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U.S. Environmental Protection Agency
National Center for Environmental Economics
1200 Pennsylvania Avenue, NW (MC 1809)
Washington, DC 20460
<http://www.epa.gov/economics>

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Do Environmental Regulations Disproportionately Affect Small Businesses? Evidence from the Pollution Abatement Costs and Expenditures Survey¹

Randy A. Becker^a
Carl Pasurka Jr.^b
Ronald J. Shadbegian^b

^a Center for Economic Studies
U.S. Census Bureau

^b National Center for Environmental Economics
U.S. Environmental Protection Agency

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Abstract

It remains an open question whether the impact of environmental regulations differs by the size of the business. Such differences might be expected because of statutory, enforcement, and/or compliance asymmetries. Here, we consider the net effect of these three asymmetries, by estimating the relationship between plant size and pollution abatement expenditures, using establishment-level data on U.S. manufacturers from the Census Bureau's Pollution Abatement Costs and Expenditures (PACE) surveys of 1974-1982, 1984-1986, 1988-1994, 1999, and 2005, combined with data from the Annual Survey of Manufactures and Census of Manufactures. We model establishments' PAOC intensity – that is, their pollution abatement operating costs per unit of economic activity – as a function of establishment size, industry, and year. Our results show that PAOC intensity increases with establishment size. We also find that larger *firms* spend more per unit of output than do smaller firms.

Keywords: environmental regulation, costs, business size, U.S. manufacturing

JEL codes: Q52, L51, L6

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I. INTRODUCTION

After the passage of the 1970 Clean Air Act Amendments and 1972 Clean Water Act Amendments, the United States realized significant improvements in both air and water quality. These improvements were due in large part to increasing stringency of environmental regulations that led to steady declines in emissions from industrial sources. According to the Pollution Abatement Costs and Expenditures (PACE) survey, the U.S. manufacturing sector spent nearly \$21 billion dollars on pollution abatement operating costs (PAOC) to comply with environmental regulations in 2005 (U.S. Census Bureau 2008). Policymakers are especially interested in how these regulations affect the economy, and there is a growing literature on the effects of environmental regulations on various plant-level outcomes, including productivity (Berman and Bui 2001a; Gray and Shadbegian 2002, 2003, 2006; Shadbegian and Gray 2005; Becker 2011b; Greenstone, List, and Syverson 2012), investment (Gray and Shadbegian 1998), location (Becker and Henderson 2000; List *et al.* 2003) and employment (Berman and Bui 2001b; Morgenstern, Pizer, and Shih 2002; and Greenstone 2002).

There is also significant interest in whether the impact of environmental regulations differs by the size of the facility. Differences in pollution abatement spending by establishment size might be expected because of statutory, enforcement, and/or compliance asymmetries (Dean, Brown, and Stango 2000; Becker 2005). Statutory asymmetries exist when regulations explicitly impose less stringent requirements on certain types of businesses, such as small businesses.² Enforcement asymmetries result

² For example, the Regulatory Flexibility Act (RFA) of 1980 places requirements on the U.S. Environmental Protection Agency (EPA) and other federal agencies to thoroughly consider the economic impacts rules and regulations will have on small businesses. The objective of the act is to ensure that small businesses have a voice in the process. Furthermore, the Small Business Regulatory Enforcement Fairness

when regulators choose to target certain establishments over others — a decision that may hinge on establishment or firm size (Gray and Deily 1996). Finally, compliance asymmetries arise when regulatory compliance involves significant fixed costs. For example, some pollution abatement is quite capital intensive, which would result in higher costs *per unit of output* for smaller establishments.

Here, we consider the net effect of these three asymmetries, by estimating the relationship between plant size and pollution abatement expenditures. In particular, we use establishment-level data from the U.S. Census Bureau's Pollution Abatement Costs and Expenditures (PACE) surveys of 1974-1982, 1984-1986, 1988-1994, 1999, and 2005. The PACE survey is the most comprehensive source of pollution abatement costs and expenditures data related to environmental protection in the U.S. manufacturing sector. These PACE data are merged to data from the Annual Survey of Manufactures (ASM) and Census of Manufacturers (CM), which include employment, value of shipments, geography, and four-digit Standard Industrial Classification (SIC) industry (or, in recent years, six-digit North American Industry Classification System (NAICS) industry). In this paper, we focus on establishments' PAOC intensity – that is, their pollution abatement operating costs per unit of economic activity – which we model as a function of establishment size, industry, and year. Our results show that PAOC intensity increases with establishment size. We also find that larger *firms* spend more per unit of output than do smaller firms.

Act (SBREFA) of 1996 enacted a range of provisions, including several amendments to the RFA. In brief, SBREFA requires EPA to solicit and consider flexible regulatory options that minimize adverse economic impacts on small entities. It also added a provision that allows small entities adversely affected by a final rule to challenge the agency's compliance with the RFA's requirements in court. Thus, on just these grounds, we might expect to find that small businesses are not disproportionately affected by environmental regulations.

The rest of the paper is organized as follows. In Section II, we survey previous studies on the effects of environmental regulations by business size. Section III describes the data and the methodology. In Section IV, results are presented, and Section V offers some concluding remarks, including directions for future research.

II. LITERATURE REVIEW

Evans (1986) notes that whether or not regulations differentially affect plants or firms by size is important for three reasons. First, if economies of scale exist in regulatory compliance then, other things equal, optimal regulatory policy could require imposing less stringent regulations on smaller plants (i.e., allowing statutory and/or enforcement asymmetries). Brock and Evans (1985) argue that this differential treatment (known as tiering) can be Pareto-superior compared to untiered regulations. Second, society may (and seems to) value small business for non-economic reasons and therefore may want to ensure they are not disproportionately affected by regulation. Finally, Evans argues that the incidence of regulatory compliance costs across plant and/or firm size may indicate why certain industry groups back alternative regulatory policies.

There have been a number of published papers which specifically examine the relationship between environmental regulations and establishment size. Pashigian (1984), using four-digit SIC industry level data between 1972 and 1977 (a period covering the implementation of many new federal environmental regulations), finds that compliance with environmental regulations caused an increase in plant size and a reduction in the number of plants per industry. From these results, Pashigian concludes that environmental regulations place a greater burden on smaller plants as small plants

find it more difficult to compete with larger plants and survive. Evans (1986) is critical of Pashigian's findings for several reasons, including the use of industry-level data. In contrast, Evans obtained data from the U.S. Census Bureau on the average pollution abatement operating costs per employee for three categories of plants: 0-99, 100-499, and 500 or more employees, for single- and multi-plant firms, from 1978-1981. In general, Evans finds evidence of diseconomies of scale in pollution abatement, with 375 of the 403 industries exhibiting diseconomies of scale, 214 of which are statistically significant.

Hartman *et al.* (1997), Dean *et al.* (2000), and Millimet (2003) all find evidence that small businesses are disproportionately impacted by pollution abatement costs. In particular, Hartman *et al.* (1997), in their study of regulatory compliance costs of U.S. manufacturing from 1979-1985, find some evidence of declining average and marginal costs of abatement with increased volume of abated pollutants. Meanwhile, Dean *et al.* (2000) find that industries with high pollution abatement costs had fewer small business formations. Millimet (2003) finds that the optimal plant size is larger in high pollution abatement intensive industries in states with more stringent environmental regulation. Finally, Becker (2005) finds mixed evidence of a disproportionate impact of abatement costs on small business. More specifically, Becker finds that air pollution abatement expenditures under the Clean Air Act were at times disproportionately higher for larger establishments, and sometimes the reverse, depending on the air pollutant.

Since the mid-1990s, there has been a series of otherwise unpublished Small Business Administration (SBA) working papers, examining the impact of environmental regulations – and federal regulations in general – on small businesses. The most recent of

these studies (Crain and Crain 2010) finds that that the cost of complying with environmental regulations, on a per employee basis, is almost five times higher for small businesses than for large businesses. Harrington (2006) argues that “their claim of economies of scale in pollution abatement is utterly without foundation.” In particular, he notes that Crain and Hopkins (2001) “cherry-pick” coefficients, focusing on average firm size as measured by the number of employees while ignoring value of sales (another firm size variables and one with a strong positive correlation with employment) which has the opposite sign.³

An important issue faced by previous studies has been the lack of official government statistics *by business size*. The Census Bureau did briefly publish such statistics as part of the PACE survey. In particular, for three years, 1976-1978, separate estimates of pollution abatement operating costs and pollution abatement capital expenditure were produced for each two-digit SIC manufacturing subsector, and for the manufacturing sector as a whole, for each of six establishment employment size classes (see U.S. Census Bureau, various years). Using value of shipments (i.e., output) statistics on these same size classes from the 1977 Census of Manufactures, we compute aggregate PAOC intensity and plot the results in Figure 1. We find that PAOC intensity increased with establishment size, peaking with the 500-999 employees category before declining a bit for the largest size category (1000+ employees).⁴ Results for the 19 major manufacturing groups (two-digit SIC industries) do not necessarily tell the same story.^{5,6}

³ Crain and Hopkins (2001), Crain (2005), and Crain and Crain (2010) all contain the same regression and the same regression results and interpret them the same way.

⁴ The increase in PAOC intensity in the 1-49 employee category after 1976 may, in part, be an artifact. In 1977 and 1978, establishments with fewer than 20 employees were not sampled in the PACE survey. Therefore, the PAOC intensity in these years is for plants that had 20-49 employees.

⁵ SIC 23 (apparel and other textile products) is not among these, having been excluded from every year of the PACE survey except 1999.

Nevertheless, in 48 of the 57 cases (19 groups x 3 years), PAOC intensity for the 1000+ employee category exceeded that of the 1-49 employee category, with peak PAOC intensity occurring at [frequency]: 1-49 [1], 50-99 [2], 100-249 [7], 250-499 [5], 500-999 [11], and 1000+ [31]. This certainly does not suggest a disproportionate impact on small businesses — if anything, the opposite. These data are obviously limited in that they are for just three years, from some 35 years ago, and at the two-digit SIC level.

III. DATA AND METHODOLOGY

In this paper, we use the establishment-level data from the Pollution Abatement Costs and Expenditures (PACE) surveys of 1974-1982, 1984-1986, 1988-1994, 1999, and 2005.⁷ Here we focus on total pollution abatement operating costs (PAOC), which includes salaries & wages, parts & materials, fuel & electricity, capital depreciation, contract work, equipment leasing, and other operating costs associated with a plant's abatement of its air and water pollution as well as its solid waste.⁸ These data are merged to data on these same establishments from the contemporaneous Annual Survey of Manufactures (ASM) or Census of Manufactures (CM). While the ASM and CM contain a host of variables, here we are simply interested in establishment employment, value of shipments, and four-digit SIC industry (six-digit NAICS industry, in later years). We accept any and all Census Bureau corrections, imputations, and use of administrative

⁶ In some cases, employment-size classes were combined to avoid disclosing information about individual companies. In these cases, PAOC was prorated across the affected cells using 1977 value of shipments, resulting in identical PAOC intensity across these cells.

⁷ The PACE survey was also conducted for reference years 1973 and 1983, but the establishment-level data for those two years are unavailable.

⁸ These survey data, as well as those from the Annual Survey of Manufactures and the Census of Manufactures, are confidential, collected and protected under Title 13 and Title 26 of the U.S. Code. Restricted access to these data can be arranged through the U.S. Census Bureau's Center for Economic Studies. See <http://www.census.gov/ces/> for details.

data. After restricting the sample to cases that had linkable PACE and ASM/CM records in a given year, and after eliminating non-respondents⁹, establishments with signs of production inactivity, plants in Alaska and Hawaii, and those with missing or incomplete data on critical items (e.g., industry code), there are 321,527 establishment-years of observations for estimating the relationship between establishment size and environmental expenditure.

In this paper, we focus on establishments' PAOC intensity – that is, their pollution abatement operating costs per unit of economic activity. Here we employ establishment output in the denominator.¹⁰ PAOC intensity has long been used as a proxy for the intensity of environmental regulation faced by plants and industries. For examples, see Pashigian (1984), Jorgenson and Wilcoxon (1990), List and Co (2000), Keller and Levinson (2002), and Becker (2011a).

Our focus in this paper is not in explaining PAOC intensity, per se, but rather in estimating the relationship between PAOC intensity and establishment size — whatever the underlying explanation(s). Consequently, we model PAOC intensity in the simplest way possible: as a function of establishment size, four-digit SIC industry (or six-digit NAICS industry), and year. To measure establishment size, we use establishment employment, either in linear or natural log form, or to construct a set of six (commonly used) establishment size categories: 1-49, 50-99, 100-249, 250-499, 500-999, and 1000 or more employees. This last variant of our estimating equation is

⁹ Code to identify cases that are thought to be survey respondents and tabulated cases is available from the authors.

¹⁰ Using output has an established precedence in this literature. An alternative that is sometimes used is establishment employment — and PAOC per employee might be said to encapsulate a regulator's implicit choice between environmental protection and jobs. Here, we also present results from a robustness check that uses employment rather than output in the denominator.

$$\log(PAOC_{it} / VS_{it}) = \lambda_0 + \sum \lambda_n \cdot SIC_{nit} + \sum \lambda_t \cdot YEAR_t + \lambda_1 \cdot EMP50_99_{it} + \lambda_2 \cdot EMP100_249_{it} + \lambda_3 \cdot EMP250_499_{it} + \lambda_4 \cdot EMP500_999_{it} + \lambda_5 \cdot EMP1000plus_{it} + e_{it}$$

where, for plant i at time t , $PAOC$ is pollution abatement operating costs, VS is output (value of shipments), SIC is a set of dummy variables indicating the plant's four-digit SIC industry (or six-digit NAICS industry, in years 1999 and 2005), $YEAR$ is a set of year dummies, and $EMP50_99$, $EMP100_249$, $EMP250_499$, $EMP500_999$, and $EMP1000plus$ is a series of establishment size indicator variables based on employment. The omitted size category is the very smallest establishments, with 1-49 employees.¹¹

One very important characteristic of these data is that some 22 percent of establishments have “zero” $PAOC$.¹² Moreover, the incidence of zero $PAOC$ appears related to our variable of interest, with incidence (from smallest to largest plants) of 51, 31, 21, 14, 9, and 5 percent, respectively. The prevalence of zeros suggests the use of models other than ordinary least squares (OLS). Tobit specifications are often employed when there is large cluster of zeros. In this paper, we briefly consider censored normal regression – a generalization of the standard Tobit that allows the censoring point to vary by observation.¹³ There are at least two issues with this approach, however. First, Tobit

¹¹ Since 1976, with the exception of 1999, establishments thought to have fewer than 20 employees were excluded from the PACE survey sampling. According to early PACE publications, early surveys “indicated that establishments with less than 20 employees contributed only about 2 percent to the pollution abatement estimates while constituting more than 10 percent of the sample size.” (U.S. Census Bureau, various years) In the 1977 CM, establishments with fewer than 20 employees accounted for 67.5% of the universe of manufacturing plants. Becker and Shadbegian (2005) find that, in 1999, establishments with fewer than 20 employees accounted for 3.0% of pollution abatement expenditure in the manufacturing sector, while accounting for 5.1% of value added.

¹² This includes cases of missing $PAOC$ which, for survey respondents, is equivalent to zero $PAOC$ for tabulation purposes.

¹³ $PAOC$ intensity, as measured by $PAOC/VS$ in linear form, is not normally distributed. However, the natural log of $PAOC/VS$ has a skewness of -0.311 and kurtosis of 2.87, which are very near the reference values for symmetry and normality. We therefore estimate a lognormal Tobit model. For observations with zero $PAOC$, we set the dependent variable equal to $\ln(0.5/VS_i)$, which is a natural censoring point: Since establishments are asked to report their expenditures in *thousands* of dollars, with rounding, a

models assume that the same process determines both the *probability* of a nonzero outcome and the *value* of a nonzero outcome. In our case, one can imagine a scenario in which establishment size has not only different but even opposite effects on the probability of nonzero PAOC and the intensity of PAOC expenditure. For example, one can imagine that smaller establishments are less likely to have nonzero PAOC — because they are small, they are perhaps rarely (if ever) inspected and therefore can forgo pollution abatement without much risk of discovery (enforcement asymmetries). However, for small establishments that *are* inspected/regulated, or otherwise decide to engage in pollution abatement, their PAOC intensity may well be higher than their larger counterparts in the industry because of fixed costs (compliance asymmetries). A second issue is that the Tobit's coefficients measure the effects on the *latent* variable found in the standard model. If zero PAOC were due to true data censoring (i.e., akin to missing true values) then the estimated coefficients are exactly the effects of interest. Here, however, zeros can be deemed true values, and our interest is not necessarily in effects on the latent variable — a construct — but in the effects on observed values.

In this paper, we estimate PAOC intensity using two different methodologies: the two-part model (TPM) and the Heckman two-step selection model (Heckit). Both models are more flexible than the Tobit model and are considered to be much better suited to estimating corner solutions (see Wooldridge 2002 and Cameron and Trivedi 2010). Indeed, both models are commonly used in the health economics literature, where zero expenditures (on health care, on cigarettes, etc.) are not uncommon. In both of these models, the probability of a nonzero outcome is estimated via a probit model, as in

response of zero reflects expenditures of less than \$500. Because the denominator (VS) can obviously vary by observation, the censoring point also varies by observation. Hence the use of censored normal regression, estimated using the `cnreg` command in Stata.

$$\Pr(PAOC_{it} > 0) = \lambda_0 + \sum \lambda_n \cdot SIC_{nit} + \sum \lambda_r \cdot YEAR_t + \lambda_1 \cdot EMP50_99_{it} + \lambda_2 \cdot EMP100_249_{it} + \lambda_3 \cdot EMP250_499_{it} + \lambda_4 \cdot EMP500_999_{it} + \lambda_5 \cdot EMP1000plus_{it} + e_{it} ,$$

and the second part estimates the (previous) intensity equation *on observations that are nonzero* (with the inclusion of the inverse Mills ratio, in the case of the Heckit). Among other things, these approaches relax the rather strong assumption of the Tobit model that the same process determines both the probability of nonzero PAOC and the intensity of PAOC expenditure. Instead, these approaches allow the two mechanisms to be distinct, and an explanatory variable (such as, establishment size) can have different – and even opposite – impacts on the outcomes of interest.

In the case of the TPM, these two equations are assumed to be completely independent and can be estimated separately – by probit and OLS, respectively. The Heckit, on the other hand, allows for dependence between the two parts of the model – that something akin to selection bias impacts the intensity equation (second part).¹⁴ In both the TPM and Heckit, we use the same regressors in both equations. That is, the Heckit is estimated without exclusion restrictions — mainly because no good, defensible candidates exist among the available variables. Therefore, for better or worse, we rely on the nonlinearity of the functional form to achieve model identification. Meanwhile, the identicalness of the regressors makes no difference at all in the TPM.

There has been significant debate – principally in the health economics literature – whether the TPM or Heckit is more appropriate in this sort of context (see Jones 2000 and references therein, plus Dow and Norton 2003). Some of the debate centers on statistical issues, while part of it focuses on theoretical matters – in particular, whether we

¹⁴ This is estimated using the heckman command in Stata, with the twostep option.

are interested in *actual* outcomes or *potential* outcomes, and what our beliefs are regarding zero values. On the one hand, the TPM reflects actual, observed outcomes, and assumes all zeros are true and valid. On the other hand, the Heckit reflects impacts on *potential* outcomes. Here, the PAOC intensity equation is interpreted as though we observe *nonzero* PAOC intensity data for *all* plants in the sample (including the non-spenders). The Heckit's results adjust for the fact that establishments with observed nonzero PAOC are (or may be) different than those with zero PAOC. The model assumes that cases with zero PAOC expenditure have *latent* nonzero PAOC intensity that was somehow unrealized. In essence, and in contrast to the TPM, the Heckit assumes that *none* of the zeros are valid.

The Heckit is most appropriate in a case like women's wages. In this classic example, the challenge is to measure the effect of, say, education on wages. The issue is that wages are missing for women who do not work, and those who do not work are not like those who do. The Heckit treats the inherent selection bias, and the estimated effects are those on actual and potential wages (were an individual to work). At first blush, our case seems different, since we do not have "missing" PAOC data in the truest sense. But perhaps we do. Say, for example, establishments are sometimes prone to report zero PAOC expenditures though untrue. Perhaps the Census Bureau is most likely to follow up with (verify or impute) cases mostly likely to have large PAOC or a large impact on specific aggregate statistics, while smaller cases (of zero PAOC) are ignored because, in the aggregate, they make relatively little difference. If this is true then the Heckit model may make sense. In this context, the *latent* nonzero PAOC intensity that went unrealized

is the nonzero PAOC intensity if the Census Bureau exerted more effort in collecting, verifying, and imputing data for these cases.

The TPM is arguably most appropriate in a case like cigarettes smoked per day. Madden (2008) suggests that in a case such as this “the participation decision dominates the consumption decision. This implies that zero consumption does not arise from a standard corner solution but instead represents a separate discrete choice.” He goes on to argue that “there is unlikely to be a latent positive expected consumption.... It follows that we are interested in the marginal effects of covariates on actual as opposed to potential smoking in which case the two-part model seems more appropriate.” It seems the analogous situation in our case would be industries and/or establishments that truly produce no pollution or waste, and therefore have no PAOC expenditures.

We believe the truth is likely a blend of these two scenarios: some cases of zero PAOC are a reporting issue, while others are true zeros. We present results from the TPM and Heckit as the outer bounds on the true relationship.¹⁵ Narrowing our analysis to just one model – one that reflects the true relationship – would require us to exert priors on which observations (or which combinations of industry, size class, state, county, year, etc.) are true zeros versus not. We do not know of an appropriate, scientifically

¹⁵ Another argument in the literature is that the preferred model depends on the purpose of the analysis, and whether the interest is in *actual* or *potential* expenditure, with the Heckit being more appropriate in the latter instance. In the case of health care expenditures, it has been argued that even persons with true zero expenditures have a positive *latent* expenditure. For example, a person may have high cholesterol that is yet unknown and goes untreated. Depending on the exact nature of the policy evaluation, one might be interested in the impacts of some factor assuming that these zero expenditure cases were in fact “off the sidelines” – for example, in a world with greater availability of free medical screenings. The corollary in our case may be that zero PAOC is in fact true but is due to a lack of regulatory attention, including facility inspections. If there were more inspectors and regulators, exerting more effort in inspecting and regulating the establishment, then the latent nonzero PAOC intensity might in fact be realized. We’ll note that the decision by the establishment/regulator to have nonzero PAOC expenditures at an establishment may well be linked to the known or perceived severity of pollution generated at the establishment, and hence PAOC intensity. Here, we simply note this argument for perhaps preferring one approach over the other without taking a stance on whether the reader’s interest is in actual or potential PAOC intensity.

defensible way of doing that. As results presented in the next section will demonstrate, the basic story is the same under both approaches.

IV. RESULTS

Before focusing on TPM and Heckit results, we first present results using censored normal regression, which is a generalization of the standard Tobit model that allows the censoring point to vary by observation, as discussed above. Table 1 contains these results, using the three different specifications of establishment employment. We see that in all three specifications, establishment employment has a positive and monotonically increasing impact on PAOC intensity. Despite the issues with Tobit specifications, noted above, the results here are in keeping with the results from the two preferred approaches, which we explore next.

Table 2 presents the results using the TPM. All three specifications suggest that the *probability* of nonzero PAOC increases – and increases monotonically – with establishment size. We saw this in the raw data as well. Meanwhile, the impact of establishment size on the intensity of PAOC expenditure (conditional on having nonzero intensity) depends on how establishment size is specified. The impact is positive, negative, and U-shaped, in columns (1), (2), and (3), respectively. Given the distribution of establishment employment, columns (2) and (3) are the preferred formulations. We will look at the combined effect (of establishment size) and evaluate magnitudes below. Meanwhile, an important point can be made here. We see instances where the impact of establishment size on the probability and on the intensity is indeed different and even opposite. This suggests that the Tobit model’s assumption that the same process

determines both the *probability* of a nonzero outcome and the *value* of a nonzero outcome is indeed a limitation of that approach. A comparison of the log likelihoods (e.g., $-608,454$ versus $-540,747$) confirms that the TPMs indeed fit the data better than the censored normal regressions.¹⁶

Table 3 contains the Heckit results. We see, as we did with the TPM, that the probability of nonzero PAOC increases – and increases monotonically – with establishment size. Indeed the results are identical. What is important are the results from the second stage, which can be interpreted in isolation, as if we observe nonzero PAOC intensity for all plants in the sample (including non-spenders). Here we find that the impact of establishment size on the intensity of PAOC expenditure is positive in all specifications (though the coefficient for plants with 50-99 employees does not quite attain statistical significance here).¹⁷ We'll note that the coefficient on lambda (the inverse Mills ratio) is statistically significant, which suggests there is indeed sample selectivity: some (unobserved or deliberately excluded) determinant of the probability of nonzero expenditure is also influencing PAOC intensity.

To better compare results, we compute the marginal effects of the establishment size dummy variables. That is, for each model, using the final column of results from Tables 2 and 3, we estimate the incremental effect on the level of PAOC intensity of being in the establishment size class of interest versus the omitted size category (i.e., establishments with 1-49 employees). Specifically, predicted PAOC intensity is computed for each observation assuming the omitted size category, and subtracted from

¹⁶ Since we assume that the two parts of the TPM are independent, the joint likelihood is simply the sum of the two log likelihoods.

¹⁷ That the estimates converge to a value of rho that is exactly 1 suggests there are issues with the estimates in column (2).

the predicted PAOC intensity assuming the size category of interest, and this difference is averaged across all observations in the sample. In the TPM, predicted PAOC intensity is the product of the predicted probability of observing nonzero PAOC and the predicted PAOC intensity. In the Heckit, predicted PAOC intensity is again a function of the estimates from the two parts. (For details, see Dow and Norton 2003.) Retransforming PAOC intensity from natural logs to levels requires special attention and here we employ a common technique, which relies on the assumption that the error terms are normally distributed with constant variance. Alternatively, for the TPM, we also employ the nonparametric “smearing” estimator of Duan (1983), which relies on weaker assumptions about the error term.¹⁸

Table 4 contains these estimates of the average incremental effects by establishment size category. Effects are all reported in dollars of *additional* PAOC per \$1000 of establishment output (value of shipments), relative to the omitted size category (i.e., establishments with 1-49 employees). We see that, for *all* the alternatives in this table, the very highest PAOC intensity occurs in the very largest establishments (with 1000+ employees). Meanwhile, the lowest PAOC intensity occurs in the second smallest size group (i.e., those with 50-99 employees) in the TPM and in the very smallest establishments (with 1-49 employees) in the Heckit. Figure 2 plots the values from the first three columns of Table 4. We see that the “normal” versus Duan retransformation makes some difference here — both curves are a similar shape, but they cross and diverge as establishment size increases.

¹⁸ To compute incremental effects and to handle this retransformation, we rely heavily on Stata code available in Carmeron and Trivedi (2010) and from the website of Professor Edward Norton of the University of North Carolina at Chapel Hill.

The results in the first three columns of Table 4 appear to be somewhat influenced by outliers. In the last three columns of Table 4, we present the corresponding results using a sample that removes observations with large (and implausibly high) values of PAOC intensity. For the purposes here, we drop observations that had PAOC expenditures that was more than 15% of establishment output, or 628 observations (0.195% of the sample). Relative to the full sample, the incremental effects here are usually higher (more positive, less negative) though not always. Setting aside the magnitude of the effects, the story is essentially the same. In the Heckit, PAOC intensity increases monotonically with establishment size. Controlling for industry and year, the very largest establishments (with 1000+ employees) had \$5.58 more PAOC per \$1000 of output than the establishments with 1-49 employees. In the TPM, PAOC nearly increases monotonically as well. Here, establishments with 1000+ employees had about \$1.90 more PAOC per \$1000 of output than the establishments with 1-49 employees. Establishments with 50-99 employees had the lowest PAOC intensity, according to the TPM, but by a mere 4 cents per \$1000 of output. With the outliers removed, there is very little difference between the “normal” and Duan retransformations. In Figure 3, which plots the values from the last three columns of Table 4, these two curves are indistinguishable from one another. Figure 3 quite clearly reveals a “cone” bounded above by the Heckit results and below by the TPM results. As we argue in the previous section, the true relationship lies somewhere between these two extremes. Wherever the true line lies within this cone, one thing is absolutely clear: Small plants do *not* appear to have PAOC intensity that is multiples of that of large plants. Quite the opposite, larger

plants spent more on pollution abatement per dollar of output than their smaller counterparts.

We now consider a few robustness checks and extensions. First, we examine the issue of outliers. Above, we presented results for the full sample and for the sample that excludes observations that had PAOC expenditures that was more than 15% of establishment output (0.195% of observations). In Figures 4 and 5, we re-graph these results along with results using cutoffs of 100%, 25%, and 5%, which drop 0.02%, 0.10%, and 1.55% of the sample, respectively. This final scenario is fairly severe – no doubt removing some legitimate cases. Figure 4 contains TPM results, and Figure 5 contains the Heckit results. In the TPM, as more outliers are dropped, the curve shifts up – from a J-shape to something that monotonically increases. These curves are all within 25 to 52 cents of one another. In the Heckit model, the curve shifts up as well, as more outliers are dropped, except in the most extreme case (PAOC of more than 5% of output) which bends below the other curves for the largest three establishment size categories. Here, the curves are all within 39 to 54 cents of one another. The fundamental story still holds, regardless of the outlier cutoff chosen, or whether outliers are dropped at all.

Next, we examine the impact of defining PAOC intensity using establishment employment in the denominator rather than output (value of shipments). As in Figure 3, we exclude those 628 observations with PAOC expenditures that was more than 15% of establishment output. The results are depicted in Figure 6. In the Heckit, as before, PAOC intensity increases monotonically with establishment size. Controlling for industry and year, the very largest establishments (with 1000+ employees) had \$1,059 more PAOC per employee (in 1979 dollars) than the establishments with 1-49

employees. In the TPM, as before, establishments with 50-99 employees had the lowest PAOC intensity. Beyond that, PAOC intensity increases, and establishments with 1000+ employees had about \$213 more PAOC per employee than the establishments with 1-49 employees. Again, the true relationship lies somewhere between these two extremes and again suggests larger plants have more intense pollution abatement spending than their smaller counterparts.

Finally, we recognize that the public discussion is often about *firm* size, not *establishment* size. With the data at hand, however, we cannot compute firm-level PAOC intensity since some of a firm's establishments may not be in a given year's PACE survey.¹⁹ An alternative would be to compute establishment-level PAOC intensity, as we do here, but regress it on (and plot it against) firm rather than establishment size categories.²⁰ Here, we instead use (more readily available) information on whether the establishment belongs to a multi-unit firm (i.e., there are other establishments in the firm) or is a single-unit firm (i.e., the observed establishment *is the entire firm*). We run our previous TPM and Heckit models on these two different samples.²¹ The results are plotted in Figure 7. We see, unambiguously, establishments in multi-unit firms spend more than otherwise similar single-unit establishment/firms. It is well-known that multi-unit firms are larger than single-unit firms on average. Here, it is less ambiguous: For

¹⁹ And a firm's non-manufacturing establishments are not even eligible to receive the survey.

²⁰ With some effort, an establishment's firm size can be constructed using the Census Bureau's business register (previously known as the Standard Statistical Establishment List), which is a database of virtually all private, non-farm business entities (establishments and companies) in the United States with paid employees. Containing establishment-level information on employment, payroll, industry, location, and firm affiliation, the business register serves as the sampling frame for nearly all of the Census Bureau's business surveys. An alternative to this would be to use the various Censuses of Manufactures to calculate the size of the firm's total manufacturing employment, ignoring any and all activity outside the manufacturing sector. However, this is only available once every five years.

²¹ Establishments belonging to multi-unit firms account for about 81% of the total sample here. 84% of multi-unit establishments have non-zero PAOC, compared to 54% among single-unit establishments.

single-unit establishments, firm and establishment sizes are one and the same. For multi-unit establishments, firm size will be at least as great as the size category the establishment is in. Therefore, not only can we say that, controlling for year and industry, larger *establishments* spend more on PAOC per unit of output than their smaller counterparts, but larger *firms* also spend more than their smaller counterparts, with the largest establishments in the larger firms spending the most of all.^{22,23}

V. CONCLUDING REMARKS

Results in this paper show that spending on pollution abatement operating costs per unit of output increases with establishment size. In the Heckman two-step selection (Heckit) model, controlling for industry and year, the very largest establishments (with 1000+ employees) had \$5.58 more PAOC per \$1000 of output than the establishments with 1-49 employees. In the two-part model (TPM), establishments with 1000+ employees had about \$1.90 more PAOC per \$1000 of output than establishments with 1-49 employees. We argue that the true relationship lies somewhere between these two extremes, approaching the TPM results as the proportion of zeros that are “true” rises. Our results apply to firm size as well as establishment size. These results are contrary to the claims by some; we certainly do not see environmental compliance costs for small businesses that are multiples of those for large (Crain and Crain 2010). Our findings suggest that there are statutory and/or enforcement asymmetries that favor smaller establishments and that outweigh any compliance asymmetries.

²² And this does not account for environmental expenditures that may occur in a firm’s corporate headquarters, unless those headquarters are co-located with a production facility in the PACE survey and the facility included those corporate expenditures.

²³ Evans (1986) also found this to be true, in most manufacturing subsectors.

In future work, we hope to explore these results further. Here, we presented results for the entire manufacturing sector. However, pollution abatement expenditures are highly concentrated. Four manufacturing subsectors (i.e., two-digit SIC / three-digit NAICS) dominate in sheer expenditure as well as in PAOC intensity. In particular, paper, chemicals, petroleum/coal products, and primary metals together accounted for 63% of total PAOC in the manufacturing sector in both 1974 and 2005 – the first and last year studied here. This paper’s analyses could be performed separately for each of these major manufacturing subsectors. Likewise, the analyses could be conducted separately for each of the 21 years here.

And, as discussed above, the estimating equation in this paper was kept deliberately simple, since our interest was not in explaining PAOC intensity, per se, but rather in estimating the relationship between PAOC intensity and establishment size — whatever the underlying explanation(s). Having estimated the basic relationship, we can begin adding other plant-level observables as explanatory variables. Indeed, we have found that the addition of state dummies has relatively little effect on the results shown in Figure 3. Heckit estimates are only about 2% lower, and TPM estimates are either identical or differ by just a penny.

More directly related to establishment size is establishment age, and there is evidence in the job creation literature that firm age actually underlies employment growth often attributed to firm size (Haltiwanger, Jarmin, and Miranda, forthcoming). Some preliminary analyses we have conducted suggest that controlling for establishment age shifts both the TPM and Heckit curves down somewhat, but the basic relationship between PAOC intensity and establishment size remains. Regression coefficients suggest

that the very oldest categories of establishments had the highest PAOC intensity, but the very newest category also had relatively high PAOC intensity. Analyses on just new market entrants may be revealing. This also hints at a caveat on our results. While we find no cost disadvantage for *existing* small businesses, regulations are often focused on *new* facilities, while grandfathering existing ones. If compliance with regulations is capital intensive, and it often is, compliance asymmetries may deter the entry of new, small establishments, particularly if they are not offset by regulatory exemptions. This possibility should be kept in mind when interpreting our results. That said, much of the public discussion is about impacts on existing businesses, not potential businesses.

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TABLE 1
Intensity of Pollution Abatement Operating Costs:
Censored Normal Regression[†]

	Log (PAOC/VS)	Log (PAOC/VS)	Log (PAOC/VS)
Establishment employment / 100	+0.0177*** (0.0004)		
Log (establishment employment)		+0.3382*** (0.0038)	
50-99 employees			+0.2815*** (0.0154)
100-249 employees			+0.6004*** (0.0142)
250-499 employees			+0.9087*** (0.0152)
500-999 employees			+1.1353*** (0.0167)
1000+ employees			+1.4288*** (0.0188)
Constant	<i>yes</i>	<i>yes</i>	<i>yes</i>
Industry effects (4-digit SIC / 6-digit NAICS)	<i>yes</i>	<i>yes</i>	<i>yes</i>
Year effects	<i>yes</i>	<i>yes</i>	<i>yes</i>
Pseudo R-squared	0.0827	0.0873	0.0874
Number of observations	321,527	321,527	321,527

[†] Robust standard errors are in parentheses. Statistical significance at the 10%, 5%, and 1% level are indicated by single, double, and triple asterisks, respectively.

TABLE 2
Intensity of Pollution Abatement Operating Costs:
Two-Part Model[†]

	(1)	(2)	(3)
Probability (PAOC/VS >0)			
Establishment employment / 100	+0.0909*** (0.0019)		
Log (establishment employment)		+0.4662*** (0.0029)	
50-99 employees			+0.5104*** (0.0092)
100-249 employees			+0.8988*** (0.0087)
250-499 employees			+1.2680*** (0.0100)
500-999 employees			+1.5343*** (0.0121)
1000+ employees			+1.9268*** (0.0163)
Constant	<i>yes</i>	<i>yes</i>	<i>yes</i>
Industry effects (4-digit SIC / 6-digit NAICS)	<i>yes</i>	<i>yes</i>	<i>yes</i>
Year effects	<i>yes</i>	<i>yes</i>	<i>yes</i>
Pseudo R-squared	0.1902	0.2391	0.2328
Log(PAOC/VS) conditional on (PAOC/VS >0)			
Establishment employment / 100	+0.0031*** (0.0002)		
Log (establishment employment)		-0.0254*** (0.0025)	
50-99 employees			-0.2761*** (0.0129)
100-249 employees			-0.3224*** (0.0121)
250-499 employees			-0.3092*** (0.0125)
500-999 employees			-0.2416*** (0.0132)
1000+ employees			-0.1417*** (0.0141)
Constant	<i>yes</i>	<i>yes</i>	<i>yes</i>
Industry effects (4-digit SIC / 6-digit NAICS)	<i>yes</i>	<i>yes</i>	<i>yes</i>
Year effects	<i>yes</i>	<i>yes</i>	<i>yes</i>
R-squared	0.3939	0.3938	0.3968
Number of observations	321,527	321,527	321,527

[†] Robust standard errors are in parentheses. Statistical significance at the 10%, 5%, and 1% level are indicated by single, double, and triple asterisks, respectively.

TABLE 3
Intensity of Pollution Abatement Operating Costs:
Heckman Two-Step Selection (Heckit) Model[†]

	(1)	(2)	(3)
Probability (PAOC/VS >0)			
Establishment employment / 100	+0.0909*** (0.0008)		
Log (establishment employment)		+0.4662*** (0.0028)	
50-99 employees			+0.5104*** (0.0093)
100-249 employees			+0.8988*** (0.0088)
250-499 employees			+1.2680*** (0.0101)
500-999 employees			+1.5343*** (0.0122)
1000+ employees			+1.9268*** (0.0162)
Constant	<i>yes</i>	<i>yes</i>	<i>yes</i>
Industry effects (4-digit SIC / 6-digit NAICS)	<i>yes</i>	<i>yes</i>	<i>yes</i>
Year effects	<i>yes</i>	<i>yes</i>	<i>yes</i>
Log(PAOC/VS) conditional on (PAOC/VS >0)			
Establishment employment / 100	+0.0051*** (0.0003)		
Log (establishment employment)		+0.2328*** (0.0064)	
50-99 employees			+0.0228 (0.0143)
100-249 employees			+0.1596*** (0.0175)
250-499 employees			+0.3188*** (0.0213)
500-999 employees			+0.4692*** (0.0238)
1000+ employees			+0.6648*** (0.0269)
Constant	<i>yes</i>	<i>yes</i>	<i>yes</i>
Industry effects (4-digit SIC / 6-digit NAICS)	<i>yes</i>	<i>yes</i>	<i>yes</i>
Year effects	<i>yes</i>	<i>yes</i>	<i>yes</i>
Rho	+0.2722	+1.0000	+0.8625
Sigma	+1.2632	+1.7153	+1.4218
Lambda	+0.3439*** (0.0251)	+1.7153*** (0.0340)	+1.2263*** (0.0343)
Number of observations	321,527	321,527	321,527

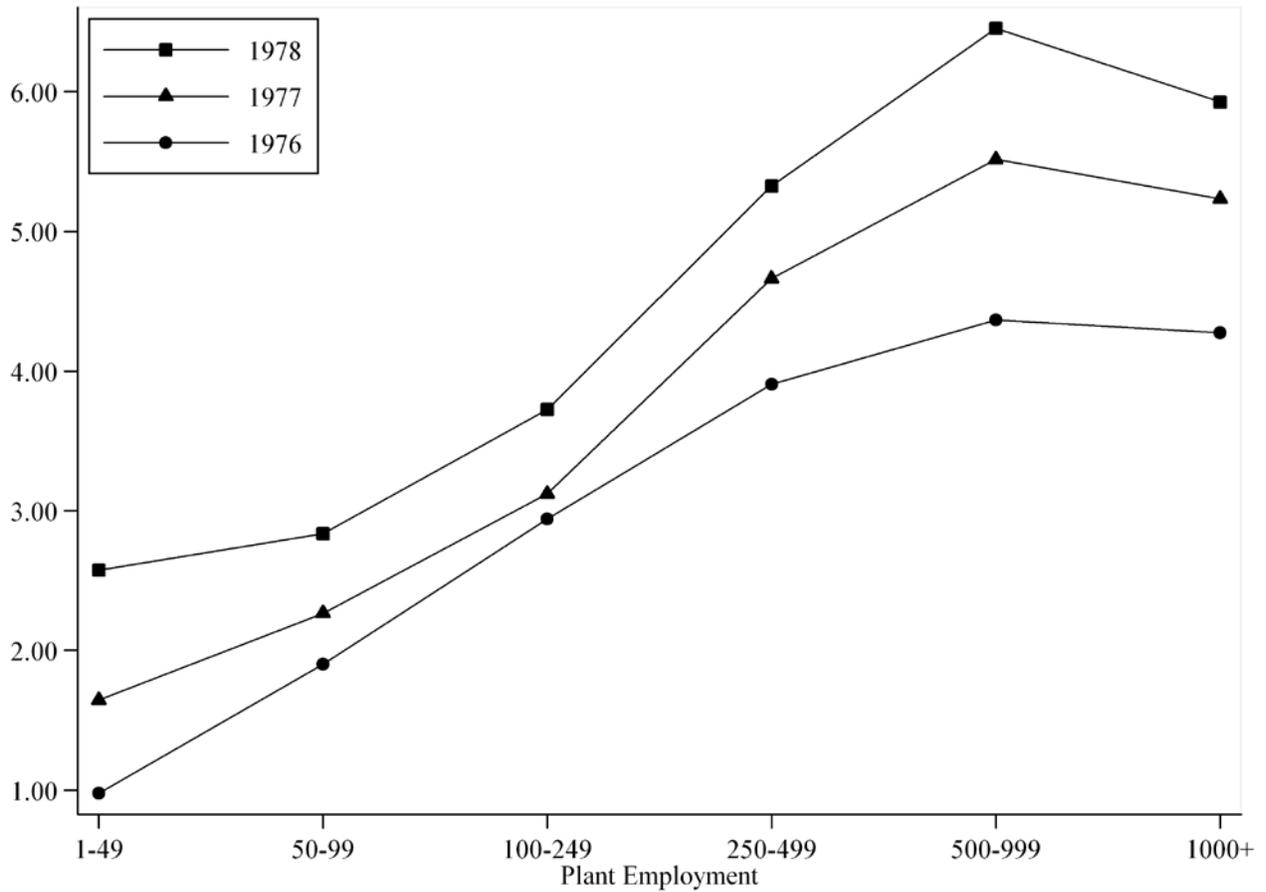
[†] Statistical significance at the 10%, 5%, and 1% level are indicated by single, double, and triple asterisks, respectively.

TABLE 4
Average Incremental Effect by Establishment Size Category[†]
(in dollars of additional PAOC per \$1000 of establishment output)

	Full sample		Sample with outliers removed			
	Two-part model		Heckit model	Two-part model		Heckit model
	Normal	Duan (1983)	Normal	Normal	Duan (1983)	Normal
50-99 employees	-0.31	-0.50	+0.19	-0.04	-0.04	+0.50
100-249 employees	+0.10	+0.17	+1.00	+0.35	+0.35	+1.36
250-499 employees	+0.55	+0.91	+2.08	+0.79	+0.78	+2.49
500-999 employees	+1.05	+1.73	+3.26	+1.27	+1.25	+3.70
1000+ employees	+1.71	+2.82	+5.09	+1.91	+1.89	+5.58
Number of observations	321,527	321,527	321,527	320,899	320,899	320,899

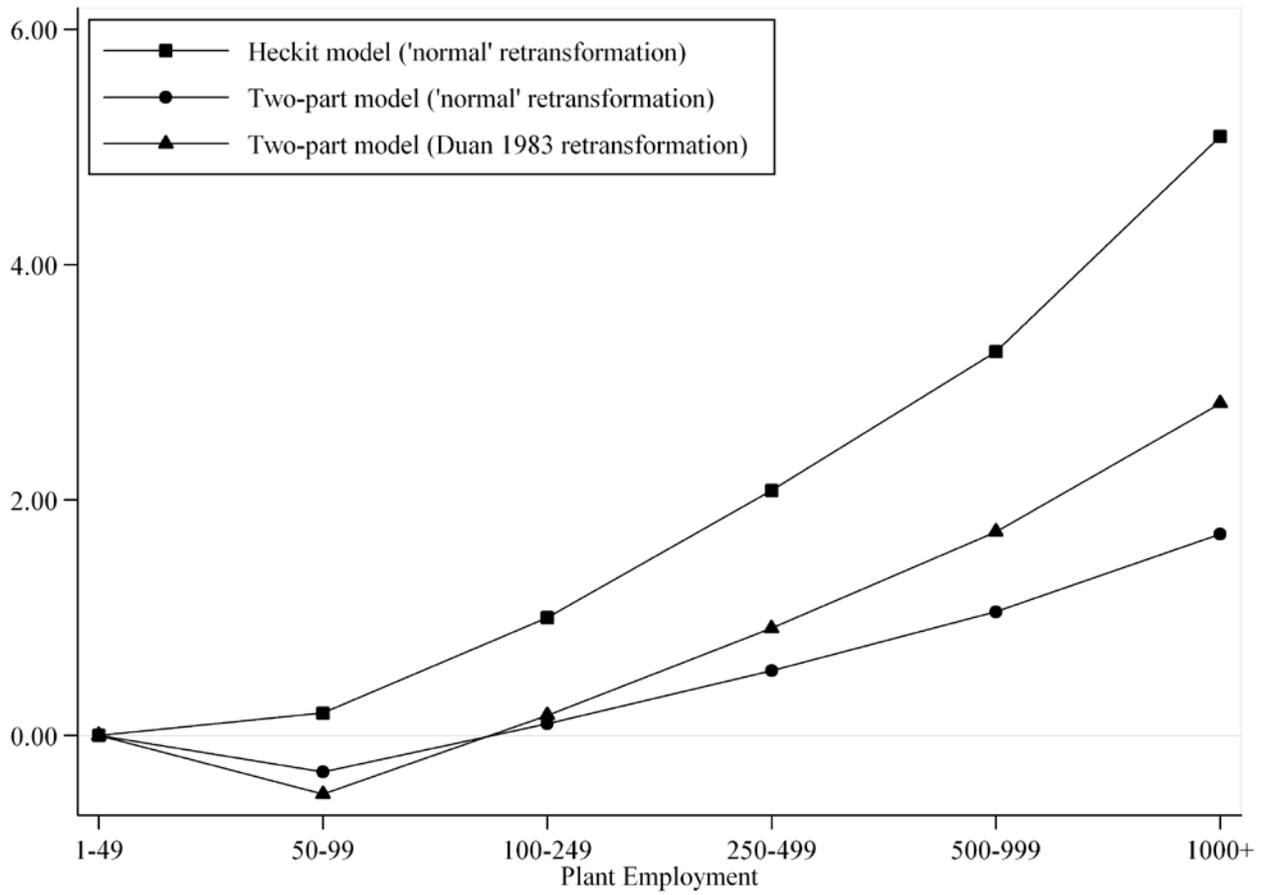
[†] Estimated incremental effects are based on column 3 of Table 2 and Table 3, respectively. Effects are relative to the omitted size category (i.e., establishments with 1-49 employees). For each model, predicted PAOC intensity is computed for each observation assuming the omitted size category, and subtracted from the predicted PAOC intensity assuming the size category of interest, and this difference is averaged across all observations in the sample. Retransformation of PAOC intensity from natural logs to levels is done assuming error terms are normal with constant variance. Alternatively, the smearing estimator of Duan (1983) is employed for the two-part model.

FIGURE 1
PAOC Intensity in the Manufacturing Sector by Establishment Size Category
(in dollars of PAOC per \$1000 of output)



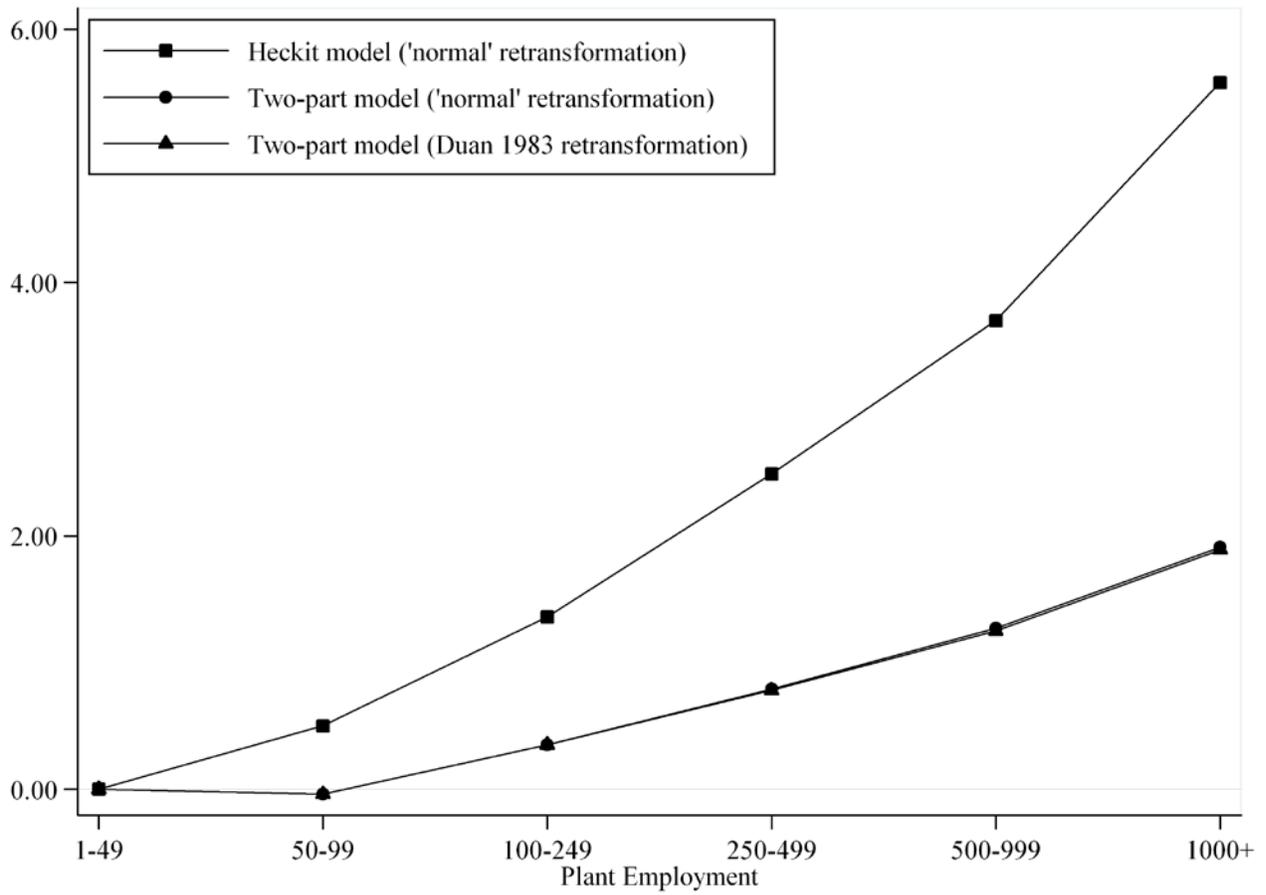
Source: Author's calculations, based on published Census Bureau statistics.

FIGURE 2
Average Incremental Effect by Establishment Size Category:
Full Sample
(in dollars of additional PAOC per \$1000 of establishment output)



Source: First three columns of Table 4.

FIGURE 3
Average Incremental Effect by Establishment Size Category:
Sample with Outliers Removed
(in dollars of additional PAOC per \$1000 of establishment output)



Source: Final three columns of Table 4.

FIGURE 4
Average Incremental Effect by Establishment Size Category
Under Different Treatment of Outliers:
Two-Part Model
(in dollars of additional PAOC per \$1000 of establishment output)

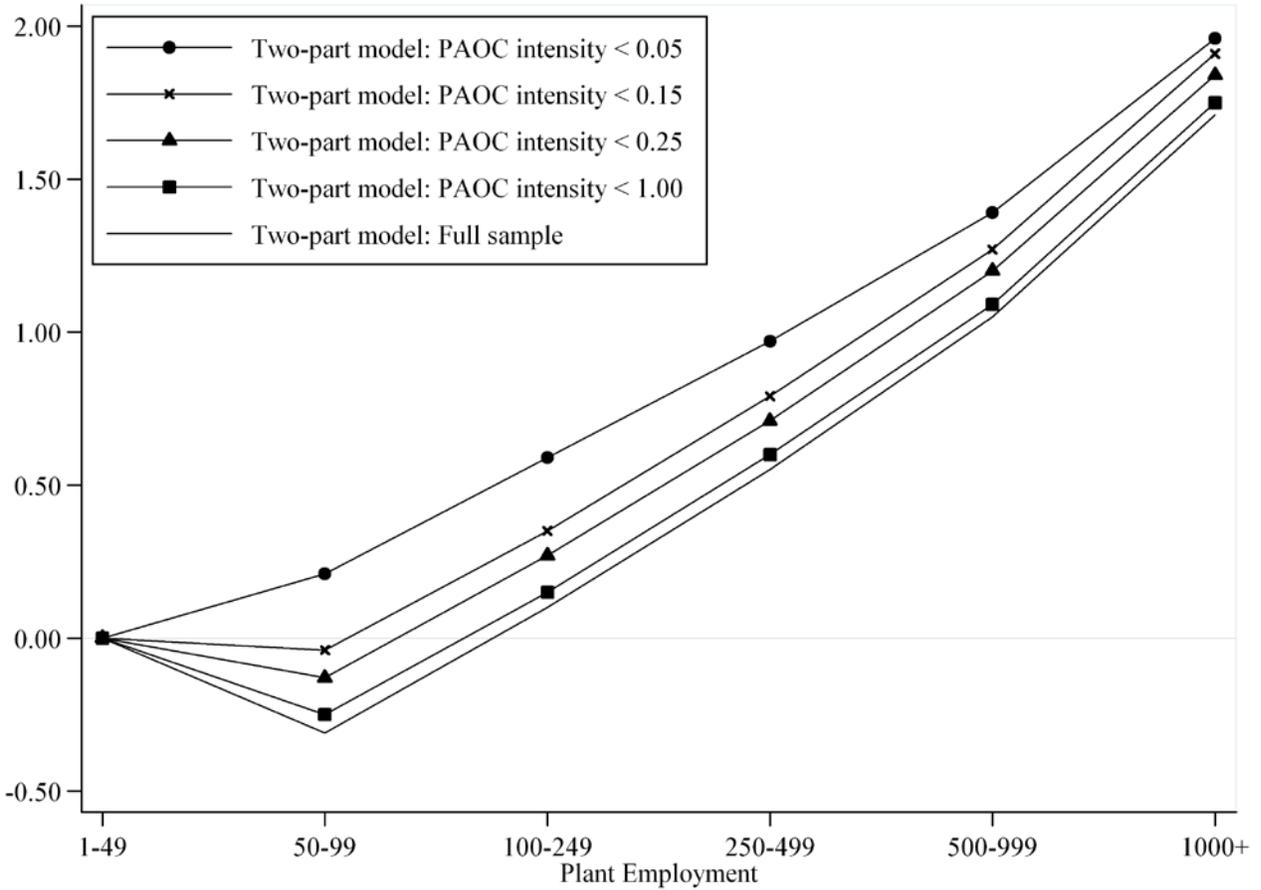


FIGURE 5
Average Incremental Effect by Establishment Size Category
Under Different Treatment of Outliers:
Heckit Model
(in dollars of additional PAOC per \$1000 of establishment output)

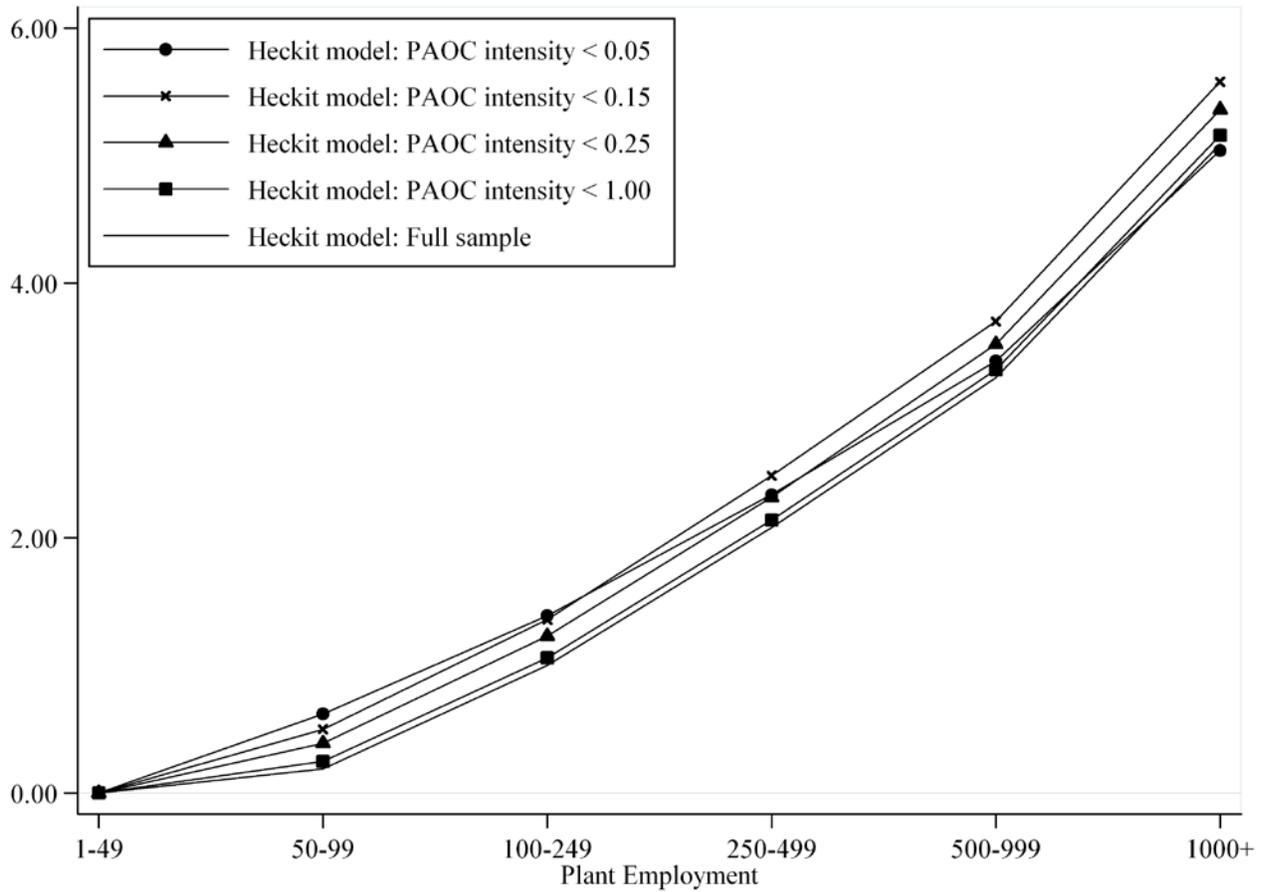


FIGURE 6
Average Incremental Effect by Establishment Size Category:
Sample with Outliers Removed
(in dollars of additional PAOC per employee)

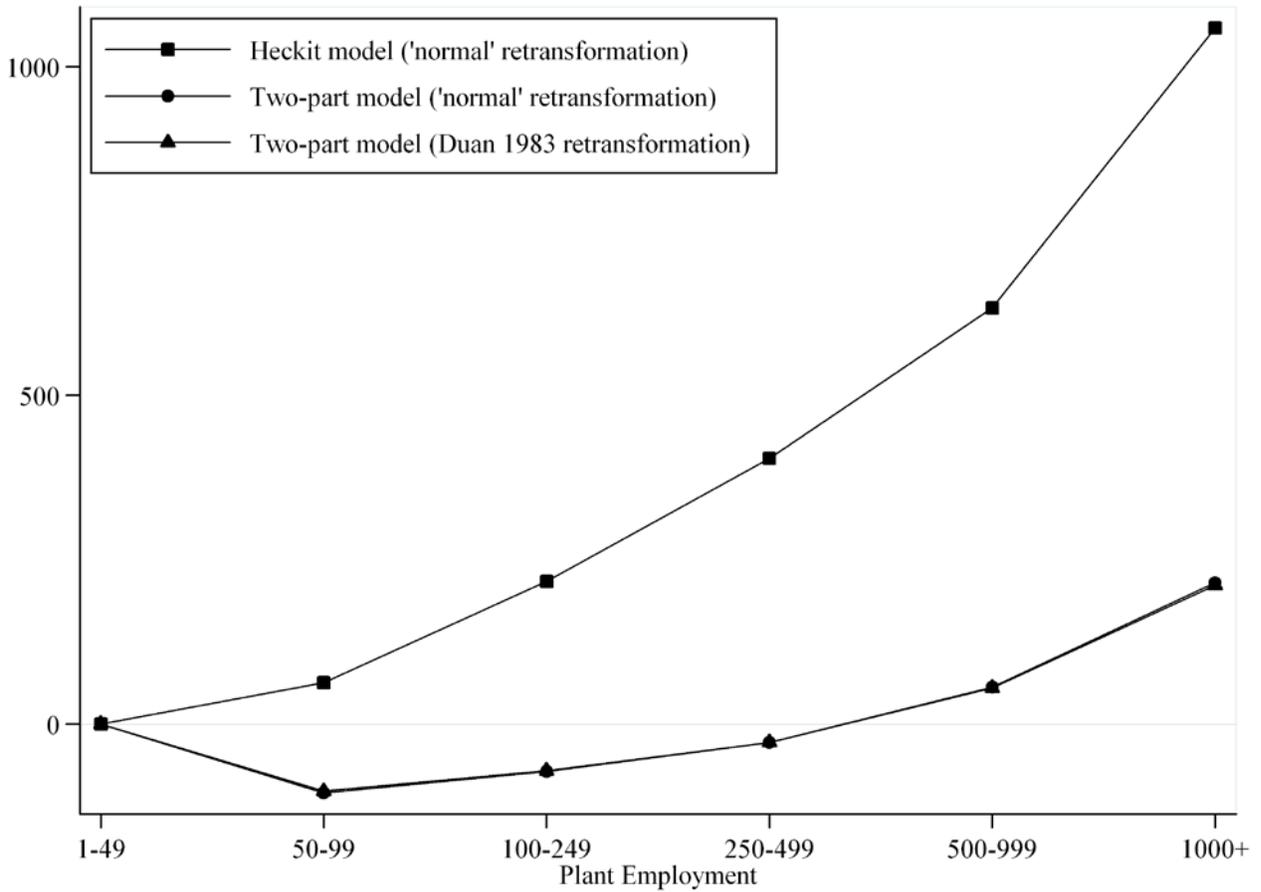


FIGURE 7
Average Incremental Effect by Establishment Size Category:
Multi-Unit vs. Single-Unit Firms
(in dollars of additional PAOC per \$1000 of establishment output)

