

Table 2. *Extent of over- or under-payment* per ton emitted *in 1994 for pollutants analyzed in this paper ($1.00 = Lt. 4.00)*

	Number of firms under-*paying by more than Lt. 1.00 per ton emitted* (minimum *value in $US in parentheses)*	*Number of firms* over-*paying by more than Lt. 100 per ton emitted* (maximum *value, in $US in parentheses)*	*Average over- or under-payment per ton emitted (in litas per ton)*	*Number of firms in sample*
Nitrogen dioxide	28 (−$1,607)	43 ($59)	−$15.71	123
Sulfur oxides	16 (−$1,507	38 ($85)	−$26.84	101
Dust	11 (−$142)	35 ($29)	$0.58	83
Manganese	20 (−$6,413)	29 ($46,784)	$1,743.3	56
Carbon monoxide	17 (−$2,510)	27 ($20)	−$24.99	108

Source: Author's calculations.

surprisingly over-charging often occurred when facilities were entitled to rates that were low or zero.[14] Conversely, those who were required to pay high rates sometimes did not pay them. In the sample there was also somewhat of a tendency for firms to pay rates equal or very close to base rates.

With a system in which central controls on regional behavior are relatively weak, relations between inspectors and polluters are often long-term and sometimes close, with a rate structure that is complicated and time consuming to check, it is perhaps not surprising there is room for negotiating charge rates that both regulator and regulated regard as 'reasonable'. One possible way to interpret this behavior is that such 'too-low' or 'too-high' charge rates are viewed as unfair in Lithuania, resulting in a system that is somewhat analogous to that of a market in which limited price negotiation takes place. Anecdotal evidence suggests there is also substantial inertia in the system. Firms can therefore expect that the rate they pay will not vary substantially from year to year, and they can plan their emissions accordingly.

Figure 1 presents net annualized abatement costs for dust emission reductions from the survey of polluters. The results are ordered from the lowest to highest annual cost, with reductions expressed as a percentage of the total emissions reduction that would occur if all projects were undertaken. From an economy-wide perspective, this figure can be considered a marginal abatement cost curve.

Dust is a case where the problem of joint costs is relatively small and respondents to the survey were able to provide estimates of pollution reductions achieved. As expected, there is a very large variance in abatement costs, with some very low values—even *negative* annual costs—reflecting the importance of resources savings (particularly energy)

[14] When asked if they knew they were paying higher charges, many firms' managers said they did know it. When asked why they paid higher charges than were required by law, a common response was that it was simply not worth antagonizing environmental inspectors.

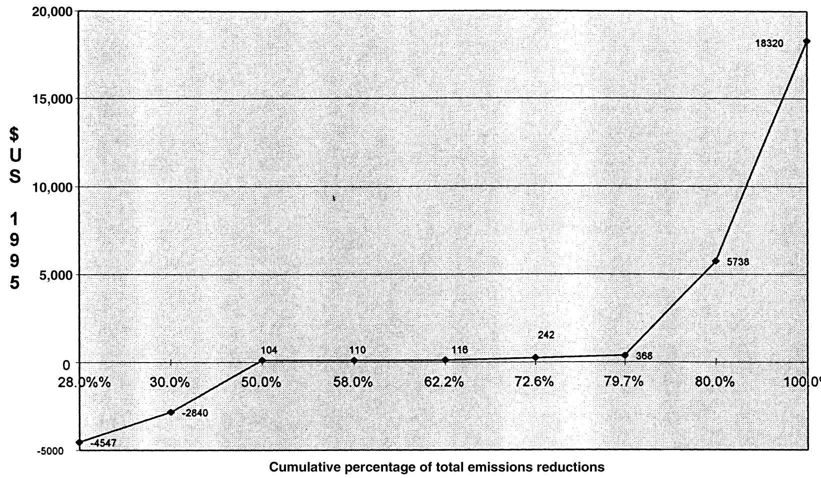

Figure 1. *Annualized costs of reducing one ton of dust based on abatement projects undertaken in 1994–95 ($US 1995 per ton reduced per year)*

as a result of expenditures that were made.[15] There were also two very large positive values, with most projects' net annualized costs in the $100–300 per ton range. It is notable that a substantial percentage of the total reduction to be gleaned came at negative cost, indicating that efficiency improvements dominated investment decisions.

The most important category of improvement is energy savings. Primary energy prices increased dramatically during the period considered in this paper, and firms therefore had strong incentives for conservation. As firms struggled to be competitive, they also often updated their production processes to produce better products. These changes resulted in lower emissions.

Figure 2 presents the net annualized costs of projects that reduced major criteria air pollutants such as sulfur dioxide, nitrogen oxide, carbon monoxide, carbon dioxide, and all projects that were simply labeled in surveys as 'air pollution' projects. In most cases these projects simultaneously reduced emissions of several pollutants, and respondents typically could not provide any estimates of the emissions reductions. It was therefore not possible to use these data to directly estimate abatement costs per ton of pollution reduced.

It is nevertheless possible to say something about the costs of emissions reductions, because of the 19 projects reported, 14 of them had net yearly costs of less than $1,000. Over half the projects were also either profitable

[15] Respondents did not differentiate different types of dust in their answers. In this survey, respondents were strongly encouraged to include all possible steps taken that reduced emissions. Directions patterned on the US Pollution Abatement Cost and Expenditure (PACE) survey, as well as examples of such steps, were given to respondents.

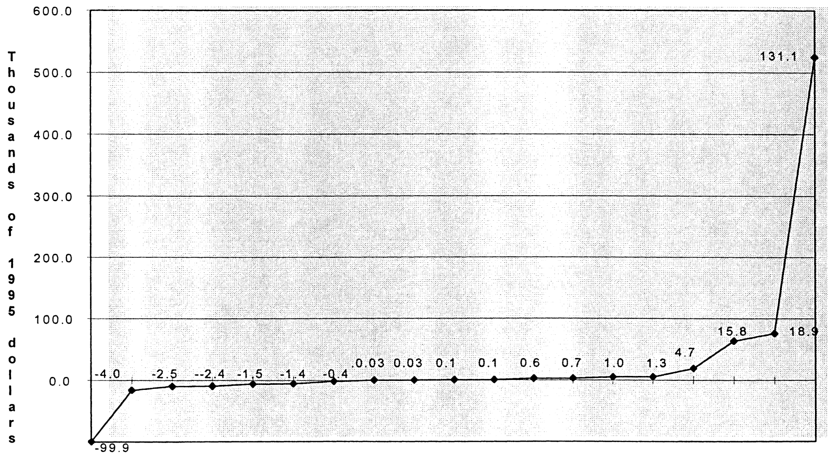

Figure 2. *Net annualized costs of projects implemented 1993–5 that reduced emissions of major air pollutants: lowest and highest values dropped (thousands of 1995 dollars)*

or very nearly so, mainly because of energy savings, suggesting that many environment projects in Lithuania were business investments in disguise.[16]

3. A model of polluter behavior

To make a more substantive estimate of either short-run or long-run abatement costs, econometric analysis is required, but *a priori* the correct specification of this model is unknown. To motivate the structure of the empirical model, a short-run representative firm model adapted to the particulars of the Lithuanian case is therefore first developed. In the analytical model, equation (1) presents a highly simplified maximization problem of a representative firm that focuses exclusively on the environmental regulatory issues. Output (Q) in this problem is exogenous, as are output and input prices. There is one choice variable, emissions (E), which is a function of environmental investments made in the past (I),[17] the monitoring frequency of the regulator (M), and other factors like management innovativeness, firm ownership structure, and information availability that affect a firm's ability and incentives to reduce emissions (O). These variables are predetermined and in the model are treated like technologies.

Emissions are scaled by an exogenous facility limit or 'standard' (S). If the firm chooses a higher level of E/S, it does not need to abate. The cost savings from avoiding abatement are given by P_A, which is a function of E/S. P_o is the price of output and C_i is a standard input cost function that depends on output and a vector of input prices (P_i). Altering emissions

[16] Dust reduction projects yielded less striking results—probably because of the higher concentration of end-of-pipe measures—but still virtually 20 per cent of the 50 projects reported were immediately profitable, and 61 per cent had a net cost of less than $1,000 per year.

[17] Investments are annualized and net of any cost savings that resulted from the investments. Net investments may therefore be positive, negative, or zero.

does not affect production costs. C_E is the emissions charge function defined in the legislation, which depends on E/S and the limit type (L). The firm also faces an exogenous positive or negative *excess* charge rate (C_x), which it pays for each unit of E/S that it emits. The total charge rate per ton emitted that the firm pays is therefore defined as $C = C_E + C_x$.

$$Max \ \Pi = P_o Q - C_i(Q,P_i) - [C_E(\frac{E(I,M,O)}{S},L) + C_x - P_A(\frac{E(I,M,O)}{S})]^* \frac{E(I,M,O)}{S}$$

$$C_E \geq 0; E \geq 0; S > 0; P_A \geq 0$$

$$\frac{\partial C_E}{\partial E/S} > 0; \frac{\partial E}{\partial I} < 0 \quad (1)$$

Maximizing equation (1) with respect to E/S gives the first-order condition in equation (2).

$$-\frac{\partial \Pi}{\partial E_E} * \frac{\partial C_E}{\partial E/S} * \frac{E(I,M,O)}{S} - C_E(\frac{E(I,M,O}{S}) - C_x + \frac{\partial \Pi}{\partial P_A} \frac{\partial P_A}{\partial E/S} * \frac{E(I,M,O)}{S} + P_A(\frac{E(I,M,O)}{S}) = 0 \quad (2)$$

To better understand the implications of this first-order condition, I assume a linear functional form for C_E such that $C_E = a + b * E/S$. For simplicity this form omits the complication associated with differing permit types (DLT versus LLT), but otherwise reflects the Lithuanian legislation reasonably well. In the explicit form I also assume that $\partial P_A/\partial\{E/S\} = 0$. Though for the case of long-run abatement this assumption would certainly be problematic, here we are interested in short-run measures like fuel switching, good housekeeping, and production changes that do not involve capital investments. It is therefore unlikely that unit abatement costs would be decreasing in E/S. If we define the first term in equation (2) as the number 'd', with $0 < d > 1$, the explicit form of equation (2) is given in equation (3):

$$d * b * \frac{E(I,M,O)}{S} - (a + b * \frac{E(I,M,O)}{S}) - C_x + P_A = 0 \quad (3)$$

Abstracting from modeling the link between E and its determinants to focus on the relationship between E/S and C_x, we get the solution in equation 4. Imposing the assumption noted assures that E/S is non-negative. With d less than one because C_E is a rate per ton emitted, $\{\partial E/S\}/\{\partial C_x\}$ is negative. Increases in excess charge rates are therefore expected to improve environmental performance.

$$\frac{E(I,M,O)}{S} = \frac{a + C_x - P_A}{b * (d-1)}$$

$$P_A \geq a + C_x \quad (4)$$

This result is useful, because it establishes our hypothesis with regard to the effect of differing levels of C_x on polluter behavior. The estimation of this relationship then provides us with an estimate of how firms respond in a given period to increases in charge rates, which is the short-run demand for pollution. We also see from the solution that because C_E is just *E/S* in disguise, it is not in itself helpful for estimating the demand for pollution. Indeed, despite the differing charge rates the legislation assigns to different polluters, this variation is no more useful than if each polluter was assigned the same rate. As expected, emissions are increasing in the unit abatement cost. Increases in the costs of better fuels, materials, and labor, for example, are expected to increase *E/S*.

$$\frac{E}{S} = f(C_x, P_A, I, M, L, M) \qquad (5)$$

In reality, of course, *E/S* is a function of several variables that should be on the right-hand side of any empirical model. The model to be estimated is therefore substantially more complicated than equation (4), at minimum looking something like equation (5). On the right-hand side is a function to be estimated that links *E/S* and the predetermined and exogenous variables *I* and *M*. The limit type is in our C_E function, and therefore should also affect the equilibrium *E/S*.

Of course other factors like management innovativeness, information availability, and ownership structure will affect a firm's ability and incentives and therefore also should be on the right-hand side. Considering the main variables, the expectation is that $\{\partial E/S\}/\{\partial C_x\} \leq 0$; $\{\partial E/S\}/\{\partial I\}\backslash \leq 0$; $\{\partial E/S\}/\{\partial M\} \geq 0$. In addition, firms with more stringent DLT standards are predicted to be closer to their limits (i.e., *E/S* is larger) than facilities with LLT limits.

With estimates of the functions in equation (5), we can then calculate long- and short-run marginal cost curves. This is the goal of section 5 of this paper. In section 4, variables used are defined and some important econometric issues are discussed.

4. Variables used and some econometric issues

The nature of the regulatory environment in Lithuania suggests that '*E/S*' is the appropriate measure of environmental performance. Because limits are set based on a variety of observable and unobservable firm-specific variables, using this measure also allows us to adjust for important cross-sectional differences such as size, technology vintage, etc. that are not possible to adequately include as right-hand-side variables.[18] Adjusting for such factors was absolutely essential, because without this scaling it was impossible to explain even a fraction of the variation in emissions.

The functional form of the relationship between excess charges and the variable *E/S* is unknown, but the form most consistent with theory is perhaps one in which as emissions fall demand becomes less elastic, i.e.,

[18] As discussed in Hettige *et al.* (1994), emissions per unit of output, per unit of revenue and per employee are other possible options.

$\{\partial(E/S)/\partial C_x\} \leq 0$; $\{\partial^2(E/S)/\partial^2 C_x\} \geq 0$. Given the low average charge rates prevailing in Lithuania, however, it is also possible that responsiveness is constant or increasing as rates rise. To allow for a variety of possibilities, squared, and cubed excess charge rates were included as independent variables.

Table 3 presents the variables used as left- and right-hand variables in the regression equations. Of perhaps most interest are proxies for the analytical model variable '*I*', in the econometric model defined as the net annual cost of criteria air and dust reduction projects (Netcostcrit and Netcostdust). As was discussed in section 2, these costs can be positive, negative, or zero. The right-hand side of all equations included variables in four areas:

1 The regulatory environment (e.g., annual facility limits, monitoring frequencies)
2 Activities undertaken by facilities to reduce emissions (e.g., Netcostcrit, Critair)
3 Basic firm information (e.g., output, percentage state ownership, employees, etc.)
4 Indications of firm innovativeness and environmental awareness (e.g., environmental staff, business plan with environmental component, plans for projects in future).

Proxies for the variable P_A were not incorporated into the empirical model, because these data were not available. Because Lithuania is a small country, one would not expect significant variation in the unit costs of controlling contemporaneous emissions. It is therefore likely that in any case it would not be possible to include these variables in a single-country firm-level analysis.

The function determining the excess charge rates firms paid is unknown. For example, it is possible that C_x is very loosely within the control of the enterprise (i.e., it is almost exogenous) and *E/S* and C_x are determined independently. Alternatively, firms may have some role in the setting of C_x. Finally, it is possible that *E/S* and C_x are simultaneously determined, but C_x is still outside the firm's control (e.g., the regulator chooses C_x based on the observed *E/S*).[19] To allow for all cases, models were estimated by both OLS and 2SLS. Because priors suggested the presence of heteroskedasticity, standard error estimates were adjusted using the method of White (1980).

To accommodate the use of 2SLS, additional instruments were included that could affect the degree of excess charges firms paid. These included variables that capture whether facilities are in large cities, how well connected firms are with other industrialists, the academic community and Ministry regional departments, and whether a facility is part of a known 'clean' industry. These variables are meant to capture the 'perception' of the firm by the larger community.

For three of the six pollutants analyzed, including facilities with $E/S > 1$ exerted an inordinately strong influence on the R^2 of equations. Indeed, in

[19] I thank an anonymous reviewer for this point.

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Table 3. *Variable definitions (Currency units are 1994 litas; $1.00 = 4 litas)*

Variable name	
E/S	Ratio of annual emissions to the facility limit (Dependent variable in regressions)
C_x	Excess charge rate paid by facility (litas/ton/year)
C_x^2	Square of excess charge rate (litas/ton/year)
C_x^3	Cube of excess charge rate (litas/ton/year)
L	Dummy for permit type (1 = DLT)
Netcostcrit[a]	Summed net annualized investment costs of all projects completed in 1993 or 1994 that reduced emissions of the criteria air pollutants NO_2, SO_2, CO, CO_2 and also responses labeled 'air pollutants'
Netcostdust	Summed net annualized investment costs of all projects completed in 1993 or 1994 that reduced emissions of dust
Critair	Total number of projects completed (including those during the Soviet period) that reduced emissions of the criteria air pollutants NO_2, SO_2, CO, CO_2, and also responses labeled 'air pollutants'
Dustair	Total number of projects completed (including those during the Soviet period) that reduced emissions of dust
Q	Output in 1994 as a percentage of 1989
Employees	Estimated ratio of energy cost per unit of main output to price per unit of output
MinMon	Frequency of monitoring by the Ministry of Environmental Protection (number of months between checks)
FirmMon	Frequency with which the facility itself measures its emissions (number of months between checks)
Envstaff	Total number of employees at the facility who regularly are involved with environmental issues
Stateown	Percentage of state ownership (0%–100%)
Energy	Dummy—heating or electric plant
Airplans	Number of air pollution reduction projects planned for the facility
Busplan	Dummy—1 = enterprise controlling the facility has a business plan that includes an environmental component
Additional variables included exclusively as instruments for use in 2SLS regressions	
Clean	Dummy—1 = Service/natural resource industry
City	Dummy—1 = Facility located in one of the five major cities
Inffirms	Ranking (1–5 with 5 as the highest value) of other firms as a source of information on pollution prevention and waste reduction
Infmin	Ranking (1–5 with 5 as the highest value) of ministry of environmental protection regional departments as sources of information on pollution prevention and waste reduction
InfSem	Ranking (1–5 with 5 as the highest value) of seminars and conferences as sources of information on pollution prevention and waste reduction

Note: [a] The formula for calculating Netcostcrit and Netcostdust was the sum for each project '*i*' implemented in 1993 or 1994. Projects completed before 1993 were omitted because of major currency changes that occurred in 1993, though it is recognized that this assumption may introduce biases. $\text{Netcost}_i = I_i * (r/(1-(1+r)^{-1})) + O - R$. '*I*' is the level of investment made in period zero. '*r*' is the annual discount rate (assumed to be 12 per cent). '*t*' is the lifetime of asset '*I*' (assumed to be 10 years). '*O*' is the operating cost of the asset and '*R*' are resources the firms saved by making the investment.

Table 4. *OLS and 2SLS regression results (Dependent variable ('E/S' (standard errors in parentheses)*

Variable	NO_x *OLS*	NO_x *2SLS*	SO_2 *OLS*	SO_2 *2SLS*	*Dust OLS*	*Dust 2SLS*	*CO OLS*	*CO 2SLS*	*Mang. OLS*	*Mang. 2SLS*
Constant	0.74 (0.82 E-01)***	0.65 (0.85 E-01)***	0.82 (0.59 E-01)***	0.85 (0.68 E-01)***	0.69 (0.52 E-01)***	0.52 (0.11)***	0.69 (0.82 E-01)***	0.45 (0.98 E-01)*	0.74 E-01)***	0.83 (0.88 E-01)***
C_x	−0.32 E-02 (0.34 E-03)***	−0.34 E-02 (0.84 E-03)***	−0.62 E-02 (0.72 E-03)***	−0.39 E-02 (0.31 E-02)	−0.27 E-02 (0.18 E-02)	−0.11 E-01 0.30 E-02)***	−0.86 E-01 (0.24 E-01)***	−0.19 (0.41 E-01)***	−0.20 E-04 (0.35 E-05)***	−0.23 E-04 (0.49 E-05)***
C_x^2	−0.97 E-05 (0.16 E-05)***		−0.91 E-04 (0.21 E-04)***		−0.14 E-04 (0.74 E-05)***	0.43 E-04 (0.17 E-04)***	−0.30 E-01 (0.13 E-01)**	0.23 E-02 (0.54 E-03)***		
C_x^3							0.39 E-03 (0.16 E-03)**			
L						0.31 (0.11)***				
Netcostcrit	−0.78 E-03 (0.30 E-03)**	−0.96 E-03 (0.34 E-03)***	−0.39 E-02 (0.17 E-02)**	−0.26 E-02 (0.58 E-03)***			−0.19 E-02 (0.36 E-03)***	−0.94 E-03 (0.52 E-03)*		
Netcostdust					−0.19 E-02 (0.36 E-03)***	−0.91 E-03 (0.32 E-03)***				
Critair			−0.66 E-01 0.56 E-01	(0.56 E-01) 0.49 E-01) **	−0.96 E-01	(0.49 E-01)**				
Dustair	0.67 E-03 (0.83 E-03)	0.16 E-02 (0.10 E-02)	0.58 E-03 (0.52 E-03)		0.12 E-02 (0.66 E-03)*		0.21 E-02 (0.72 E-03)***	0.43 E-02 (0.13 E-02)***	0.25 E-02 (0.16 E-02)	
Q										

Employees			−0.17 E-03 (0.10 E-03)*						0.67 E-02 (0.39 E-02)*	0.71 E-02 (0.37 E-02)**
EnergyInt							−0.25 E-02 (0.19 E-02)			
MinMon	0.77 E-03 (0.51 E-02)			−0.77 E-02 (0.71 E-02)				0.12 E-01 (0.10 E-01)	−0.38 E-01 (0.11 E-01)***	−0.38 E-01 (0.10 E-01)***
FirmMon				−0.15 (0.85 E-01)*		−0.15 (0.80 E-01)*	−0.15 (0.72 E-01)**			
Envstaff	0.11 (0.49 E-01)**	0.11 (0.63 E-01)*		0.12 (0.68 E-01)*	0.10 (0.80 E-01)		0.71 E-01 (0.63 E -01)			
Stateown	−0.16 E-02 (0.10 E-02)*	−0.22 E-02 (0.13 E-02)*				0.40 E-02 (0.12 E-01)***		−0.13 E-02 (0.13 E-02)	0.24 E-02 (0.14 E-02)*	0.29 E-02 (0.14 E-02)**
Energy	0.25 (0.96 E-01)**	0.31 (0.12)***								
Airplans			0.11 (0.56 E-01)*				1.0 E-01 (0.71 E-01)			
Busplan	0.60 E-01 (0.49 E-01)	0.75 E-01 (0.56 E-01)			−0.23 E-03 (0.81 E-01)***	−0.26 (0.11)***				
N	86	66	91	63	83	49	69	54	36	36
Adj. R^2	0.33	0.30	0.42	0.33	0.17	0.20	0.28	0.24	0.41	0.40

Notes: *** Significant at 99% level using a two-tailed test.
** Significant at 95% level using a two-tailed test.
* Significant at 90% level using a two-tailed test.

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some cases the R^2 approached one.[20] In all cases very few facilities were over their limits, but leaving out these observations typically reduced the R^2 by half. Omitting these observations did not, however, substantially alter the coefficient estimates for the variables of interest and never caused signs to switch. To avoid the possibility of problems, the analysis presented in the following section is therefore restricted only to facilities that had annual emissions less than or equal to annual limits.[21]

5. Results

Table 4 presents the OLS and 2SLS regression results for each of the five pollutants. The table gives only the final regressions after variables were tested out of equations using standard t and F tests. Reported sample sizes are substantially less than the 366 observations in the overall sample, because not all respondents emitted all pollutants. Some polluters in the Ministry of Environmental Protection database also refused to participate in the survey.

In table 4 we see that coefficients on excess charge rates always had the expected sign (negative) and estimates were typically significant at the 99 per cent level whether OLS or 2SLS was used. Coefficient estimates also did not differ dramatically depending on the estimation method used. With regard to the squared terms, when OLS was used a concave relationship between C_x and *E/S* was in general suggested. Modeling C_x as endogenous by estimating using 2SLS, resulted in either linear or convex functions that were more consistent with priors.

There were no priors on the coefficient estimates for Netcostcrit and Netcostdust, because the coefficient signs and magnitudes should depend on whether abatement costs are positive, negative, or zero. That signs on both variable coefficients were negative and significant for all pollutants suggests that zero-cost or 'win–win' investments should not be considered typical in Lithuania.[22]

Also perhaps of interest is that the coefficients on the variable 'Q' are in general not significant, suggesting that increases in output do not imply poorer environmental performance. To the extent that 'Q' is a proxy for profitability, these results also suggest a neutral relationship between profits and emissions. Only in the case of carbon monoxide does this conclusion not seem to hold, possibly because mitigation measures are much more limited. It is also of note that the permit type (DLT or LLT) in and of itself does not seem to influence *E/S*. Dust emitting firms that have business plans with environmental components appear to have systematically better environmental performance. Particularly the 2SLS estimation indicated that these effects are quite large. Evidence also seems to exist that

[20] This may be related to the particular form for calculating charge rates defined in the legislation.

[21] OLS and 2SLS regression results for the full sample are available from the author.

[22] Manganese emissions mainly come from welding, which can be adjusted by switching rod types. Environmental investments made were therefore not included.

Table 5. *Marginal abatement costs and demand elasticities derived from price variables in the econometric models ($US 1995 per ton per year)**
Point elasticities at the given levels of reductions are in parentheses

	0% reduction (base case)	*10% reduction in emissions*		*25% Reduction in emissions*		*40% reduction in emissions*	
Pollutant		Using OLS	Using 2SLS	Using OLS	Using 2SLS	Using OLS	Using 2SLS
SO2	$12.80	$25.38	$42.24	$37.12	$80.00	$53.44	$118.08
		(e = −0.21)	(e = −0.148)	(e = −0.44)	(e = −0.36)	(e = −1.05)	(e = −0.68)
NO_x	$23.65	$58.88	$59.20	$106.56	$117.12	$152.96	$165.76
		(e = −0.17)	(e = 0.15)	(e = −0.39)	(e = −0.37)	(e = −0.70)	(3 = −0.67)
CO	$0.81	$1.04	$1.00	$1.34	$1.26	$1.61	$1.54
		(e = −0.47)	(e = −0.55)	(e = −0.83)	(e = −0.88)	(e = −1.35)	(e = −1.24)
Dust	$13.78	$47.36	$17.95	Not achievable	$24.93	Not achievable	$32.67
		(e = −0.095)	(e = −0.40)		(e = −0.63)		(e = −0.92)
Manganese	$4,333.12	$7,683.84	$7,769.60	$12,992	$11,910.40	$18,400	$16,464
		(e = −0.22)	(e = −0.25)	(e = −0.44)	(e = −0.46)	(e = −0.80)	(e = −0.83)

Note: * The representative facility simulated is assumed to be average in all ways. Its base emissions are consistent with the mean value of *E/S*. It pays the mean charge rate as well as the mean *excess* rate.

firms that monitor their emissions more often have better environmental results.

Table 5 presents estimates of marginal abatement costs required to achieve 10 per cent, 25 per cent, and 40 per cent emissions reductions. The estimated elasticities of demand associated with those reductions are also given. It should be emphasized that these simulations are for a representative firm, where being 'representative' means that with no reduction in emissions from 1994 levels, the firm pays a total charge rate per ton ($C = C_E + C_x$) equal to the mean of the sample, has the mean level of 'C_x' and all other variables are also set equal to their sample means. The firm is therefore average in all ways.

We expect that in equilibrium profit-maximizing firms will choose abatement effort such that marginal abatement costs equal total charge rates per ton ($C = C_E + C_x$). Marginal abatement costs can therefore only be estimated with regard to total charge rates, but our estimates are based on responsiveness to changes in *excess* charge rates (C_x). To make this conversion, elasticities from the estimated functions were applied to proportionate increases in total charge rates to get the rates (and marginal abatement costs) needed to achieve the different levels of reduction. If we start the simulation from the base case in which our representative firm is average in all ways, this means that the elasticity associated with an initial 10 per cent increase in 'C_x' was applied to an initial 10 per cent increase in the total charge rate paid per ton, the elasticity linked to the second 10 per cent increase in 'C_x' was applied to the second 10 per cent increase in the total charge rate, etc.

What we see in table 5 are elasticities that are consistent with what one might expect given the low overall level of charge rates and charges paid in Lithuania. Elasticities are relatively low for small rate increases—typically in the -0.20 to -0.50 range—but they increase substantially as rates rise above base levels. Elasticities rise rather slowly, and to achieve, for example, a 25 per cent reduction in emissions, total charge rates must at least double. Again, because in equilibrium charge rates equal marginal abatement costs, for nitrogen dioxide we can conclude that a four- to five-fold increase in marginal abatement costs result in a 25 per cent emissions reduction. Carbon monoxide costs, on the other hand, would need to rise by only 50–60 per cent to get that level of reduction.

Marginal abatement costs in this model typically rise rather quickly and then taper off as increasing reductions are demanded. Presumably this pattern is a function of the existing low charge rates (and matching low levels of marginal abatement costs). As very large reductions (e.g., 85 per cent or 95 per cent) are demanded, the marginal abatement cost functions would move into steeply increasing ranges.

In terms of marginal cost *levels,* other than comparison with engineering-based estimates that typically overstate costs, I am aware of no cases against which we can judge whether costs in Lithuania are low or high. Perhaps the only reasonable estimates that can be used are economy-wide *average cost* estimates from the US by Hartman *et al.* (1994) for sulfur dioxide, nitrogen dioxide, and dust. Of course we can derive average costs from the series of marginal costs underlying table 5. Average costs associ-

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Table 6. *Estimates of average costs to achieve 40% reductions in emissions of selected air pollutants ($US 1995 per ton per year)*

Pollutant	*Using OLS estimates*	*Using 2SLS estimates*
Sulfur dioxide	$33.60	$70.10
Nitrogen dioxide	$94.70	$100.50
Carbon monoxide	$1.25	$1.21
Dust	Not achievable	$22.44

ated with the last two columns of table 5 are given in table 6. The 40 per cent reduction level was chosen, because for most pollutants it is close to the maximum reduction that can reasonably be predicted without forecasting outside the sample of observed excess charge rates. The maximum is used, because it is recognized that the US is much farther up its marginal abatement cost curve than Lithuania.

Table 7 presents what we have been calling long-run marginal costs, where in this case marginal and average costs are equal. These cost calculations come from the coefficients estimated for the variables Netcostcrit and Netcostdust. Comparing with table 6, except for sulfur dioxide and 2SLS long-run cost estimates for nitrogen dioxide, estimates in table 7 are always greater. This pattern is consistent with the notion that table 7 gives *long-run* costs. OLS estimates for sulfur dioxide are equivalent for the two methods.

Table 7. *Average abatement costs based on project cost variables in regression equations ($US 1995 per ton per year)**

Pollutant	*Median annual limit*	*Constant average abatement cost OLS estimate*	*Constant average abatement cost 2SLS estimate*
SO_2	2.69 tons	$23.20	$25.73
NO_x	2.70 tons	$118.75	$96.00
CO	10.04 tons	$13.25	$26.50
Dust	1.43 tons	$93.00	$190.75

Note * Calculations assume that representative facilities have mean values of *E/S* and median annual limits.

Comparing table 6 estimates (with the exception of the OLS estimates for dust) with those of Hartman *et al.* (1994) discussed in section 1 indicates that at least at the 40 per cent level of reduction, average and marginal costs are probably substantially lower in Lithuania than in the US. Indeed, average cost estimates are 25–50 per cent of US levels for sulfur dioxide and even lower for dust. Nitrogen dioxide average cost estimates are almost exactly the same as those derived by Hartman *et al.* (1994). I am not aware of any study that is a suitable basis for considering carbon monoxide or manganese reductions.

If we instead compare Hartman *et al.* (1994) results with table 7, sulfur dioxide abatement costs are still substantially lower in Lithuania and nitrogen dioxide abatement costs are about the same as in the US. The conclusion for dust is not nearly as neat, because the cost estimate from the

OLS regression is virtually the same as that of Hartman *et al.* (1994), but the two-stage least squares estimate indicates costs twice that of the US.

Which project-based dust estimate is more likely to be correct? Referring back to figure 1, where data on the annualized costs of projects are presented along with reported emissions reductions, if we omit the top three and bottom two observations and take an average, we get $143, which is somewhere between the OLS and 2SLS values in table 7. Perhaps this is as good an estimate as we can get for what an average annual cost of a dust reduction project might be.

6. Conclusion

The purpose of this paper was to propose air pollution abatement cost estimates based on observed behavior in a transition country. The paper partially fills an important policy research gap, because such estimates are required to calibrate pollution charge rates and also to determine a baseline cost estimate for those countries approximating their legislation with the European Union. Despite their importance, cost estimates are non-existent in CEE and FSU and a rather thorough combing of the literature reveals that relatively few estimates based on observed behavior are available for *any* region.

The major result is that the costs of reducing sulfur dioxide, and perhaps also dust, are likely to be substantially lower in transition countries than in the west. This supports the conventional wisdom. Stationary source nitrogen dioxide abatement costs, on the other hand, are about the same as in the US. No comparisons were possible for carbon monoxide or manganese.

It was also found that in the Lithuanian case the elasticities of pollution emissions with respect to excess charge rates (and presumably also total charge rates) are low, but by no means zero. They also increase substantially as greater reductions in emissions are sought. These findings are potentially quite useful for proponents of pollution charges, because they suggest that reasonable increases in the existing (low) level of charge rates can potentially have large effects. For example, in 1995 dollars, an $80.00 per ton charge on SO_2 will probably reduce emissions by an average of 25–30 per cent from 1994 emissions levels. A charge on carbon monoxide of $1.25 per ton could yield a similar level of reduction.

The results on projects implemented suggest that even in the depths of the economic contraction in Lithuania in 1993 and 1994, environmental projects that were largely production modifications were being undertaken. These projects often were relatively low cost, but as indicated by the regression results had significant environmental effects. These results again suggest that low charge rates can have effects in transition economies, if abatement costs are low enough.

In terms of further work, it seems likely that in other CEE and FSU countries similar analyses could be undertaken, because the regulatory systems are similar. In Lithuania, data on water pollution are also available and analysis of these data could potentially yield some interesting insights. An important methodological extension is to endogenize the level of environmental investments, but this requires an analytical model that is dynamic and the development of a panel of data for years subsequent to 1994. These extensions are left for future research.

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