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LONGITUDINAL PATTERNS OF COMPLIANCE WITH OSHA HEALTH AND SAFETY REGULATIONS IN THE MANUFACTURING SECTOR

Wayne B. Gray

Carol Adaire Jones

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ABSTRACT

We examine the impact of OSHA enforcement on company compliance with agency regulations in the manufacturing sector, with a unique plant-level dataset of inspection and compliance behavior during 1972-1983, the first twelve years of the agency operation. The analysis suggests that, for an individual inspected plant, the average effect of OSHA inspections during this period was to reduce expected citations by 3.0 or by .36 s.d. The total effect on expected citations of additional inspections can be decomposed into two parts: evaluated at the mean of the sample, 59 percent of the total change in citations occurred due to an increase in the compliance rate; 41 percent was due to a reduction in citations among continuing violators.

Wayne B. Gray
Clark University
Department of Economics
950 Main Street
Worcester, MA 01610

Carol Adaire Jones
Quality of the Environment Division
Resources for the Future
1616 P Street, NW
Washington, DC 20036

INTRODUCTION

During the 1970s the United States experienced a dramatic expansion in public controls on private behavior designed to upgrade environmental, occupational and product safety. To improve occupational safety and health, the Occupational Safety and Health Administration (OSHA) was established in 1970. Numerous studies have subsequently examined the impact of OSHA on safety performance in the U.S. Case studies of individual firms have suggested that OSHA improves firm safety performance and safety-related investment.[2] However, findings from the regression-based studies have been far more mixed. Among industry-level studies, Viscusi (1986) found a limited effect, but Bartel and Thomas, and Viscusi (1979) found no significant effect of OSHA on aggregate injury rates. Among plant-level studies, Smith found a reduction in injuries within the same year for 1973 OSHA inspections but not for 1974 inspections; McCaffrey found no significant effect for inspections during the years 1975-1978. The discrepancy between the case studies and the statistical studies may in part be due to statistical problems, including measurement

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The authors are, respectively: Assistant Professor, Economics Department, Clark University, and Research Economist, NBER; and Assistant Professor, Economics Department and School of Natural Resources, University of Michigan, and Visiting Scholar, Resources for the Future.

For case studies, see Cambridge Research Reports, Freedman, and Kochan; for regression-based studies, see Bartel and Thomas, McCaffrey, Mendeloff, Russell, Smith, and Viscusi (1979) and (1986).

error and autocorrelation between the injury rate and inspection rate series.[3]

With the recent availability of longitudinal plant-level data, current research is corroborating the speculation that OSHA has a salutary effect on safety performance. Analyzing a 7-year panel with plant-specific injury rates and OSHA inspection data, Gray and Scholz estimated that a 10% increase in inspections with penalties would have a cumulative effect lagged over 3 years of reducing total accident rates by 2%.[4]

In this paper we consider the longitudinal impact of OSHA from a different but complementary perspective to that of Gray and Scholz. We examine the effect of OSHA's inspections of individual plants on the plants' compliance with OSHA standards, using a unique panel dataset derived from OSHA's enforcement Management Information System [MIS]. The longitudinal structure of the data allows us to provide a far richer picture of plant-level inspection and compliance patterns through the first 12 years (1972-1983) of the agency's history than possible in previous studies.

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[3] For example, McCaffrey et al. suggested that injury rates are measured with error. Furthermore, the highly auto-correlated data series on inspection rates and injury rates can produce unstable parameter estimates across time periods, particularly in models with lagged enforcement variables such as Viscusi (1986).

Also Mendeloff demonstrated that the pervasive use of total accident rates obscures the effect of OSHA on selected categories of accidents which have been independently identified by safety professionals as having a high proportion of injuries caused by detectable violations of OSHA standards.

[4] These results suggest the limitations of the earlier plant-level studies by Smith and by McCaffrey, in which the tests for inspection effects were limited to the 8 or 20 months following the inspection, respectively. Furthermore, the procedure McCaffrey used to generate the sample of plants may have seriously distorted the measurement. To analyze determinants of injuries in year t, he deleted all plants that had inspections in the year t-1 or the year t+1.

Bartel and Thomas have published the only previous study, to our knowledge, analyzing firms' compliance with OSHA standards. In their industry-level analysis, they found that increasing enforcement intensity was positively associated with greater compliance. As noted above, they also found that the relationship between OSHA violations and the injury rate was small and imprecisely estimated (as with most previous studies using industry-level accident data).

The following section of the paper presents a simple model of enforcement and compliance. The third section describes the data used in the analysis. The fourth section presents the empirical results, and the final section discusses the results.

THE MODEL

Firm Decision-Making

The major actors in the model of workplace safety and health are OSHA and private companies. OSHA sets standards, inspects plants, and issues citations and penalties when violations of the standards are detected. Each company is assumed to choose a level of compliance with the standards for each of its plants. The compliance level, in turn, has implications for the workplace safety level. Following the tradition in the plant-level analysis in the OSHA literature, we employ a specific-deterrence framework estimating the impact of an inspection of a plant on the subsequent compliance behavior of the plant. To measure agency enforcement, we employ dummy variables indicating the sequence number of the inspection for the first through the fifth inspection [SEQNUMj, j=1,...,5]. We also employ a continuous variable denoting each additional inspection after the fifth [SEQNUMC].[5]

At any given point in time, the number of previous inspections signals the intensity of (past) enforcement. The initial inspections may disseminate information to firms about OSHA requirements and may provide a "management shock" to action. In addition, we implicitly assume that firms' responses to inspections are partially motivated by the trade-off between the anticipated future penalties for non-compliance and the costs of compliance. Though OSHA penalties for initial violations tend to be very low, the penalty schedules for repeat and willful violations cited in subsequent inspections are substantially higher.

We do not have direct measures of the private costs of compliance. We assume that they vary with the employment size (ESTSIZE) and industry (SIC) of the plants or are captured in the plant-specific dummy in a fixed effect framework.[6]

Controls for Variability in the Relationship between "True" and Measured Citations

In the OSHA enforcement data, the number of citations (NUMCITE) provides a measure of violations of all OSHA standards. Because this variable forms the basis for our violation measure, we control for several factors which may affect the consistency of the relationship between "true" and measured violations across inspections or through time.

First, different Administrations may vary in the rate at which enforcement officers choose to cite various types of violations. For

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[5] The variable equals (total inspections - 5), for those plants with more than five inspections, and equals 0 otherwise.

[6] The costs of compliance include the expenditures on machinery, protective clothing and equipment, and (possibly) the foregone revenues associated with a slower workpace or alternative operating procedures necessary to comply with the standards.

example, the agency was widely criticized in its initial years for extensively citing trivial standards. OSHA substantially reoriented its policy in 1977, emphasizing detection of violations of more serious standards. The penalty policy associated with repeat and willful violations (which represents an important source of the deterrent threat associated with repeat inspections) also changes across Administrations. We control for variations in agency policy across Administrations with dummy variables for each year (INYEAR).[7]

Second, the origin of each inspection (complaint, follow-up, general schedule, accident) affects how much of an establishment is inspected, and therefore affects the likelihood that violations will be detected. General schedule inspections involve the broadest coverage of the workplace; complaint and follow-up inspections generally are focused narrowly on the subject of the complaint or of recent past violations, respectively. To control for these variations in the relationship between "true" violations and citations, we will include dummy variables for inspection origin in the equation (INORIGIN).

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7. Also, the relationship between true and measured citations through time is potentially affected by the relative shares of "detectable" and "non-detectable" violations. Non-detectable violations include short-term stochastic events that are unlikely to be detected because inspections are relatively infrequent. Since presumably non-detectable violations are reduced by OSHA inspections less effectively than detectable violations, the observed decrease in detectable violations will overstate the decrease in total violations through time.

Because the coefficients of INYEAR are capturing the changes in agency citation policy, the induced deterrent effects of citation and penalty policy on violations by firms, as well as changes in the relative proportions of detectable and undetectable violations, they must be interpreted with great care.

Controls for Agency Selection of Plants for Inspection

Note we only observe the violation level when an enforcement officer inspects an establishment. Forty percent of the plants in the sample are inspected only once, though at the upper tail, 2% [N=2667] have experienced 10 or more recorded inspections. [See Table A1.] The criteria OSHA uses to select plants for repeated inspections will affect the choice of an appropriate estimation procedure.

Targeting high hazard plants for general schedule inspections has been identified as a priority for the agency since the early 1970s, though the early targeting was criticized for its undue emphasis on the numbers of inspections and its "haphazard targeting".[8] A comprehensive high-hazard targeting scheme for general schedule inspections has been in place for safety since 1977 and for health since 1979. High hazard SICS are identified on the basis of employment size and independently determined numbers and severity of safety or health hazards present in each industry. The selection of plants within those high hazard SICs is to be random in order to comply with the requirements, specified in the Barlow decision, to establish the right of the agency to enter without full legal hearings to obtain a search warrant.[9] This policy suggests that the selection of plants for (re) inspection occurs along characteristics for which we can control in the analysis.

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[8] Mintz, p. 422-424.

[9] In Marshall v. Barlow, 436 US 307 (1978) the court specified that the agency must establish a well defined targeting scheme that is not susceptible to discretionary abuse.

Nonetheless, we employ techniques to control for plant-specific effects suited to the OLS and Tobit estimation methods in the analysis. In the OLS regressions, we employ a fixed effects model.[10] Because fixed effects would yield inconsistent estimators in the Tobit version of the model, we employ an alternative specification with the Tobit model, incorporating the total number of inspections received by a plant (NUMINSP) as a proxy for the fixed effect.

OLS and Tobit Models

The dependent variable in the analysis is the number of citations detected in an inspection (NUMCITE), a continuous variable for which 42% of the sample has the lower limit value of 0. Applying the Tobit framework to this OSHA enforcement context, the variable NUMCITE can be interpreted as a truncated representation (y) of a "workplace hazard index" y^*, where y^* is only observed if ($y^* > 0$) and:

$$y = \begin{cases} \alpha + X\beta + u, & \text{if } y^* > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$\text{where } y^* = \alpha + X\beta + u.$$

In the standard Tobit formulation, the independently distributed error term u is assumed to have mean 0, and constant variance σ^2. OLS provides inconsistent estimators of α, β, σ^2 and R^2.

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[10] The fixed effect model does not require specific distributional assumptions about the plant-specific error term. As a result, it allows for correlation between the plant effect and the observed exogenous variables, unlike the more restrictive random effects framework. Inferences with the model are conditional on the plant error term in the model; unconditional inferences are not possible without more specific distributional assumptions. Tests of heteroskedastic models on a sub-sample of the data support the preferability of the fixed effect framework.

The inspection coefficients estimated in the Maximum Likelihood Tobit procedures represent the change in the expected workplace hazard index as a result of inspections, $\partial Ey^*/\partial X_i$. In this context, however, an alternative interpretation of plant behavior may be of at least equal interest: the change in expected citations with additional inspections, $\partial Ey/\partial X_i$. In the Tobit framework, it is readily shown that $\partial Ey/\partial X_i = \Phi\beta_i$, where $\Phi = pr(y^*>0)$.[11] Alternatively, OLS coefficients a, $\underline{c}$ in the regression equation, $y = a + \underline{Xc} + e$, are consistent (though not efficient) estimators of $\partial Ey/\partial \underline{X}$ when the full sample, including limit observations, is used in the estimation.[12]

We estimate the determinants of citations (NUMCITE) using both OLS and Tobit procedures. As noted above, with the OLS estimation procedure, we are able to control for plant-specific effects with the more general framework of the fixed effect model. The fixed effect γ incorporates unobservable as well as observable plant characteristics, such as SIC and employment size class, so the latter variables are not included in the estimating equation. The inspection-specific variables incorporated in the estimating equation are category of inspection (health or safety) [INCAT], inspection origin (complaint, general schedule, accident or follow-up) [INORIGIN] and inspection year [INYR]. All the explanatory

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[11] For the intercept term, the formula is $\Phi\alpha + \sigma\phi$. P, the share of non-limit observations in the sample, is a consistent estimator of Φ.

[12] Greene's proof of the consistency of the OLS estimators is based on the assumption that the exogenous variables and the error term are distributed normally. Based on a variety of empirical work including Monte Carlo studies, he concludes that his results are probably fairly robust, particularly in the case of uniformly distributed or binary variables (as in our study.)[p. 510]
The corrected estimators of σ^2 and R^2 and the translation formulas between OLS and Tobit estimators, which are provided in the notes at the end of Table 3, are based on his analysis.

variables (except SEQNUMC) are incorporated in the estimation as dummy variables.

The fixed-effect form of the violation equation, to be estimated with OLS, is:

$$(1)\quad y_{ij} = a_0 + \Sigma c_{1,j}\mathrm{SEQNUM}_{ij} + \Sigma c_2\mathrm{SEQNUMC}_{ij} + \Sigma c_{3,m}\mathrm{INORIGIN}_{ij,m} + c_{4,n}\mathrm{INYR}_{ij,n} + \Sigma c_{5,o}\mathrm{INCAT}_{ij,o} + \gamma_i + u_{ij}$$

where the subscript i refers to plant i; subscript j refers to inspection sequence number j; m, n and o are indices of the dummy variable sequences; γ_i is the plant effect; and u_{ij} is the random error term for inspection i of plant j.

For the Tobit model, we control for the selection effect by incorporating the variable NUMINSP, the total number of inspections experienced by a plant, as a proxy for the plant fixed effect, γ. As with the inspection sequence series of variables [SEQNUM], we employ dummy variables for NUMINSP values equal to 1 through 5, and a continuous variable for additional inspections. We show in the Appendix that the coefficients on NUMINSP are underestimated by a factor equal to the ratio of the variance of the "noise" in NUMINSP (as a proxy for γ) to the total variance of NUMINSP.[13] Of greater interest is the result that the coefficients of the inspection sequence variables [SEQNUM], the focus of our inquiry, are estimated without bias. For additional plant-specific

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[13] We write $\mathrm{NUMINSP}_i = \gamma_i + \xi_i$, where γ is the signal component and ξ is the orthogonal "noise" component of NUMINSP. The bias in the estimate of β_8 is $-\beta_8 V(\xi)/V(\mathrm{NUMINSP})$. This result assumes continuous variables rather than the binary variables in our analysis.

controls, we incorporate plant SIC and employment size class dummies in the estimating equation.

We can write the Tobit version of the model, with NUMINSP as a proxy for fixed effect γ, as follows:

$$(2)\quad y_{ij}^{*} = \alpha_0 + \Sigma\beta_{1,j}\text{SEQNUM}_{ij} + \beta_2\text{SEQNUMC}_{ij} + \Sigma\beta_{3,m}\text{INORIGIN}_{ij,m} + \Sigma\beta_{4,n}\text{INYR}_{ij,n} + \Sigma\beta_{5,o}\text{INCAT}_{ij,o} + \Sigma\beta_{6,p}\text{ESTSIZE}_{i,p} + \Sigma\beta_{7,q}\text{SIC}_{i,q} + \Sigma\beta_{8,r}\text{NUMINSP}_{i,r} + \beta_9\text{NUMINSPC}_i + \nu_{ij}$$

$$\text{where } y_{ij} = \begin{cases} y_{ij}^{*} & \text{if } y_{ij}^{*} > 0 \\ 0 & \text{otherwise} \end{cases}$$

For comparability we also estimate (2) within an OLS framework. The formulas for comparing OLS and Tobit parameter estimates appear at the end of Table 3.

Heteroskedasticity

If unmeasured effects result in a non-constant σ^2, another source of inefficiency will be introduced in the OLS estimation of equation (2), though the OLS estimators of $\partial Ey/\partial X$ will still be consistent. Due to the extremely large sample size (N = 299,295 inspections), inefficiency of the estimators is not an important issue. In Tobit procedures, however, heteroskedasticity may cause inconsistent estimators. Due to computer capacity constraints, we re-estimated a model incorporating heteroskedasticity for a sub-sample of 5000 records. None of the parameter estimates for the SEQNUM variable series were not significantly different from the estimates for the models based on the assumption of constant variance σ^2, which are reported below.

DATA

The source of data for the analysis is OSHA's enforcement Management Information System [MIS], used by the agency to track agency enforcement and company compliance performance. The version of the MIS data obtained for this study includes the 299,295 federal inspections performed in manufacturing establishments between 1972 and the middle of 1983.[14] The MIS provides information about OSHA's enforcement actions, identifying which standards are cited and what penalties are levied. In order to create longitudinal records of plant inspection histories, Gray [1986] matched all inspections of individual establishments using establishment-level identifiers.[15] The dataset also contains the inspection and establishment characteristics necessary for the analysis, identified above.

Table A1 presents the means and standard deviations of the variables for the analysis sample. The matching procedure identified 115,236 plants in the sample. Approximately 42% of the plants were inspected only once. The conditional probabilities of subsequent inspections were approximately 60%, (almost) independent of the current sequence number. For example, conditional upon having been inspected once, the probability of a second

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14. Not included in the data are those few inspections done in 1971 and 1972 before the MIS was operational, and inspections performed in "state plan" states, where state authorities have taken over responsibility for enforcement.

15. This project used the Fellegi-Sunter technique of record matching, based on establishing the likelihood of agreement in the various fields. Because of the variation in coding of establishment data over time (including errors in data entry), there are almost certainly cases in which inspections of the same establishment are not identified as such. It is also possible (though less likely given the structure of the weights) that inspections of different establishments are mis-identified as repeat inspections of a single establishment.

inspection was 57%; conditional upon having been inspected eight times, the probability of a ninth inspection was 67%.

The inspections were fairly evenly distributed through time. Approximately 1 in 5 were health inspections. General schedule targeting procedures generated approximately half of the inspections. Complaints or follow-ups to previous inspections each motivated approximately one-quarter of the inspections. Accident investigations comprised a minimal 2% of inspections.

Across the full sample, inspectors wrote citations in 58% of the inspections (ANYCITE), averaging 4 citations across all inspections and 7 citations in inspections with citations (NUMCITE). Table 1 illustrates the variation in the citation variables by inspection and plant characteristics. General schedule inspections average the highest number of citations (5.6) with complaint inspections not far behind (4.5). Safety inspections average almost twice an many citations as health inspections. However, there is little variation in citations across plants by employee size group; an alternative interpretation of this result is that the number of citations per workplace employee declines substantially as the number of employees increases.

EMPIRICAL RESULTS

The major issue considered in this paper is: Do OSHA's enforcement efforts deter violations of OSHA safety and health standards? Table 1 reports the simplest possible panel analysis of this question, identifying how the percentage of plants with citations (ANYCITE) and the average number of citations (NUMCITE) varies with inspection sequence number (SEQNUM).

Table 1. Effect of sequence number and other inspection variables.
Sample = All safety and health inspections (N = 299,295).

	ANYCITE	NUMCITE
SEQNUM		
1	.794	6.3
2	.430	2.8
3	.485	3.1
4	.445	2.7
5	.440	2.8
6	.434	2.6
7	.435	2.6
8	.413	2.6
9	.424	2.5
10-14	.427	2.6
15-19	.428	2.4
20+	.424	2.4
INSPECTION TYPE		
Accident	.607	2.8
Complaint	.631	4.5
Follow-up	.112	0.4
General	.750	5.6
INSPECTION CATEGORY		
Health	.494	2.5
Safety	.602	4.6
ESTAB SIZE		
1-19 emp	.595	3.7
20-99	.598	4.2
100-499	.569	4.4
500+	.487	4.2

The results suggest that the initial inspection of an establishment may reduce subsequent violations, but that the following inspections have little effect on compliance. These results are misleading, however, because the agency decision to perform repeated inspections of a plant is highly correlated with poor compliance performance.

Table 2 displays the pattern of violation rates in sequential inspections (SEQNUM), controlling for the total number of plant inspections (NUMINSP) during the 1972-83 panel period. The pattern, which is remarkably consistent, confirms that the plants OSHA chooses to inspect repeatedly tend to have more citations. To a large extent, for any given inspection sequence number, plants with more total inspections more frequently have violations cited and, on average, have more citations. The differentiation appears to be weaker among NUMINSP classes with five or more inspections, particularly for ANYCITE, but it is important to remember that 90% of all plants are inspected 5 or fewer times.

Once we control for the total number of inspections of an establishment (NUMINSP), it is clear that the number of citations declines with the sequence number of an inspection (increasing values of SEQNUM). In Table 2, the reduction in citations following the first inspection of a plant is very large: the sample average is a reduction of 5 citations, an effect which is remarkably consistent across the NUMINSP sub-samples.

Table 2. Joint effects of SEQNUM and NINSP on citations.
Sample = All safety and health inspections (N = 299,295).

A. Mean ANYCITE value.

SEQNUM:

NINSP	1	2	3	4	5	6	7	8	9	10+
1	.67	.	.	.	.	.	.	.	.	.
2	.88	.32	.	.	.	.	.	.	.	.
3	.89	.47	.39	.	.	.	.	.	.	.
4	.91	.50	.51	.39	.	.	.	.	.	.
5	.90	.53	.54	.46	.39	.	.	.	.	.
6	.89	.52	.56	.48	.47	.41	.	.	.	.
7	.89	.56	.59	.48	.45	.44	.41	.	.	.
8	.88	.55	.58	.46	.46	.47	.47	.40	.	.
9	.87	.55	.58	.50	.49	.43	.43	.43	.44	.
10+	.81	.58	.55	.51	.48	.45	.44	.42	.42	.43
TOTAL	.79	.43	.49	.45	.44	.43	.44	.41	.42	.43

B. Mean NUMCITE value.

SEQNUM:

NINSP	1	2	3	4	5	6	7	8	9	10+
1	4.2	.	.	.	.	.	.	.	.	.
2	6.8	1.6	.	.	.	.	.	.	.	.
3	7.9	2.9	1.9	.	.	.	.	.	.	.
4	8.7	3.5	3.0	1.9	.	.	.	.	.	.
5	8.9	4.0	3.4	2.7	2.1	.	.	.	.	.
6	9.4	4.1	4.1	3.0	2.7	2.1	.	.	.	.
7	9.6	4.9	4.5	3.2	3.0	2.3	2.2	.	.	.
8	10.1	5.2	4.5	3.5	3.2	3.0	2.5	2.4	.	.
9	9.8	4.8	4.9	3.8	3.5	2.6	2.7	2.4	2.3	.
10+	9.9	5.4	5.2	3.9	3.9	3.4	2.9	2.7	2.6	2.5
TOTAL	6.3	2.8	3.1	2.7	2.8	2.6	2.6	2.6	2.5	2.5

C. Number of inspections.

SEQNUM:

NINSP	1	2	3	4	5	6	7	8	9	10+
1	49609	.	.	.	.	.	.	.	.	.
2	27383	27383	.	.	.	.	.	.	.	.
3	14179	14179	14179	.	.	.	.	.	.	.
4	8490	8490	8490	8490	.	.	.	.	.	.
5	5266	5266	5266	5266	5266	.	.	.	.	.
6	3231	3231	3231	3231	3231	3231	.	.	.	.
7	2114	2114	2114	2114	2114	2114	2114	.	.	.
8	1362	1362	1362	1362	1362	1362	1362	1362	.	.
9	935	935	935	935	935	935	935	935	935	.
10+	2667	2667	2667	2667	2667	2667	2667	2667	2667	14595
TOTAL	115236	65627	38244	24065	15525	10309	7078	4964	3602	14595

Table 3 reports the OLS and Tobit estimates of the determinants of the total number of citations, NUMCITE. Across all specifications, the results are consistent with the qualitative conclusions that citations decrease with additional inspections, and the first inspection has by far the strongest impact. In the OLS model with fixed effects (Col. 1),the effect of the first inspection is to reduce violations by 2.9 citations, approximately 60% of the reduction observed in the raw data in Table 2. The next three inspections yield reductions by 1.4, .8 and .9 citations each, with all subsequent inspections estimated to reduce citations by .07. In the OLS equation with NUMINSP and other plant controls (Col. 2), the estimated reduction in citations due to the first inspection is comparable (2.9 citations); subsequent inspections are estimated to reduce citations somewhat less than in the first model, (.8, .5, .3) with all additional inspections yielding reductions of .03 citations.

The "raw" Tobit coefficients ($\partial Ey^*/\partial X$) for equation (2) (with the NUMINSP proxy for fixed effects and other plant controls) are presented in Col. 3A. In Col. 3B, the coefficients have been transformed to make them comparable to the linear regression parameter estimates ($\partial Ey/\partial X$). The transformed Tobit estimators yield estimated reductions in citations similar to those estimated in the OLS regressions with NUMINSP: 2.3, .6, .5, .3 citations for the first through fourth inspections, and .03 citations for all subsequent inspections. Note the estimated reduction in citations from the first inspections is .5 citation smaller than with OLS-NUMINSP model.

With a censored dependent variable, OLS underestimates R^2 and generally underestimates σ. At the bottom of Table 3, we present the

Table 3. Determinants of citations.
Sample = All inspections (N = 299,295).
Dependent Variable = NUMCITE (Mean = 4.2; sd = 6.74)
For 42% of sample, NUMCITE = 0)
(Standard errors are below coefficients in parentheses.)

	1	2	3	
	OLS-Fixed Effect[a]	OLS-NUMINSP[a]	TOBIT-NUMINSP	
	$\frac{\partial Ey}{\partial X}$	$\frac{\partial Ey}{\partial X}$	$\hat{\beta}^b$	$\frac{\partial Ey}{\partial X}$*
CONSTANT		5.18	1.94	4.32
		(.10)	(.16)	
Enforcement				
SEQNUM2	-2.93	-2.86	-4.05	-2.34
	(.04)	(.04)	(.06)	
SEQNUM3	-1.38	-.79	-1.06	-.61
	(.05)	(.04)	(.07)	
SEQNUM4	-.77	-.50	-.82	-.48
	(.05)	(.05)	(.09)	
SEQNUM5	-.90	-.27	-.45	-.26
	(.07)	(.05)	(.09)	
SEQNUMC	-.066	-.028	-.056	-.033
	(.005)	(.005)	(.000)	
Plant Enforcement Controls				
NUMINSP2		2.10	2.59	1.50
		(.04)	(.06)	
NUMINSP3		2.84	3.68	2.13
		(.05)	(.07)	
NUMINSP4		3.41	4.57	2.65
		(.05)	(.08)	
NUMINSP5		4.15	5.76	3.34
		(.05)	(.07)	
NUMINSPC		-.011	-.012	-.007
		(.003)	(.005)	

Table 3. Determinants of citations. (Continued)

	1 OLS-Fixed Effect[a]	2 OLS-NUMINSP[a]	3 TOBIT-NUMINSP	
	$\frac{\partial Ey}{\partial X}$	$\frac{\partial Ey}{\partial X}$	$\hat{\beta}^b$	$\frac{\partial Ey^c}{\partial X}$
Inspection Controls				
HEALTH	-2.48	-1.92	-2.95	-1.71
	(.04)	(.03)	(.05)	
ACCIDENT	-4.25	-3.20	-4.55	-2.63
	(.10)	(.08)	(.12)	
COMPLAINT	-1.63	-.90	-1.64	-.95
	(.04)	(.03)	(.05)	
FOLLOWUP	-5.98	-4.88	-14.5	-8.41
	(.04)	(.03)	(.07)	
YR72	2.74	.72	2.38	1.38
	(.17)	(.10)	(.16)	
YR73	-1.80	1.16	3.16	1.83
	(.12)	(.07)	(.11)	
YR74	-.73	1.76	4.15	2.40
	(.11)	(.06)	(.10)	
YR75	.77	2.59	5.30	3.07
	(.10)	(.06)	(.10)	
YR76	1.65	3.07	6.04	3.50
	(.10)	(.06)	(.10)	
YR77	.82	1.80	4.03	2.33
	(.09)	(.06)	(.10)	
YR78	.95	1.63	3.72	2.15
	(.09)	(.06)	(.10)	
YR79	1.25	1.75	4.02	2.33
	(.09)	(.06)	(.10)	
YR80	1.47	1.73	3.96	2.29
	(.09)	(.06)	(.10)	
YR81	.66	1.00	2.76	1.60
	(.09)	(.06)	(.10)	
YR82	-.18	-.06	.08	.049
	(.09)	(.06)	(.10)	

Table 3. Determinants of citations. (Continued)

	1	2	3	
	OLS-Fixed Effect[a]	OLS-NUMINSP[a]	TOBIT-NUMINSP	
	$\frac{\partial Ey}{\partial X}$	$\frac{\partial Ey}{\partial X}$	$\hat{\beta}^b$	$\frac{\partial Ey}{\partial X}^c$
Plant Controls				
ESTSIZE1		-1.76	-2.10	-1.22
		(.05)	(.08)	
ESTSIZE2		-.98	-.81	-.47
		(.05)	(.07)	
ESTSIZE3		-.36	-.047	-.029
		(.05)	(.07)	
SIC	No	Yes	Yes	Yes
FIXED EFFECTS	Yes	No	No	No
R^2	.475	.196		
$\bar{R}^2$	.146	.196		
$\hat{\rho}_*^2$	.586	.242		
$\hat{\rho}_*^2$	.327	.242		
F	1.45	1555		
pr>F	0.0	0.0001		
log L			-68719	
MSE (OLS is biased)	6.23	6.04		
$\hat{\sigma}^d$ (consistent estimator)	6.75	9.14	8.55	
$\hat{\sigma}^*$	10.49	10.49		
$\hat{\mu}^*$	1.637	1.637		
$\bar{y}$	4.147	4.147		

Table 3. Determinants of citations. (Continued)

NOTES

a The OLS coefficients (a, $\underline{c}$) are consistent estimators of $\partial Ey/\partial X$ in the regression equation, $y = \bar{a} + \underline{c}\ \underline{X} + e$, where y is the variable NUMCITE. The standard errors are under-estimated.

b Tobit coefficients, from the model,

$$y^* = \alpha + \underline{\beta}\ \underline{X} + \nu,$$

where y^* is the workplace hazard index, underlying the truncated variable NUMCITE.

c The formulas for translating the Tobit coefficients to $\partial Ey/\partial X_i$ (and thereby achieving comparability with the OLS coefficients) are:

$$\hat{c} = \Phi\hat{\beta}$$

$$\hat{a} = \Phi\hat{\alpha} + \hat{\sigma}^* \phi$$

where $\Phi(\mu^*/\sigma^*) = \mathrm{pr}(y^* \geq 0)$ and ϕ is the associated marginal density. Note that:

P (= share of non-limit observations) is a consistent estimator of Φ, with variance $\Phi(1 - \Phi) / N$

$m = \Phi^{-1}(P)$, is a consistent estimator of μ^* / σ^*

$f = \phi(m)$ is a consistent estimator of ϕ

From $E(y) = \mu^* \Phi + \sigma^* \phi$ it can be shown that:

$$\hat{\sigma}^* = \bar{y}/(f) - m\,P$$

d Consistent estimators for the OLS regression can be calculated from parameters estimated in the OLS procedure:

$$1)\quad \hat{\rho}^2_{*} = R^2 \left\{ \frac{P - (f+mP)\,(f-m(1-P))}{P^2} \right\}$$

$$2)\quad \hat{\sigma}^2 = \hat{\sigma}^{*2} - R^2 S_{yy}/P^2$$

In our analysis, P=.579; m=.20; f=.3910.

See Greene (1981) for a more complete derivation of the formulas.

corrected estimates of σ and R^2 for the two OLS regressions. The corrected OLS estimator for σ in the NUMINSP model in Col. 2 (9.1) is close in value to the Tobit estimator for the analogous model in Col. 3 (8.6). The corrected estimate, $\hat{\sigma}$, for the OLS fixed effect model (Col. 1) is somewhat lower than the Tobit estimator (6.8 relative to 8.6). We also report an estimated mean of the workplace hazard index y^* of 1.6 and an estimated standard deviation $\hat{\sigma}^*$, of 10.5. These estimates appear reasonable when compared to the mean (4.2) and standard deviation (6.7) of the censored variable NUMCITE in the data.

Table 4 summarizes the estimated impact on citations and on the underlying hazard index of sequential inspections (based on the Tobit estimators). Col. 1 reports $\partial Ey/\partial X$ and Col. 3 reports $\partial Ey^*/\partial X$. Col. 2 and Col. 4 present the inspection effects in units of $\hat{\sigma}$ and $\hat{\sigma}^*$, respectively. We assume that the reduction in citations induced by an inspection is permanent, which yields a conservative interpretation of the incremental effects of repeated inspections.[16] From Col. 1 and 2, we observe that the average effect of OSHA's federal inspection program, as recorded in the sample, is to reduce expected citations by 3.0, or by .36 s.d.[17]

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[16] Alternatively, if the impact is short-lived, the effect of inspection i-1 equals the sum of the i^{th} coefficient plus all earlier SEQNUM coefficients. A longer term effect seems more appropriate when compliance predominantly involves making capital investments with long time horizons; the short-term effect seems more appropriate when compliance primarily requires the payment of operating expenses. Conventional wisdom suggests safety compliance is more oriented toward operating expenditures and health to capital expenditures.

[17] Note that in our specification the effect of an inspection is observed in the <u>subsequent</u> inspection. The reported calculation of OSHA's impact assumes that the (unobserved) effect of the last inspection of a plant equals the effect measured for that sequence number inspection in the subset of the sample receiving such an inspection. A calculation based on a more conservative assumption, that there is <u>no</u> effect associated with the last inspection of any plant, yields an estimated average reduction of -1.9 citations.

Table 4. Effect of past inspections on the number of citations (y) and the workplace hazard index ($y^* = X\beta + u$)

	EFFECT ON CITATIONS:		EFFECT ON HAZARD INDEX:	
Inspection sequence number:	$b_j = \frac{\partial Ey}{\partial SEQ_j}$[a]	$\frac{b_j}{\hat{\sigma}}$[b]	$\hat{\beta}_j = \frac{\partial Ey^*}{\partial SEQ_j}$[c]	$\frac{\hat{\beta}_j}{\hat{\sigma}^*}$[b]
2	-2.34	-.35	-4.05	-.39
3	-.61	-.10	-1.06	-.10
4	-.47	-.07	-.82	-.08
5	-.26	-.04	-.45	-.04
6+	-.033	-.005	-.056	-.005
TOTAL SAMPLE EFFECT[d]				
1) assume no effect of plant's last insp	-1.91	$-.22\hat{\sigma}$	-3.30	$-.32\hat{\sigma}^*$
2) infer effect of plants' last insp	-3.04	$-.36\hat{\sigma}$	-5.25	$-.50\hat{\sigma}^*$

FRACTION OF TOTAL RESPONSE IN REDUCING EXPECTED CITATIONS DUE TO:[e]

1) increasing compliance rate:	59%
2) reducing citations among violators:	41%

NOTES

a. From Col. 3B, Table 3. Calculated from Tobit coefficients ($\hat{\beta}$) where $b_j = P\hat{\beta}_j$, and P=% non-limit observations (57.9%).

b. From Tobit estimators, $\hat{\sigma}=8.55$; $\hat{\sigma}^*=10.49$.

c. Tobit coefficients ($\hat{\beta}$).

Notes to Table 4. (Continued)

d. Weighted averages of inspection sequence number effects.

1) is calculated by assuming that the (unmeasured) expected effect of the last inspection of a plant equals the effect measured for that sequence number in the rest of the sample. The weights on $b(SEQ_j)$ are the values of variables SEQ_{j-1}. The values of SEQNUM1-5 are: 1, .615, .396, .268, .188. The value of SEQNUMC is .841.

2) is calculated based on the conservative assumption of no effect of the last inspection in each plant; weights are values of $SEQNUM_j$ variables (% of inspections of that order, or greater).

e. Moffitt and MacDonald show that $\partial Ey/\partial X_i = P(m)[\partial Ey^+/\partial X_i] + Ey^+[\partial P(m)/\partial X_i]$, where Ey^+ is the expected value of y for non-limit observations. They also show that the fraction of the total effect due to the first part is: $1-mf(m)/F(m) - f(m)^2/F(m)^2$.

The total effect of additional inspections on the expected number of citations can be decomposed into two parts: the effect due to bringing more plants into compliance and the effect due to reducing citations among continuing violators. The fraction of inspections in the sample with citations is 57.9%. Evaluated at this point in the sample, 59% of the total change in citations is due to increasing the probability of compliance; 41% is due to the reduction of citations among violators.

From Col. 3 and 4, we observe that the average effect of OSHA's federal inspection program in inspected plants is to reduce the hazard index by 5 or .5 s.d.

SUMMARY AND DISCUSSION OF RESULTS

In this paper, we have examined the impact of OSHA enforcement on company compliance with the agency's regulations in the manufacturing sector. We were able to estimate the impact of OSHA enforcement on citations from safety and health inspections. The analysis suggests that, in ever-inspected manufacturing plants, OSHA inspections have reduced the number of detected citations on average by 3 or .36 s.d. and have reduced the underlying workplace hazard index by .5 s.d.

It is important to remember that our methodology does not allow us to estimate the indirect or general deterrent effects of inspections on other non-inspected plants, for example in the same industry or the same geographical region. Gray and Scholz (1989) provide evidence supporting both the existence of both specific- and general-deterrence effects. Also our analysis is strictly limited to federal OSHA inspections: it does not necessarily measure the impact of enforcement efforts in state plan states.

To make recommendations for future enforcement policy would require extrapolations beyond the plants ever-observed in the sample. Nonetheless, one particularly robust result in the analysis deserves comment. Within the 12-year panel period, the large reduction in citations following the first several inspections of a plant (and most particularly, after the first inspection) contrasts greatly with the small measured effect of inspections number 5 and beyond. The results suggest that, on the margin, substantial gains could occur if inspections resources were reallocated from the intensive margin to the extensive margin of OSHA's inspection strategy.

This conclusion only applies on the margin: as anticipated future inspection patterns change, firms' responses to current inspections presumably would change. A full behavioral model of enforcement and compliance decision-making, including the generation of expectations of future enforcement activity, is necessary to determine how much reallocation would be optimal.

Table A1. Descriptive statistics.

Sample = All safety and health inspections (N = 299,295).

Name	Description	Mean	(std. dev.)
ANYCITE	Dummy variable for any citations on this inspection (=1 if yes).	0.58	.49
NUMCITE	Number of citations on this inspection (includes health <u>and</u> safety citations).	4.15	6.7
SEQNUM	Sequence number of this inspection of this establishment (Dummy variables).		
SEQNUM1	=1 if [Sequence number ≥1]	1.00	
SEQNUM2	≥2]	.6150	
SEQNUM3	≥3]	.3957	
SEQNUM4	≥4]	.2679	
SEQNUM5	≥5]	.1875	
SEQNUMC	Continuous variable: $= \begin{cases} \text{SEQNUM-5 if SEQNUM>5;} \\ \text{0 otherwise.} \end{cases}$	.841	4.111
NINSP	Number of total inspections of this establishment (Dummy variables).		
NINSP1	=1 if [Total inspections = 1]	.163	
NINSP2	= 2]	.183	
NINSP3	= 3]	.142	
NINSP4	= 4]	.114	
NINSP5	≥ 5]	.398	
NINSPC	Continuous variable: $= \begin{cases} \text{NINSP-5 if NINSP>5;} \\ \text{0 otherwise.} \end{cases}$	1.998	6.521
ACCIDENT	=1 if [Origin of inspection = accident]	.023	
COMPLAINT	= complaint]	.220	
GENERAL	= general]	.535	
FOLLOWUP	= followup]	.222	

Table A1. Descriptive statistics (continued).

Name	Description	Mean
YR72	=1 if [Year of inspection = 72]	.017
YR73	= 73]	.067
YR74	= 74]	.108
YR75	= 75]	.120
YR76	= 76]	.107
YR77	= 77]	.103
YR78	= 78]	.092
YR79	= 79]	.084
YR80	= 80]	.084
YR81	= 81]	.072
YR82	= 82]	.088
YR83	= 83]	.055
HEALTH	=1 if [Category of inspection = health]	.212
SAFETY	= safety]	.788
ESTSIZE1	=1 if [Number of employees < 20]	.246
ESTSIZE2	= 20-99]	.402
ESTSIZE3	= 100-499]	.251
ESTSIZE4	≥ 500]	.101

APPENDIX

Measurement Error Bias with NUMINSP as a Proxy for the Plant Fixed Effect

For simplicity, assume the true model is:

(1) $y_{ij} = \alpha \text{ SEQNUM}_{ij} + \beta\gamma_i + \nu_{ij}$

where y is the number of violations, SEQNUM is the sequence number of the current inspection, γ_i is a fixed effect term for each plant, and i and j are the plant and inspection indices, respectively.

In the estimating equation, the variable measuring the total number of plant inspections during the panel period, (NUMINSP_i), is employed as a proxy for the fixed effect γ_i:

(2) $y_{ij} = a\text{SEQNUM}_{ij} + b\text{NUMINSP}_i + u_{ij}$

The proxy NUMINSP measures γ_i with error:

(3) $\text{NUMINSP}_i = \gamma_i + \xi_i$, where $\gamma \perp \xi$

Note that SEQNUM and NUMINSP are correlated, such that the expected value of any inspection sequence number for a plant is 1/2 x (total inspections of the plant + 1). We can write:

(4) $\text{SEQNUM}_{ij} = 1/2(\text{NUMINSP}_i + 1) + \varepsilon_{ij}$

$= 1/2(\gamma_i + \xi_i + 1) + \varepsilon_{ij}$, where $\varepsilon \perp \gamma, \xi$

From (3), (1) can be rewritten:

(5) $y_{ij} = \alpha \text{ SEQNUM}_{ij} + \beta \text{ NUMINSP}_i - \beta\xi_i + \nu_{ij}$

We define the auxiliary regression of the measurement error, ξ_i, on the two included variables:

(6) $\xi_i = \pi_1 \text{SEQNUM}_{ij} + \pi_2\text{NUMINSP}_i + \eta_{ij}$

The standard formula for the bias in the estimated parameters in (2) are:

(7) $a = \alpha - \beta b_{CS.N} = \alpha - \pi_1 \beta$

$b = \beta(1 - b_{CN.S}) = \beta(1 - \pi_2)$

We show below that the SEQNUM coefficient is estimated without bias ($\pi_1 = 0$) and that the NUMINSP effect is underestimated ($\pi_2 > 0$) in the regression equation (2).

We first examine the bias in the SEQNUM coefficients. It is well known that:

(8) $\pi_1 = b_{cS.N} = [b_{cS} - b_{NS}b_{cN}] / (1 - r^2_{SN})$

which can be simplified to:

$$= [C(\xi,S)V(N) - C(N,S)C(\xi,N)]/[V(S)V(N) - C(S,N)^2]$$

Given that ξ is orthogonal to γ, and ε is orthogonal to γ and ξ, the following formulas for variances and covariances can be derived (where S refers to SEQNUM and N refers to NUMINSP):

(9) $C(\xi,S) = 1/2\ V(\xi)$

$C(N,S) = 1/2[V(\gamma) + V(\xi)]$

$C(\xi,N) = V(\xi)$

$V(N) = V(\gamma) + V(\xi)$

$V(S) = 1/4\ V(\gamma) + 1/4\ V(\xi) + V(\varepsilon)$

Substitution from (9) into (8) readily demonstrates that $b_{cS.N} = 0$, which implies that the SEQNUM coefficients are estimated without bias.

We turn now to determine the bias in the NUMINSP coefficient. We know that:

(10) $\pi_2 = b_{cN.S} = [b_{cN} - b_{SN}b_{cS}]/(1 - r_{2SN})$

By substitution from (9), (10) becomes:

(11) $b_{cN.S} = [C(\xi,N)V(S) - C(S,N)C(\xi,S)]/[V(S)V(N) - C(S,N)^2]$

$$= V(\xi)/V(N) = \text{var(noise)}/[\text{var(noise)} + \text{var(signal)}]$$

It follows then that there will be a downward bias in the estimate of the NUMINSP coefficients in proportion to the ratio of the variance of the noise in NUMINSP, the proxy for the fixed effect, to the total variance of the proxy:

(12) $E(b - \beta) = -\beta V(\xi)/[V(\gamma) + V(\xi)]$

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