The Evolution of Economies of Scale Regarding Pollution Control: Cross-Sectional Evidence from a Transition Economy

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This paper assesses whether firms face economies and/or diseconomies of scale with respect to air pollution control by evaluating the effects of production on firm-level air emission levels. To achieve this objective, this paper uses an unbalanced panel of Czech firms during the country's transitional period of 1993 to 1998. By examining each year separately, the analysis permits firms' abilities to control air pollution to vary over time. In general, results indicate that, as production rises, Czech firms first face diseconomies of scale but later enjoy economies of scale.

INTRODUCTION

Several recent economic studies empirically examine the factors driving corporate environmental performance, generally measured by pollutant emissions, in mature market economies (Foulon et al., 2002; Konar and Cohen, 2001; Khanna and Damon, 1999) and transition economies (Wang and Wheeler, 2005; Bluffstone, 1999). While some of these studies include production as a control variable in their empirical analysis (Foulon et al., 2002; Khanna and Damon, 1999; Magat and Viscusi, 1990), most fail to scrutinize the important relationship between pollution and production.

Only two previous studies - Earnhart and Lizal (2006b) and Earnhart and Lizal (2007) - scrutinize this relationship. Earnhart and Lizal (2006b) examine exclusively on cross-sectional (i.e., inter-firm) variation by using a between-group estimator to study this relationship. Earnhart and Lizal (2006b) examine cross-sectional variation, but do not allow the emission-production relationship to evolve over time. Earnhart and Lizal (2007) rely exclusively on intra-firm variation by using a fixed effects estimator to study this relationship. Earnhart and Lizal (2007) allow the emission-production relationship to evolve over time, but examine only intra-firm variation since they use a fixed effects estimator. The fixed effects estimator cannot shed light on across-firm variation. This feature may limit the analytical ability to examine production scale effects if production levels do not vary sufficiently within firms. Arguably, an examination of cross-sectional (i.e., across-firm) variation may better capture production scale effects than an examination of intra-firm variation.

In contrast to these two previous studies, the current study examines cross-sectional variation in emissions and production, while allowing the relationship between emissions and production to evolve (or at least vary) over time. This study closely examines the emission-production relationship by analyzing firm-level environmental performance, as measured by air pollutant emissions, in the transition economy of the Czech Republic during the years 1993 to 1998. In particular, our study assesses whether Czech firms in this period faced economies and/or diseconomies of scale with respect to pollution control by evaluating the effects of production on the level of air pollution emitted by large stationary sources. By estimating a separate set of production-related coefficients for each individual year of the sample period, the analysis permits economies/diseconomies of scale to vary over time, which seems critical in the context of a transition economy.

Contrary to the two noted previous studies, the current paper also assesses whether the curvature in the emission-production relationship meaningfully deviates from a simple linear relationship by examining the lower and medium ranges of production and the threshold point between economies and diseconomies of scale. Neither of the two previous studies assess the absolute or relative shape of the year-specific emission-production relationships.

These differences permit this study to identify production scale effects that depend on the range of production. Specifically, this study is able to discern third-order effects in the emission-production relationship. The two previous studies either do not discern these types of effects or find them only for a limited set of sectors.

In general, results indicate that, as production rises, Czech firms first face diseconomies of scale but later enjoy economies of scale. However, for most firms in any given year, these diseconomies and economies are economically irrelevant.

This paper explores air pollution control by Czech firms within the following format. The next section develops a simple framework for understanding production scale effects. Section 3 describes the database on firm-level air pollutant emissions and production. Section 4 estimates and interprets the effects of production scale on air pollutant emissions. The final section concludes.

SCALE OF PRODUCTION: ECONOMIES AND/OR DISECONOMIES OF SCALE

This paper analyzes the effects of production scale on the level of air pollutant emissions. In particular, this paper analyzes whether or not firms face economies and/or diseconomies of scale, possibly depending on the level of production, with respect to pollution control. The analysis assesses these possibilities by constructing emissions as a third-degree polynomial function of production. Specifically, the level of air emissions depends on production (linear), production-squared (quadratic term), and production-cubed (cubic term). Let p denote the level of pollution and y denote the level of production. The following equation captures the relationship between pollution and production:

$$p = \alpha + ßy + \tau y^2 + \delta y^3, \tag{1}$$

where α denotes a constant term.[1] Based on equation (1), the two following equations capture the first and second derivatives with respect to production, denoted as p' and p'', respectively:

$$p' = ß + 2\tau y + 3\delta y^2, \text{ and} \tag{2}$$

$$p'' = 2\tau + 6\delta y. \tag{3}$$

A firm faces economies of scale if $p'' < 0$ and faces diseconomies of scale if $p'' > 0$.

As displayed in equation (3), the quadratic and cubic production parameters - τ and δ - and the production level, y, collectively determine whether a firm faces economies or diseconomies of scale. If the quadratic parameter is negative ($\tau < 0$) but the cubic parameter is positive ($\delta > 0$), then the sign of p'' and thus the production scale effect depends on the level of production. Figure 1.a demonstrates that as production increases, a firm first faces economies of scale then later diseconomies of scale, as p'' shifts from negative to positive once production becomes sufficiently high for the cubic term to dominate. If the quadratic parameter is positive ($\tau > 0$) but the cubic parameter is negative ($\delta < 0$), the sign of p'' and the production scale effect again depend on the level of production. However, in this case, the opposite conclusion follows. Figure 1.b demonstrates that as production increases, a firm first faces diseconomies of scale then later economies of scale. If both the quadratic and cubic production parameters are negative

Figure 1

Economies and Diseconomies of Scale

Figure 1.a: $\tau<0$, $\delta>0$

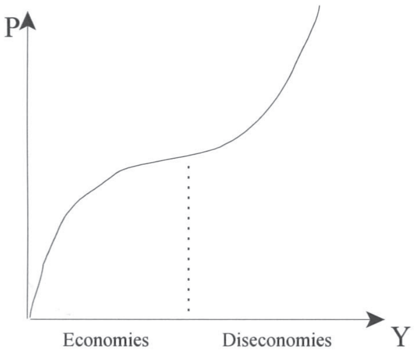


Figure 1.b: $\tau>0$, $\delta<0$

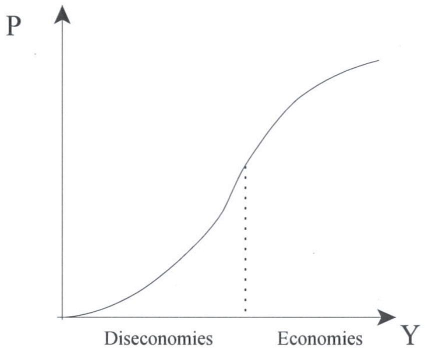


Figure 1.c: $\tau\leq 0$, $\delta\leq 0$

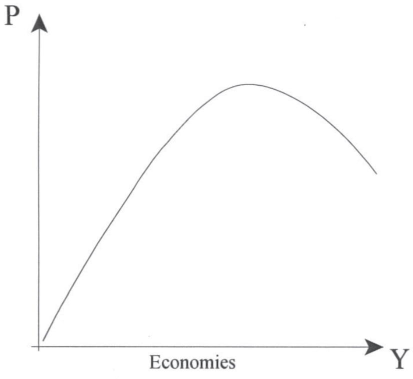
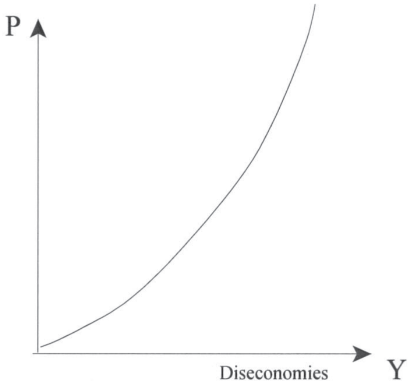


Figure 1.d: $\tau\geq 0$, $\delta\geq 0$



($\tau < 0$, $\delta < 0$), then p'' is unambiguously negative and a firm faces economies of scale regardless of the production level, as shown in Figure 1.c. If both parameters are positive ($\tau > 0$, $\delta > 0$), then p'' is unambiguously positive and a firm faces diseconomies of scale regardless of the production level, as shown in Figure 1.d.

Figures 1.c and 1.d also display four remaining possibilities that are relevant when either the quadratic or the cubic parameter equals zero ($\tau = 0$ or $\delta = 0$), which applies when either the estimated quadratic or cubic parameter is insignificantly different from zero. If the cubic term equals zero, then the quadratic parameter (τ) alone dictates whether a firm faces economies or diseconomies of scale; consequently, the identified scale effect is independent of the production level. Figure 1.c displays the case of economies of scale ($\tau < 0$, $\delta = 0$) and Figure 1.d displays the case of diseconomies of scale ($\tau > 0$, $\delta = 0$). If the quadratic term equals zero, then the cubic parameter (δ) alone dictates whether a firm faces economies or diseconomies of scale and the identified scale effect is independent of the production level. Figure 1.c displays the case of economies of scale ($\tau = 0$, $\delta < 0$); Figure 1.d displays the case of diseconomies of scale ($\tau = 0$, $\delta > 0$).

In those cases where both economies and diseconomies of scale exist depending on the level of production, a particular production level discerns the two scale regions. In particular, the second derivative with respect to production, p'', identifies the threshold when it equals zero: p'' = 0. Based on the estimated coefficients, Section 4.2 identifies the level of production that serves as the transition from economies of scale to diseconomies of scale - from p'' < 0 to p'' > 0 - or from diseconomies of scale to economies of scale - from p'' > 0 to p'' < 0.

Below this paper empirically assesses whether or not firms Czech face economies and/or diseconomies of scale, possibly depending on the level of production.

DATA ON EMISSIONS AND PRODUCTION

Czech Republic as Study Site

To examine the effects of production scale on firm-level air pollutant emissions, we exploit data on firms in the Czech Republic between 1993 and 1998, which is an excellent site and time period for our study. First, the Czech Republic had a substantially degraded environment; in particular, poor ambient air quality and air pollution were large environmental problems of public concern in the Czech Republic (World Bank, 1992). In response to public concern, the Czech Republic's government authorities took substantial and effective steps to decrease air emissions dramatically during the period 1991 to 1998 (Czech Ministry of Environment, 1998). Specifically, the Czech government raised the emission charge rates imposed on the four air pollutants examined in this study and lowered the emission limits imposed on sources of the same air pollutants. Figure 2.a displays the downward trend of economy-wide air emissions over this period. A substantial decline in overall economic activity in the early 1990s helps to explains part of this trend.[2] In addition to this output decline, firms' pollution control efforts, such as the installation of electrostatic precipitators ("scrubbers") and fuel switching, may also explain much of the displayed reduction in air pollutant emissions (World Bank, 1999).

Second, consistent with this focus on pollution control efforts, investment in environmental protection was most important during the period between 1992 and 1998, as shown in Figure 2.b. As a percentage of Czech gross domestic product (GDP), investment rose dramatically after 1991 from a level of 1.3 % to a peak of 2.5 % in 1997 and tailed off after 1998 back to a pre-transition level of 1.1 % by 2000; in 1990, investment was only 1.1. % of GDP.

Third, the Czech Republic was the first transition country to join the OECD (in 1997), which reflects the high quality of the country's statistical information.

Fourth, the Czech Republic was attempting to enter the European Union (EU) during this period and was required to reduce its industrial emissions in order to qualify for membership.[3]

Figure 2.a: Air Pollutant Emissions in Czech Republic

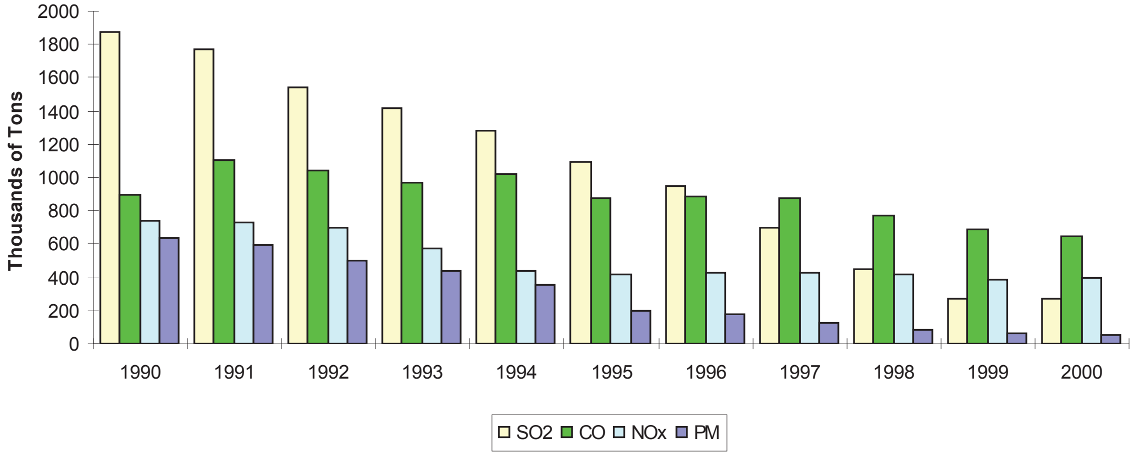
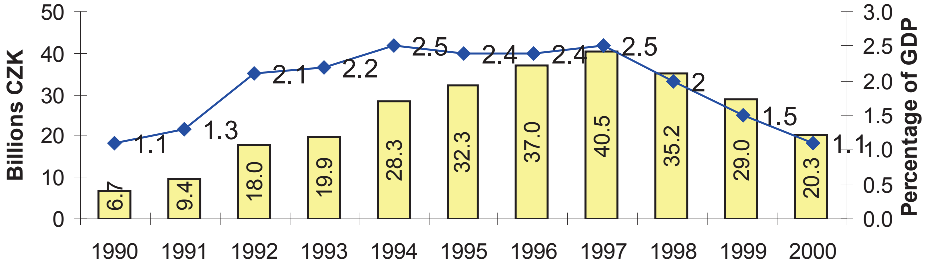


Figure 2b: Investment in Environmental Protection



Source: Czech Statistical Office, Czech Ministry of Environment

Panel Data on Production and Emissions

To examine production at Czech enterprises, we gather data from a database provided by the private data vendor Aspekt. The database provides information drawn from firms' balance sheets and income statements. This database also identifies a firm's primary sectoral classification. We gather balance sheet and income statement data for the years 1993 to 1998. The Aspekt database includes all firms traded on the Prague Stock Exchange, publicly traded firms [i.e., firms registered for trading on the RMS (Registracní místo system) secondary market], and a majority of the remaining large Czech firms (plus the key trading partners of these large firms). This comprehensive database has been used by previous studies of Czech firm-level performance (e.g., Claessens and Djankov, 1999; Hanousek et al.,2007; Djankov, 1999; Earnhart and Lizal, 2006a).[4] Production is measured as production value in terms of Czech Crowns. In order to compare properly across the six years of the sample period, the analysis adjusts the production value data according to the Czech Consumer Price Index so that all values are denominated in 1998 Czech Crowns.[5]

We also gather data on air pollutants emitted by facilities located in the Czech Republic during the years 1993 and 1998. The included pollutants are carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter (PM), and nitrous oxides (NO_x), which represent the main and most heavily regulated pollutants in the Czech Republic, similar to other industrialized nations. The Czech Hydrometeorological Institute maintains the REZZO-1 database, which records emissions for large, stationary sources. While the REZZO-1 database records emissions at individual units of individual facilities, the Czech Hydrometeorological Institute aggregates the air emissions to the level of each facility before public release of the data. We further aggregate air emissions across all facilities associated with a single firm. Thus, the analysis links emissions data aggregated to the firm level with other firm-level data, consistent with previous studies of firm-level environmental performance (Konar and Cohen, 1997; Konar and Cohen, 2001; Earnhart and Lizal, 2006a; Khanna and Damon, 1999; Khanna et al., 1998; Arora and Cason, 1995; Arora and Cason, 1996). We add the four pollutants into one composite measure of air emissions, similar to previous studies of environmental performance (Konar and Cohen, 1997; Konar and Cohen, 2001; Earnhart and Lizal, 2006a; Khanna and Damon, 1999; Khanna et al., 1998; Arora and Cason, 1995; Arora and Cason, 1996).

In order to generate the largest sample possible and to avoid a sample selection bias due to attrition, we create an unbalanced panel of firm-year observations for the time period 1993 to 1998.[6] The overlap between the production data set and the air emissions data set is quite limited. The two data sets only hold 4,688 observations in common.[7] Then we screen for meaningful data by applying the following criteria: non-missing emissions and positive production value.[8] This screening and restriction generates an unbalanced panel of 2,632 observations.[9] The dataset contains 631 firms.

Descriptive Statistics

Table 1 presents a statistical summary of the data. As shown in Table 1.a, our data are sufficiently spread across the six years of our time frame. Table 1.b presents a statistical summary of emissions and production value. As demonstrated by the standard deviation measures and range of values, our data set contains much variation in production value and total emissions, which facilitates our estimation. Table 1.c disaggregates the emissions data by year. Consistent with the economy-wide statistics shown in Figure 2.a, over the six years of the sample period, per-firm emissions declined. In 1993, the average firm emitted 1,287 tons of pollutants. In between 1993 and 1998, the mean value steadily and monotonically declined. By 1998, the average value had dropped to 774 tons. These tabulated differences seem to indicate that allowing the functional relationship between emissions and production to vary over time might be warranted. Table 1.d indicates the distribution of firms by industrial classification. Table 1.d also demonstrates that emissions differ dramatically across the variety of sectors. In particular, per firm emissions vary substantially across the sectors. These tabulated differences seem to indicate that controlling for sectoral variation is important.

TABLE 1
DESCRIPTIVE STATISTICS

Table 1.a. Statistical Summary of Production Value and Emissions

Variable	Mean	Std Dev	Minimum	Maximum
Production Value (000s Czech Crowns) [a]	1,618,320	4,618,679	1,869	89,906,018
Emissions (tons)	962	4,056	0	48,883
N = 2,632				

[a] Production value is adjusted to 1998 real Czech Crowns using the Czech Consumer Price Index.

Table 1.b. Year Distribution of Data and Year-Specific Descriptive Statistics for Emissions

Year	# of Firms	Percent of Sample	Mean Emissions (tons)
1993	356	13.5	1,287
1994	469	17.8	1,017
1995	468	17.8	1,002
1996	484	18.4	853
1997	457	17.4	891
1998	398	15.1	774

Table 1.c. Distribution According To Sectoral Classification and Sector-Specific Statistics

Industry	Obs	%	Mean (tons)
Agriculture, Hunting, Forestry, Fisheries	20	0.76	16.1
Mining and Quarrying	33	1.26	3,621.6
Manufacturing of Food Products, Beverages, & Tobacco	397	15.11	150.2
Manufacturing of Textiles, Textile Products, Leather, and Leather Products	216	8.22	265.5
Manufacturing of Wood, Wood Products, Pulp, Paper, Paper Products, and Publishing & Printing	89	3.39	1,116.7
Manufacturing of Coke and Refined Petroleum	14	0.53	1,107.6
Manufacturing of Chemicals, Chemical Products, and Synthetic Fibers	126	4.79	2,732.2
Manufacturing of Rubber and Plastic Products	53	2.02	92.9
Manufacturing of Other Non-Metallic Mineral Products	234	8.90	542.3
Manufacturing of Basic Metals and Fabricated Metal Products	308	11.72	1,702.5
Manufacturing of Machinery and Equipment n.e.c.	301	11.45	165.6
Manufacturing of Electrical and Optical Equipment	117	4.45	83.5
Manufacturing of Transport Equipment	193	7.34	151.5
Manufacturing n.e.c.	92	3.50	144.8
Electricity, Gas, and Water Supply	160	6.09	6,677.0
Construction	120	4.57	42.0
Wholesale and Retail Trade; Motor Vehicle Repair; Hotels and Restaurants; Transport, Postal Service, Storage, and Telecommunications [b]	50	1.91	17.8
Finance, Real Estate, Rentals, Business, Research, Public Administration	73	2.74	14.4
Education, Health, and Veterinary Services; Other Public and Social Services	33	1.26	27.1

[b] These disparate sectors are combined because individually they represent too small a portion of the sample to facilitate estimation. This sectoral category also includes 17 observations (0.65 % of sample) from the sector of “Other n.e.c.”

ANALYSIS OF AIR POLLUTANT EMISSION LEVELS

In this section, we use the described data to explore the effects of production on Czech air pollutant emissions.

Econometric Structure

We estimate the relationship between air pollution levels and important explanatory variables. For two reasons, we estimate air pollutant emissions in absolute levels. First, this form is relevant for the Czech legal framework since Czech government regulators impose quantity-based limits (e.g., tons per month), which relate directly to absolute levels. Second, this form cleanly connects production levels to emission levels.[10]

To construct the econometric models, we define the following notation. As the dependent variable, p_{it} denotes the amount of pollution emitted by firm *i* in time period *t*. Emissions most likely depend strongly on the level of production, which is denoted as y_{it}. The level of production enters in three terms: linear (y_{it}), quadratic (y_{it}^2), and cubic (y_{it}^3).[11] To control for sector-specific variation, we include a sectoral indicator for each sector displayed in Table 1.d. These indicators are collectively denoted as vector X_i. By design, the regression equation (shown below) contains both a constant and an indicator for each sector. To accommodate this combination of regressors, the estimation must restrict the sum of the coefficients associated with the sectoral indicators to equal zero (Suits, 1984). By including all the sectoral indicators, while restricting the sum of coefficient values to zero, each sectoral coefficient is calculated relative to the average sector rather than a specific sector. (The latter reference applies when a single sectoral indicator is excluded from the regressor set.) Thus, each sectoral coefficient represents a particular sector's deviation from the sample-wide mean, as captured by the constant term. This construction facilitates the generation of predicted emissions values, which are examined below.

Given this notation, we formulate the following econometric model:

$$p_{it} = \alpha + \beta\, y_{it} + \tau\, y_{it}^2 + \delta\, y_{it}^3 + \theta\, X_{it} + e_{it}\,, \qquad (4)$$

where e_{it} denotes the error term. To accommodate the panel data structure, we estimate equation (4) separately for each individual year using year-specific data. Specifically, the analysis divides the sample into various year-specific sub-samples and estimates each year-specific sub-sample as a separate equation within a multi-equation regression system:

$$p_{i93} = \alpha_{93} + \beta_{93}\, y_{i93} + \tau_{93}\, y_{i93}^2 + \delta_{93}\, y_{i93}^3 + \theta_{93}\, X_{i93} + e_{i93}\,, \qquad (5a)$$

$$p_{i94} = \alpha_{94} + \beta_{94}\, y_{i94} + \tau_{94}\, y_{i94}^2 + \delta_{94}\, y_{i94}^3 + \theta_{94}\, X_{i94} + e_{i94}\,, \qquad (5b)$$

$$p_{i95} = \alpha_{95} + \beta_{95}\, y_{i95} + \tau_{95}\, y_{i95}^2 + \delta_{95}\, y_{i95}^3 + \theta_{95}\, X_{i95} + e_{i95}\,, \qquad (5c)$$

$$p_{i96} = \alpha_{96} + \beta_{96}\, y_{i96} + \tau_{96}\, y_{i96}^2 + \delta_{93}\, y_{i96}^3 + \theta_{96}\, X_{i96} + e_{i96}\,, \qquad (5d)$$

$$p_{i97} = \alpha_{97} + \beta_{97}\, y_{i97} + \tau_{97}\, y_{i97}^2 + \delta_{93}\, y_{i97}^3 + \theta_{97}\, X_{i97} + e_{i97}\,, \qquad (5e)$$

$$p_{i98} = \alpha_{98} + \beta_{98}\, y_{i98} + \tau_{98}\, y_{i98}^2 + \delta_{93}\, y_{i98}^3 + \theta_{98}\, X_{i98} + e_{i98}\,, \qquad (5f)$$

where e_{i93} through e_{i98} represent the year-specific error terms. Thus, the analysis generates six sets of estimation results. This approach permits the functional relationship between emissions and production to vary over time. Given the transitional nature of the Czech economy between 1993 and 1998, this flexibility seems reasonable, if not warranted.[12] Moreover, this approach examines cross-sectional variation in each year.

For reasons described below, we do not utilize standard panel estimators: between-group, pooled OLS, fixed effects, and random effects. First, the between-group estimator calculates the mean value of the dependent and independent variables for each firm and then estimates the model based on these mean values. This approach does not allow the functional relationship between emissions and production to vary over time. Second, the pooled OLS estimator frequently suffers from omitted variable bias by excluding firm-specific intercept terms. This study tests for this bias by implementing a F-test of fixed effects. If the F-test indicates significant firm-specific effects, the pooled OLS estimator is biased. Based on the estimated F-test statistic of 26.29 (p=0.0001), the pooled OLS estimator suffers from the noted omitted variable bias. Third, the random effects estimator might not be consistent. Based on the estimated

Hausman test statistic of 24.76 (p=0.0017), the random effects estimator is inconsistent.[13] Fourth, while the fixed effects estimator is consistent by construction, it examines only within-firm variation. By including firm-specific intercept terms as regressors, the fixed effect estimator examines deviations from each firm's individual mean. Thus, the fixed effects estimator cannot shed light on across-firm variation. This feature may limit the study's ability to examine production scale effects if production levels do not vary sufficiently within firms.

In contrast, estimation of multiple year-specific sub-samples examines exclusively across-firm variation (i.e., cross-sectional variation) in each year. Arguably, across-firm variation better captures sectoral production scale effects than does intra-firm variation. While analysis of across-firm variation is not able to capture the experience of a single firm, this type of analysis serves our purpose effectively. We are not interested in capturing the experience of a single firm. Instead, we are interested in capturing the experience of a set of firms within a single industrial sector.

By considering a range of production levels, we allow a given sector to select its optimal pollution control method for each relevant production level. In contrast, examination of intra-firm variation, based on fixed effects estimation of the panel data set, may not observe a full set of optimal choices. Instead, this examination of intra-firm variation may observe one optimal choice and a set of sub-optimal choices due to the strong need to install physical capital with high fixed costs. By analyzing multiple years of cross-sectional variation, the analysis increases the likelihood that our sample will capture an individual firm switching from one optimal choice to another optimal choice as time progresses and new investment becomes cost-effective. These individual choices would be reflected in our estimates, as the tendency of a given set of firms shifts.

Estimation Results

As its primary objective, this paper examines production scale effects. To examine the economies and diseconomies of scale associated with pollution control, the econometric analysis evaluates the estimated effects of the three production terms: linear, quadratic, and cubic. Results from the estimation of the multi-equation regression system are shown in Table 2. We interpret each year's results separately, while comparing the full set of six year-specific results as a whole, in order to assess how the production terms vary over the transitional period of 1993 to 1998.

TABLE 2
OLS ESTIMATION OF AIR POLLUTANT EMISSIONS USING YEAR-SPECIFIC REGRESSION SAMPLES [A]

Year	Intercept		Production [b] (Linear Effect)		Production-squared [b] (Quadratic Effect)		Production-cubed [b] (Cubic Effect)	
1993	200.667		0.4056	**	28.439 E-6	**	- 53.98 E-11	**
	(356.594)		(0.1586)	*	(8.504 E-6)	*	(10.74 E-11)	*
1994	250.600		0.3003	**	5.7586 E-6	**	- 148.00 E-11	**
	(284.420)		(0.1553)		(1.2983 E-6)	*	(24.61 E-11)	*
1995	62.593		0.2350	*	56.401 E-6	**	- 123.00 E-11	**
	(267.338)		(0.1373)		(9.530 E-6)	*	(15.34 E-11)	*
1996	- 446.670	**	0.7872	**	- 2.167 E-6		- 18.42 E-11	**
	(233.114)		(0.1190)	*	(6.723 E-6)		(8.73 E-11)	
1997	- 347.836		1.0002	**	- 23.351 E-6	**	13.67 E-11	**
	(272.755)		(0.1271)	*	(5.477 E-6)	*	(4.77 E-11)	*
1998	- 36.738		0.1324		85.594 E-6	**	- 235.00 E-11	**
	(209.009)		(0.1577)		(17.463 E-6)	*	(44.38 E-11)	*

Year	# of Obs	Adjusted R^2
1993	356	0.5175
1994	469	0.4211
1995	468	0.4537
1996	484	0.3736
1997	457	0.3126
1998	398	0.4809

Standard errors are noted inside parentheses.
*, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

[a] Each regression model also includes 19 sectoral indicators. Moreover, the sum of the sectoral indicator coefficients is restricted to zero.

[b] Units for production are millions of Czech crowns; units for production-squared are trillions of Czech crowns; units for production-cubed are quintillions of Czech crowns.

When relevant, we also identify the threshold level of production between economies and diseconomies of scale when relevant. As noted in Section 2, this threshold level of production sets the second derivative with respect to production equal to zero: p" = 0. The second derivative equals zero when the threshold level of production $Y_t^* = -2\tau_t / 6\delta_t$ for year *t* within the multi-year-specific-equation regression system. [Manipulation of equation (4) or equations (5a) through (5f) identifies this relationship.] The units for τt and Θ_t are emission tons per trillions of Czech Crowns; the units for δ_t and ξ_t are emission tons per quintillions of Czech Crowns. Thus, Y_t^* is measured in millions of Czech Crowns.

The results for 1993 indicate that the linear and quadratic production effects are both significantly positive, while the cubic production effect is significantly negative. In other words, emissions are generally rising in production, initially at an increasing rate but eventually at a declining rate. The threefold effect of production on emissions in 1993 is captured by Figure 1.b. As production rises in 1993, firms first face diseconomies of scale but later enjoy economies of scale, after production clears the threshold level of 17,561 million Czech Crowns.

Results for 1994 are qualitatively identical to the 1993 results. Again, the linear and quadratic production effects are significantly positive, while the cubic production effect is significantly negative. Thus, similar to 1993, emissions in 1994 are captured by Figure 1.b. As production rises in 1994, firms first face diseconomies of scale, while later enjoying economies of scale, once production exceeds the threshold level of 12,970 million Czech Crowns.

Results for 1995 are qualitatively identical to both 1993 and 1994. The particular threshold level between diseconomies and economies of scale is 15,285 million Czech Crowns.

Results for 1996 indicate that the linear production effect is significantly positive, the quadratic production is insignificantly negative (i.e., indistinguishable from zero), and the cubic production effect is significantly negative. In contrast to the preceding years of 1993 to 1995, firms in 1996 do not face diseconomies of scale at any production level. Instead, firms in 1996 enjoy economies of scale regardless of the production level, as captured by Figure 1.c.

The results for 1997 indicate that the linear production effect is significantly positive, the quadratic production effect is significantly negative, and the cubic production effects is significantly positive. In other words, emissions are generally rising in production, initially at a declining rate but eventually at an increasing rate. This relationship between emissions and production is captured by Figure 1.a. As production rises in 1997, firms first enjoy economies of scale, while later facing diseconomies of scale, once production clears the threshold level of 56,940 million Czech Crowns. These results for 1997 stand in contrast to all of the preceding years' results. Perhaps, 1997 represents a fundamental shift in Czech firms' abilities to control air emissions. Possibly, the Czech Republic's successful transition from a plan-based economy to a market-based economy altered firms' approaches to environmental management. Part of this shift is perhaps reflected in the 1996 results since the quadratic production effect first becomes negative in 1996, even though it is not statistically significant in that year. By 1997, this negative quadratic term is statistically significant.

Lastly, the results for 1998 indicate that the linear production is insignificantly positive (p=0.40). Even though the coefficient's positive sign is reassuring, its insignificance is surprising. In contrast, the quadratic production effect is significantly positive, while the cubic production effect is significantly negative. Perhaps, the significant quadratic and cubic production terms are absorbing too much of the explanatory power provided by production, leaving none for the linear production term. This discussion notwithstanding, we focus on the quadratic and cubic terms in order to identify the production scale effect. [As shown in equation (3), the second derivative of emissions with respect to production - p"- does not depend on the linear production effect.] Similar to the years of 1993 to 1995, as production rises in 1998, firms first face economies of scale but later enjoy economies of scale, after production exceeds the threshold level of 12,141 million Czech Crowns. Again, Figure 1.b captures this emission-production relationship.

Since 1998 is qualitatively identical to the years of 1993 to 1995, the year of 1997 most likely does not represent a fundamental shift in pollution control, prompted potentially by the Czech economy's transition. Instead, it appears that 1997 is an outlier. As one possible explanation, 1997 represents the start of a three-year recession. Perhaps, this macroeconomic fluctuation affected the relationship between emissions and production.

In this new light, 1996 probably does not represent a modest move towards the alternative relationship between emissions and production revealed in 1997. Instead, 1996 more likely represents a minor modification of the general pattern found in 1993, 1994, 1995, and 1998. Perhaps, in 1996, the diseconomies of scale are simply too weak to identify from the estimated quadratic production term. Of course, the (insignificantly) negative coefficient on the quadratic production term in 1996 weakens this conclusion.

Finally, we compare across the years based on the year-specific coefficients, as tabulated in Table 3.a. The pattern of intercept terms does not seem informative. The linear production effect declines insignificantly from 1993 to 1995, then increases significantly in 1996 and 1997, while significantly dropping in 1998, as shown in Table 3.a. Specifically, the linear effects in 1996 and 1997 are significantly stronger than the effects in the other four years. The quadratic production effect varies significantly across the years, as shown in Table 3.b. More positive quadratic effects indicate stronger diseconomies of scale. The most positive quadratic effect of 1998 is significantly greater than the effects in 1993, 1996, and 1997 but comparable to the effects in 1994 and 1995. The most negative quadratic effect of 1997 clearly differs from all of the other years. Moreover, the negative effect in 1996 significantly differs from the positive effects of 1993, 1994, 1995, and 1998. The cubic production effects also vary significantly across the years, as shown in Table 3.b. More positive cubic effects indicate stronger diseconomies of scale. The cubic effect is clearly most positive in 1997. The effect is most negative in 1998, though 1994 is comparably negative. These comparisons reaffirm the exceptional nature of 1996 and 1997, especially 1997 since it clearly contrasts with the other years, including 1996.

TABLE 3
F-TESTS OF COMPARISON BETWEEN YEAR-SPECIFIC COEFFICIENTS: BASED ON ESTIMATION OF YEAR-SPECIFIC SAMPLES

Table 3.a. Year-Specific Intercepts and Year-Specific Linear Production Effects

Reference Year	Comparison Year	Intercept		Linear Production	
		Difference	p-value	Difference	p-value
1993	1994	49.933	0.9138	- 0.1054	0.6175
	1995	- 138.073	0.7545	- 0.1707	0.3745
	1996	- 647.337	0.1334	0.3816	0.0396
	1997	- 548.503	0.2084	0.5946	0.0010
	1998	- 237.405	0.5963	- 0.2732	0.2683
1994	1995	- 188.007	0.6311	- 0.0653	0.7538
	1996	- 697.270	0.0664	0.4869	0.0160
	1997	- 598.436	0.1203	0.7000	0.0004
	1998	- 287.339	0.4712	- 0.1679	0.5177
1995	1996	- 509.263	0.1525	0.5522	0.0025
	1997	- 410.429	0.2564	0.7653	0.0001
	1998	- 99.332	0.71917	- 0.1026	0.6748
1996	1997	98.834	0.7769	0.2131	0.2108
	1998	409.932	0.2600	- 0.6548	0.0062
1997	1998	311.097	0.3998	- 0.8679	0.0002

Table 3.b. Year-Specific Quadratic Production Effects and Year-Specific Cubic Production Effects

Reference Year	Comparison Year	Quadratic Production		Cubic Production	
		Difference	p-value	Difference	p-value
1993	1994	29.15 E-6	0.0561	- 94.34 E-11	0.0005
	1995	27.96 E-6	0.0186	- 68.79 E-11	0.0001
	1996	- 30.61 E-6	0.0027	35.57 E-11	0.0064
	1997	- 51.79 E-6	0.0001	67.65 E-11	0.0001
	1998	57.16 E-6	0.0166	- 181.02 E-11	0.0019
1994	1995	- 1.18 E-6	0.9419	25.54 E-11	0.3846
	1996	- 59.75 E-6	0.0001	129.90 E-11	0.0001
	1997	- 80.94 E-6	0.0001	161.99 E-11	0.0001
	1998	28.01 E-6	0.2870	- 86.68 E-11	0.1684
1995	1996	- 58.57 E-6	0.0001	104.36 E-11	0.0001
	1997	- 79.75 E-6	0.0001	136.44 E-11	0.0001
	1998	29.19 E-6	0.2334	- 112.22 E-11	0.0595
1996	1997	- 21.18 E-6	0.0140	32.08 E-11	0.0015
	1998	87.76 E-6	0.0002	- 216.58 E-11	0.0002
1997	1998	108.94 E-6	0.0001	-248.66 E-11	0.0001

While the estimation controls for sectoral variation, given our focus on production effects, we neither report nor interpret the estimation results for the set of individual sectoral indicators. These estimation results are available from the authors upon request.

Predicted Emissions Levels

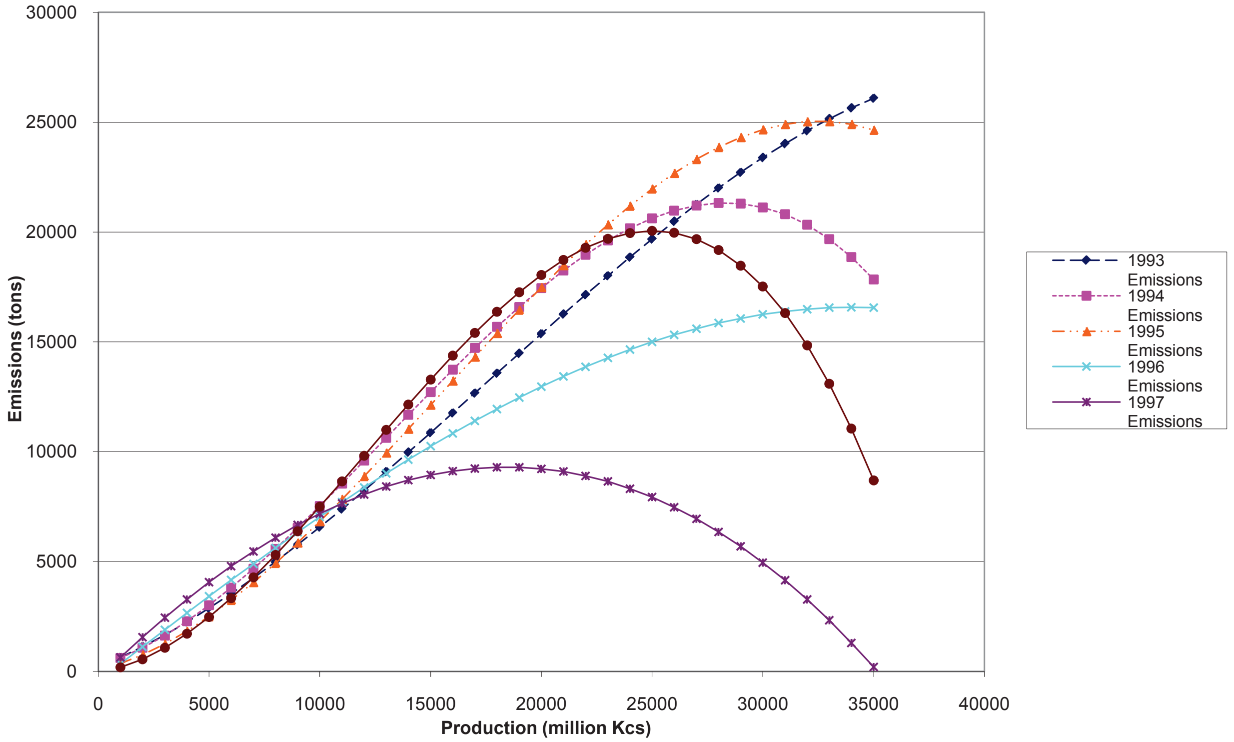
To facilitate a better understanding of production scale effects, we next generate predicted emission values based on the year-specific estimated coefficients and various production levels. We separately generate a set of predicted values for each year. Then we visually relate these predicted emission values to production scale by graphing the predicted values against a broad range of production levels. While the graphing of predicted emissions helps to visualize the production scale effects, it does not assess whether the predicted emissions statistically differ across the years. The next sub-section attempts to assess any statistical differences properly by testing whether the predicted emissions differ significantly between each pair of years based on the coefficient estimates. This testing takes into account the statistical significance of each relevant coefficient used to generate the predicted emission level.

Emissions depend on a constant term, production, and sectoral indicators, as shown in equations (5a) through (5f). Since the estimation restricts the sum of sectoral indicator coefficients to equal zero, the predicted values for the average sector do not depend on the sectoral coefficient estimates. Instead, the predicted values apply to the average sector without any further adjustment. Thus, the sectoral indicators do not need to be incorporated into the prediction of emission levels. Instead, we focus exclusively on the constant and production coefficients. In this regard, we utilize both statistically significant and insignificant coefficients. Any concern over the use of insignificant coefficients applies only to two coefficients: the quadratic production term in 1996 and linear production term in 1998.

Figure 3 displays the predicted emission values graphed against production levels. We display a range of production levels between 1,000 million Czech Crowns and 35,000 million Czech Crowns. We omit production levels below 1,000 million since the graph displays intervals of 1000 and the minimum sample value is positive. We omit production levels above 35,000 million Czech Crowns, which represents the 99.4-tile value of the sample distribution, since we regard these upper values as outliers and their inclusion disrupts the visual effectiveness of the graph. Moreover, we do not display negative predicted emission values since their inclusion also disrupts the graph's visual effectiveness.

As shown in Figure 3, in each year, the graphed curves at sufficiently high levels of production begin to fall, i.e., as production rises, emissions actually drop. At first, this relationship may seem odd. However, as noted above, the estimation represents a set of optimal choices selected over a range of production levels. With this perspective in mind, a firm may not choose to adopt a highly effective pollution control method until production rises to a justifiable level. In this case, a firm may increase its production, while operating a more effective pollution control method, causing emissions to fall, despite the increase in production. This point notwithstanding, please note that this negative relationship between production and emissions exists only at extremely high production levels. For a very large percent of the sample, emissions are rising in production.

FIGURE 3
PREDICTED EMISSIONS BY YEAR



The pattern of predicted emission values shown in Figure 3 helps to discern the curvatures of the estimated third-degree polynomial function between emissions and production. For low levels of production, up to approximately 15,000 million Czech Crowns, the year-specific curves do not deviate much from one another. However, starting at about 15,000 million Czech Crowns, certain year-specific curves begin to diverge from the pack. Most noticeably, the 1997 emissions curve begins to fall away from the other curves and remains substantially below the other curves for the rest of the relevant production range. As displayed in Figure 3, the 1997 emissions curve demonstrates that Czech firms in 1997 enjoyed strong economies of scale for the entire production range. (Recall that the 1997 threshold level between economies and diseconomies of scale is 56,940 million Czech Crowns, well above the relevant production range: 0 to 35,000 million Czech Crowns.) Thus, even though the estimated cubic production coefficient for 1997 indicates that Czech firms eventually encounter diseconomies of scale, the positive quadratic production term overwhelms the relatively smaller negative cubic production term, implying economies of scale for all relevant production levels. (Below, we evaluate the implication of this result.)

At the identified departure point of 15,000 million Czech Crowns, the 1996 emissions curve starts to fall away from the other curves (excepting the 1997 curve). The 1996 curve stays below the remaining curves until the 1998 emissions curve crosses it at about 31,000 million Czech Crowns. While the 1996 emissions curve displays low predicted values, the economies of scale are less pronounced in the upper production range than the economies of scale displayed in the 1994 and 1998 curves. As noted above, the 1996 emissions curve displays economies of scale over the entire production range.

The 1993 emissions curve remains in the middle of the set of emission curves for most of the relevant production range, while demonstrating little curvature. While statistically significant, apparently the estimated quadratic and cubic production terms are not very economically meaningful.

Once production increases to a level beyond the first identified departure point of 15,000 million Czech Crowns, the remaining curves - for years 1994, 1995, and 1998 - lie above the other emission curves until approximately 24,000 million Czech Crowns. By this higher production level, economies of scale begin to drive the 1998 emissions curve down. This curve drops substantially over the rest of the production range. The 1994 emissions curve begins to drop soon after the 24,000 million Czech Crown departure point. In contrast, the 1995 emissions curve remains above all of the other curves until the 1993 emissions curve crosses it at approximately 33,000 million Czech Crowns. At this very high production level, the 1995 emissions curve is just starting to drop.

In sum, the display of predicted emission values graphed against production levels helps to compare and contrast the year-specific emission-production relationships. First, at low levels of production, the year-specific emissions do not appear dramatically different. Second, at sufficiently high production levels, even years with qualitatively identical curvatures (based on coefficient signs) distinguish themselves. Namely, emissions in 1993 seem quantitatively different from emissions in 1994, 1995, and 1998. Third, emissions in 1996 and 1997 are both qualitatively and quantitatively different from emissions in other years. Nevertheless, the range of scale economies in 1996 and 1997 is comparable to the range found in the other years since firms in 1996 face no scale diseconomies and firms in 1997 face scale diseconomies only at extremely high production levels. (Specifically, both 1996 and 1997 possess economies of scale over 99.9 % of the lower production range since the 1997 threshold level between economies and diseconomies of scale is 56,940 million Czech Crowns, which lies at the 99.9-tile of the production distribution.)

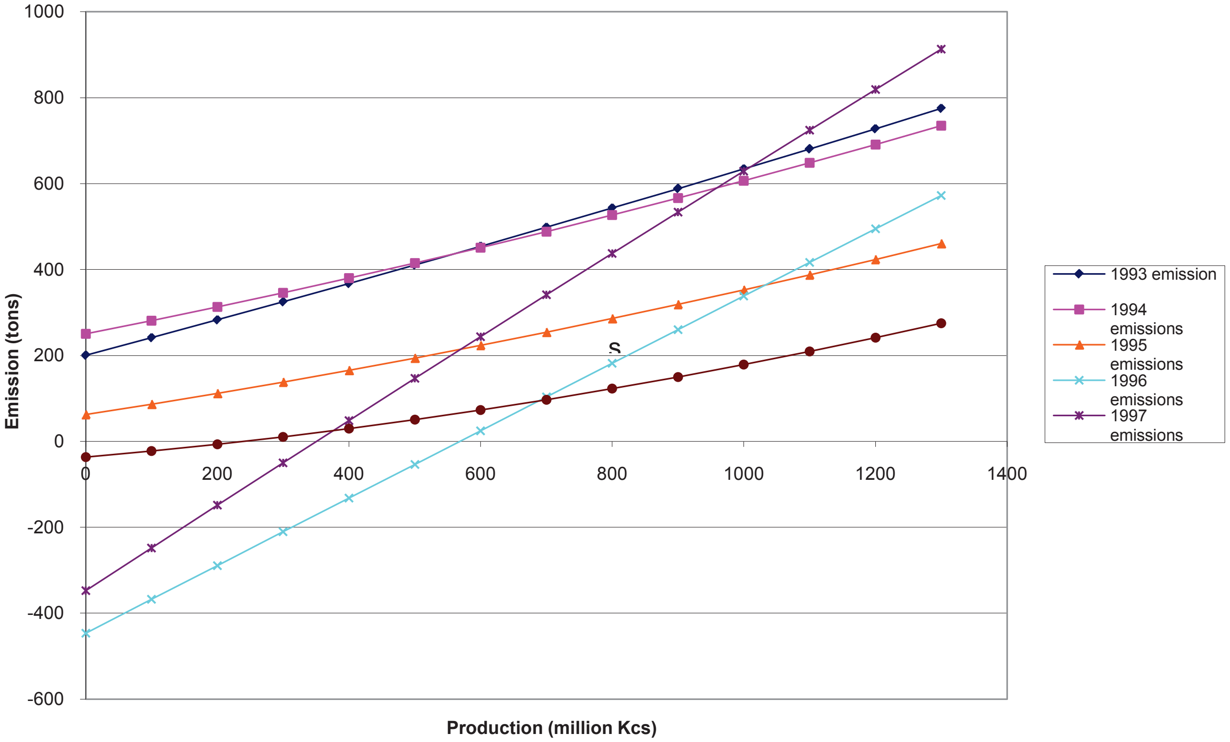
Above, we identify 1997 as possible outlier year. However, with our new insight, To elaborate, the year of 1997 may not be as different as it appears. In particular, 1997 appears less different from the other years in that Czech firms enjoy economies of scale in 1997 over a similar range of production levels as Czech firms in other years. As displayed in Figure 3 and demonstrated by the assessment of 1997's threshold between economies and diseconomies of scale, 1997 is reasonably similar to 1993, 1994, 1995, and 1998 once these other years possess economies of scale. In other words, the apparent diseconomies of scale for 1997 never conflict with the economies of scale for 1993, 1994, 1995, and 1998, as shown in Figure 3.

Thus, even though the estimated cubic production coefficient for 1997 indicates that Czech firms eventually encounter diseconomies of scale, the positive quadratic production term overwhelms the relatively smaller negative cubic production term, implying economies of scale for all relevant production levels. Thus, 1997 is highly similar to 1996, as shown in Figure 3.

This evaluation of predicted emission values considers a very broad range of production levels. However, 75 % of the sample distribution lies between 1.869 million Czech Crowns and 1,306.870 million Czech Crowns. In contrast, the relevant threshold levels that discern economies of scale from diseconomies of scale lie between 12,140.991 million Czech Crowns and 56,939.697 million Czech Crowns. Thus, in any given year, for a large portion of the sample, Czech firms experience only one type of production scale effect. Based on this 75th percentile benchmark, most firms in 1993, 1994, 1995, and 1998 experience only diseconomies of scale, while most firms in 1996 and 1997 experience only economies of scale. If we focus the analysis exclusively on the production levels between 0 and 75th percentile of 1,306.870 million Czech Crowns, as shown in Figure 4, then the graph of predicted emission values is much less able to discern economies of scale from diseconomies of scale. (Nevertheless, Figure

4 is able to demonstrate substantive differences in emission levels and slopes, which is not the focus of this paper.) Apparently, the differences between economies and diseconomies of scale are meaningful mostly at the upper range of production levels. In other words, the statistical significance appears to translate into economic substance only for rather large firms.

FIGURE 4
PREDICTED EMISSIONS BY YEAR AT LOWER PRODUCTION LEVELS



Comparison of Apparent Emission Control Abilities across Years

This last sub-section attempts to assess whether firms appeared to possess better or worse abilities to control emission in certain years relative to other years. As one part of this assessment, this sub-section analyzes the set of production-related coefficients in order to discern “better years” from “worse years”. By better, we mean that the overall effect of production indicates a lower level of emissions. For this assessment, we ignore the intercept terms, which obviously also affect the emissions levels, since intercept terms are based on the situation when production equals zero. One year is unambiguously “better” than another year if each production effect is smaller (including less negative) so that a given level of production translates into a lower level of emissions. Put differently, one year generates an unambiguously lower level of emissions if each relevant estimated coefficient is significantly smaller than another year’s set of estimated coefficients. Specifically, one year’s emissions are lower if the year-specific linear, quadratic, and cubic production coefficients are smaller than another year’s pair of production-related coefficients. Of course, if not all of the comparisons of production effects align between two years, then no unambiguous ranking exists between two years. The difficulty of identifying unambiguous rankings is great because we are considering higher-order polynomials, especially since many of the years possess countervailing quadratic and cubic production effects.

Given this difficulty, we also implement an alternative approach for discerning “better years” from “worse years”: comparing predicted emission levels across the years. In this approach, one year is “better” than another year if its predicted emissions level is lower. Since predicted emissions integrate production-related coefficients in a systematic manner, this alternative approach does not suffer the noted ambiguity concern, e.g., one year's linear production coefficient is smaller yet the other year's quadratic production coefficient is smaller. Specifically, this approach analyzes whether the predicted emissions statistically differ across years by testing whether predicted emissions differ significantly between each pair of years based on the coefficient estimates. This testing takes into account the statistical significance of each relevant coefficient used to generate the predicted emission level. The associated test statistics are shown in Table 4. For each pairwise comparison, the analysis evaluates the difference in predicted emissions at the median production value of 552 million Czech Crowns. Since predicted emissions incorporate year-specific intercept terms, they extend beyond a narrow assessment of the production-emission relationship.

In turn, we assess the ranking of production-related coefficients and predicted emission levels. A joint assessment of the three production-related effects reveals only one unambiguous ranking of year-specific results generated by the estimation of year-specific samples: 1994 is unambiguously better than 1993, though the difference in linear production effects is insignificant. Similarly, based on predicted emission levels drawn from year-specific-sample estimates, no significant difference exists between any pair of years, as shown in Table 4.

TABLE 4
F-TESTS OF COMPARISON BETWEEN YEAR-SPECIFIC PREDICTED EMISSION LEVELS: BASED ON OLS ESTIMATION OF YEAR-SPECIFIC SAMPLES

Production level = median value of 552.334 million Czech Crowns

Reference Year	Comparison Year	Difference	p-value
1993	1994	0.474	0.9991
	1995	- 223.918	0.5750
	1996	- 445.857	0.2558
	1997	- 235.752	0.5545
	1998	- 371.191	0.3537
1994	1995	- 224.392	0.5206
	1996	- 446.331	0.1909
	1997	- 236.226	0.4982
	1998	- 371.665	0.2887
1995	1996	- 221.939	0.4848
	1997	- 11.834	0.9710
	1998	- 147.273	0.6528
1996	1997	210.105	0.5076
	1998	74.667	0.8148
1997	1998	- 135.439	0.6786

These results seem to indicate that most of the discernible differences in the production-emission relationship do not translate into discernible differences in emission levels, at least when evaluated at the median production level. Based on this assessment, one may wish to focus on the discernible differences within the production-emission relationship only for the purpose of evaluating the general nature of the relationship: economies of scale versus diseconomies of scale.

Trend over Time

All of the preceding results stem from analysis that allows the production-emission relationship to vary across all of the individual years. While this flexibility proves useful and certainly appears warranted, it does not facilitate a compact depiction of the evolution of scale economies regarding pollution control over the 1990s in the Czech Republic. In order to deliver a compact depiction, we replace the year indicators with a time trend (which takes a value of zero in 1993 and a value of five in 1998) and replace the year-specific production terms with interactions between the time trend and the three productions (linear, quadratic, cubic). By not allowing the sector indicators to vary over time, the resulting estimates focus on the trend in the effects of production terms. (We continue to restrict the sum of sectoral coefficients to zero so that the intercept retains a useful interpretation.) The resulting estimates are shown in Table 5.

TABLE 5
OLS ESTIMATION OF AIR POLLUTANT EMISSIONS USING A POOLED REGRESSION SAMPLE: INCLUSION OF A TIME TREND AND INTERACTIONS WITH PRODUCTION TERMS

Regressor [a]	Coefficient	
Time Trend	- 126.26 (48.72)	***
Production [b]	0.6178 (0.0941)	***
Production × Time Trend	0.1003 (0.00001)	***
Production-squared [b]	1.099 E-5 (0.525 E-5)	**
Production-squared × Time Trend	- 0.852 E-5 (0.159 E-5)	***
Production-cubed [b]	- 3.443 E-10 (0.698 E-10)	***
Production-cubed × Time Trend	1.180 E-10 (0.194 E-10)	***
# of observations	2632	
Adjusted R^2	0.390	

Standard errors are noted inside parentheses.
*, **, and *** indicate statistical significance at the 10 %, 5 %, and 1 % levels, respectively.

[a] Each regression model also includes an intercept and 19 sectoral indicators. The sum of the sectoral indicator coefficients is restricted to zero.

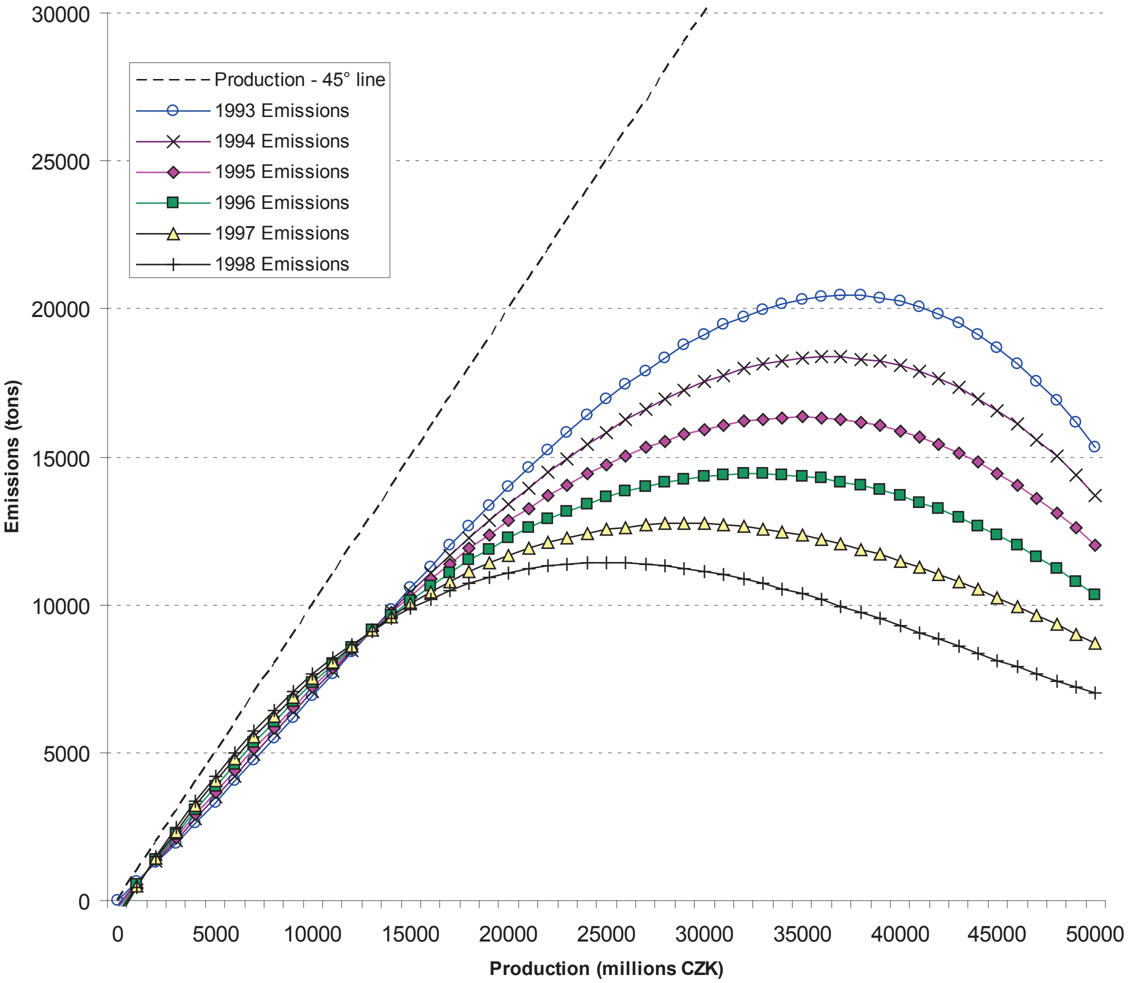
[b] Units for production are millions of Czech crowns; units for production-squared are trillions of Czech crowns; units for production-cubed are quintillions of Czech crowns.

As hoped, the results deliver a compact depiction of the evolution. First and foremost, all of the estimates prove statistically significant so our interpretation is not affected by the absence of significance. Second, the downward trend in emissions is clear. Third, the linear production effect is strongly positive in the baseline year of 1993 and strengthens over time. Fourth, the quadratic production effect is positive in the baseline year of 1993 but has a negative trend so strong that the quadratic production effect turns negative during the sample period. Fifth, the cubic production effect is negative in the baseline year of

1993 but has a positive trend so strong that the cubic production effect turns positive during the sample period. The latter two sets of results indicate that economies of scale are growing over time at lower levels of production, while diseconomies of scale are growing over time at higher levels of production. In sum, these results support the preceding conclusions based on year-specific estimates in a compact package.

Finally, we use these trend-based estimates to generate and display predicted emission values graphed against production levels, as shown in Figure 5. The graphed curves demonstrate two points. First, over the sample period the production-emissions relationship changes from mix of diseconomies and economies of scale (see Figure 1.b) to economies of scale. Second, over the sample period the peak of the production-emission curve shifts down from a production level of 37,000 million CZK to 25,000 million CZK, while the peak of emissions drops by nearly 50 % from 21,000 tons to 12,000 tons.

Figure 5 - Predicted Emissions by Years with Timetrends



SUMMARY

Based on our analysis of Czech firms in the years 1993 to 1998, we conclude that the average Czech firm enjoys economies of scale and encounters diseconomies of scale - depending on the production level - with respect to emission controls, in every year except 1996. In this exceptional year, the average Czech firm enjoys only economies of scale, regardless of the production level. In all but one of the unexceptional years - 1997, as production rises, firms initially face diseconomies of scale, while eventually enjoying economies of scale. In 1997, similar to 1996, the average Czech firm enjoys economies of scale for practically every level of production found within the studied sample. Thus, larger firms - in terms of production - are better able to manage their emissions.

However, the difference between economies and diseconomies of scale are meaningful mostly, if not exclusively, at the upper range of production levels. Therefore, we are compelled to qualify our main conclusion: quite large firms are better able to manage their emissions than moderately large or small firms.

These results generate policy implications. When placing pollution control restrictions on facilities, Czech policymakers should avoid the conventional wisdom that "bigger is better" without proper qualification. Policymakers should realize that "bigger" is not always "better": it appears to depend on the scale of production. As a matter of fact, for most of the years in our sample, moderately large firms are worse than, not better, than small firms at controlling air pollutant emissions. Thus, policymakers should consider the level of production when writing air pollution control permits. This point notwithstanding, for most firms, the difference between economies and diseconomies of scale appears of minor importance. Therefore, for most small- to moderately-sized firms, the consideration of production scale effects need not be critical.

NOTES

1. For the purposes of this conceptual framework, we assume that α is non-negative. For the purposes of illustration in Figure 1, we assume α equals zero, which implies no emissions when production is absent. For the econometric analysis, we place no restrictions on the value of α since we do not know the exact shape of the polynomial function. By not restricting the value of α, the econometric analysis is able to estimate at least an approximation of any unknown higher-order polynomial function.
2. After 1989, the last year under communist control, GDP declined each year between 1990 and 1992, accumulating a 15.4 % reduction - relative to 1989 - by 1992.
3. Further details on air protection policies, country-wide emissions, environmental investment, and environmental issues related to EU accession are available upon request.
4. Estrin et al. (2009) provide a survey of studies on the effects of privatization on firm-level performance in various transition economies.
5. Estimation of values that are adjusted according to the Czech Producer Price Index would generate nearly identical results since the Consumer Price Index and Producer Price Index are strongly and significantly correlated (ρ=0.997, p=0.00001).
6. Use of a balanced panel in the context of a transition economy seems especially ill-advised. One expects many firms to enter and exit the market. This entry and exit is especially important for our study since these movements may represent the main venue for incorporating technological advancement, including more efficient management techniques, and increasing their prevalence, through attrition of those firms lacking them, into our sample of firms. Those firms who remain for the entire sample period poorly represent the relevant population. For this reason, we see little need to estimate a balanced panel dataset even merely to compare the estimation results as a check for robustness. If a balanced panel represents a highly biased sample, one would not expect the correspondingly biased estimation results to "confirm" the unbalanced panel estimates.

7. While unfortunate, this limited overlap does not indicate a problem with the data. Instead, it may simply indicate that firms included in the Aspekt database do not own large stationary air emission sources. In this way, the Aspekt database need not completely represent large stationary air polluters. Therefore, our results may not generalize to all or most large stationary air polluters. The opposite concern is not relevant. The REZZO-1 database is fully comprehensive of all large polluters.

8. We also apply these additional screening criteria: positive total assets and positive fixed assets.

9. Missing values, not inconsistent values, cause most of the reduction in sample size. The final sample size is highly comparable to previous studies of firms in the Czech Republic (e.g., Kocenda and Svejnar, 2002).

10. Alternative analysis estimates air pollutant emissions relative to production ("relative emissions"). To generate relative emissions, this alternative analysis divides the absolute emissions level by the production level. This alternative form may also plausibly capture firm-level environmental performance. However, this alternative form has two disadvantages. First, it does not permit a general analysis of economies and diseconomies of scale. Second, estimation of relative emissions generates much less meaningful and significant results, as judged by *a priori* coefficient sign expectations, estimated individual coefficients, and overall explanatory power.

11. Previous studies of environmental performance also incorporate a contemporaneous measure of production as an explanatory factor, implicitly treating production as pre-determined with respect pollution (Mickwitz, 2003; Foulon et al., 2002; Bluffstone, 1999; Khanna and Damon, 1999; Magat and Viscusi, 1990). As important, based on highly similar data from the Czech Republic, Earnhart and Lizal (2006a) use Granger causality tests to demonstrate that production appears to Granger-cause emissions yet emissions do not appear to Granger cause production, i.e., the Granger causality test statistics reject the null hypothesis of zero influence in the former case but cannot reject the null hypothesis of zero influence in the latter case.

12. By estimating each year separately, the sample size for each regression equation differs from year to year because the panel of Czech firms is unbalanced.

13. The Hausman test statistic is χ^2-distributed with 7 degrees of freedom.

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