PROTECTING WORKERS FROM ADVERSE CHEMICAL EXPOSURE:

DO VOLUNTARY STANDARDS REDUCE EXPOSURE?

Stephen Finger
and
Shanti Gamper-Rabindran

5/2/2012

Abstract

Our study is the first to test if voluntary contaminant standards, which are used widely to achieve food, product and workplace safety, reduce exposure to those contaminants. We analyze workers' actual measured exposure to toxic chemicals at 1,103 chemical plants between 1984 and 2009. We find that voluntary workplace exposure standards contribute to only limited reductions in workers' exposure. Measured at the point at which voluntary limits are most effective, a 1% reduction of the exposure limits recommended by the voluntary standards leads to only 0.42% reduction in exposure. We also find that legal standards reduce exposure by a larger magnitude than voluntary standards. Plants, on average, reduce their exposure by almost equal amounts to the reduction mandated by the legal limits, but by only one tenth of the amount of reduction recommended by the voluntary limits.

Keywords: private standards, legal standards, private standard setting, chemical industry, worker exposure
JEL codes: K32 L51 L65 Q53 Q58

Authors are listed alphabetically. Stephen R. Finger, Assistant Professor, Moore School of Business, University of South Carolina, and Shanti Gamper-Rabindran, Assistant Professor, Graduate School of Public and International Affairs, University of Pittsburgh. We thank the University of Pittsburgh's Central Research Development Fund, the Center for Social and Urban Research, and the Global Studies and European Union Center. Errors are ours.

1. Protecting health: the role of private voluntary standards

To protect workers and consumers, government agencies have set legal standards on exposure to contaminants from food, products, and in the work environment. Voluntary standards, set by non-profit organizations, private standard-setting bodies and trade groups, are playing an increasing role in providing safety guidelines. Many legal standards are out-of-date or non-existent (Cheit, 1990) due to onerous public rule-making procedures and court challenges (Adler, 1989; Weimer, 2006). In contrast, voluntary standards are flexible and can respond quickly to new technologies and new information on health risks (Weimer, 2006; Meidinger, 2009). Moreover, standards designed by trade associations can tap into producers' information, expertise, and resources, which regulators lack (National Academy of Engineering, 2010).

Given the increased reliance on voluntary standards, we provide the first study that tests (i) if voluntary limits on contaminants reduce exposure and (ii) if voluntary and legal limits lead to comparable magnitudes of exposure reduction. Specifically, we examine if chemical manufacturing plants reduce workers' ***actual measured*** exposure to toxic chemicals in response to voluntary workplace exposure standards.[1] We also compare these plants' exposure reductions in response to voluntary and legal standards. To our knowledge, no study has examined the impact of voluntary contaminant limits, which are used widely to achieve food, product and workplace safety, on exposure. Instead, studies to date focus on evaluating the ability of voluntary programs to reduce pollution and rely on ***self-reported*** pollution data. These studies report mixed results on the effectiveness of these voluntary programs (Morgenstern and Pizer, 2007; Lyon and Maxwell, 2008).

---

[1] The largest share of plants in our sample are in "Paints, Varnishes, Lacquers, and Enamels" (19.2%), "Plastics Materials and Synthetic Resins" (13.0%), and "Industrial Inorganic Chemicals, not elsewhere classified" (9.8%).

Industrial workers' exposure to chemicals is one of the highest risk areas for human health (EPA, 1987; EPA-SAB, 1990), inflicting costs of $58 billion per year in the US alone (Leigh, 2011). The Occupational Health and Safety Administration (OSHA) sets legal standards for workplace chemical exposure. Most of these standards, for about three hundred chemicals, are "out-of-date, not readily updated, and not sufficiently protective of worker health" (Presidential Commission, 1997; Froines et al., 1995; Howard, 2010; Walter, 2010; GAO, 2012). Most standards were adopted in 1971, based on scientific evidence from the 1950s and 1960s (McCluskey, 2003). OSHA has issued new or revised standards for only sixteen chemicals in the last forty years (Mirer, 2007). In contrast, the non-profit scientific association, the American Conference of Industrial Hygienists (ACGIH) has published voluntary standards, the Threshold Limit Values (TLV), for twice as many chemicals and has updated these standards periodically based on current scientific knowledge (McCluskey, 2003).

We exploit a newly available database of measurements of workers' personal exposure to air contaminants, collected with sampling devices worn by workers during OSHA's inspections.[2] The Chemical Exposure and Health Data (CEHD), collected in 29 states where Federal OSHA enforces the law, is the largest and most detailed worker exposure database worldwide (Yassin et al., 2005). We examine exposures at 1,103 unique plants between 1984 and 2009 for 75 chemicals. Of these plants, 23.4% have exposure levels for at least one chemical that exceeds the voluntary limit, indicating adverse exposure levels. Variation in the limits for individual chemicals over time and across different chemicals allows us to identify the impact of voluntary standards on exposure. Exposure is measured as the ratio of test results (which measure the concentrations of chemicals sampled) to the legal limits.

[2] Gray and Jones' (1991) seminal study on inspections and worker exposure secured the use of the CEHD when its dissemination was restricted.

We conclude that voluntary standards can serve as complements, but not as perfect substitutes to legal standards. High exposure plants reduce their exposure, measured by the ratio of test results to legal limits, by only a ***small*** percentage in response to voluntary standards, as captured by the difference between the TLVs and PELs. Even when the largest reductions in response to voluntary standards are observed, i.e. at the 95th quantile of exposure, the exposure reduction is only two fifths of the amount recommended by the voluntary standards. We observe far larger reductions in exposure in response to legal standards than to voluntary standards. Plants reduce their exposure, on average, by almost equal amounts to reductions mandated by the legal standards, but by only one-tenth of the amount of reduction recommended by the voluntary standards.

To revise legal limits that are insufficiently protective, public health experts have called on Congress to pass legislation that would allow OSHA, through a single rulemaking effort, to update legal standards to the current levels of the TLVs (Presidential Commission, 1997; GAO, 2012). Our study provides some evidence in support for this policy change, though a cost-benefit analysis is outside the scope of our study. First, at least 51.8% of chemicals have stricter voluntary than legal standards (Table 1), and a further 300 chemicals have only voluntary standards (McCluskey, 2003). Second, mandating that plants meet stricter exposure limits, which are now only met on a voluntary basis, is necessary to prompt plants to reduce their exposure to the full amount indicated by these stricter limits. In contrast, voluntary standards can prompt only limited exposure reductions. Third, this policy change can help reduce workers' exposure at an important subset of plants. For 18.1% of inspected plants between 2003 and 2009, workers' exposure level for at least one chemical is between the voluntary and legal standards. Fourth, this policy change would meet the threshold of economic feasibility applied to OSHA's standards, i.e., they are permitted to impose financial burden on plants that laggards in health and safety, but not to cause dislocation, loss of competitiveness or undue concentration of the entire industry. As all test results for 74.8% of inspected plants between 2003 and 2009 already meet the voluntary standards, this policy change would not adversely affect the majority of plants.

2 Background

2.1 Voluntary and legal standards

Voluntary standards that are stricter than legal standards are prevalent in the food and product safety areas and in workplace exposure. For example, McDonalds sets stricter standards for salmonella in meat purchased from suppliers than the standards set by Department of Agriculture (Schlosser, 2002).[3] Walmart has required its meat suppliers to adopt even stricter tests for *Escherichia coli* (Falkenstein, 2010). In contrast, the Agriculture Marketing Service sets less strict standards for indicator bacteria for the meat purchased for school lunches than that set by fast food restaurants and has not required as frequent testing for these bacteria (Ziperstein, 2011).

In several cases, private voluntary standards have been revised to provide more protection against health and safety risks. Private standard setting bodies accept lower thresholds of scientific evidence to justify a given standard and update these standards as information becomes available (Cheit, 1990; Weimer, 2006). In contrast, public standard-setting bodies have required higher thresholds of evidence on adverse health effects before setting a strict standard, as they face more onerous rule-making procedures (Adler, 1989) and numerous court challenges (Weimer, 2006). These procedures, court challenges, and limited resources contribute to the slow pace of standard-setting in public agencies. For example, the Consumer Product Safety

[3] Interview with Frontline documentary, Modern Meat. 2002

Commission issued just over twenty standards in the first decade of its operations (Viscusi, 1985), and OSHA takes an average of seven years to issue a standard (GAO, 2012). In contrast, private standards have been revised more frequently and expanded (Cheit, 1990; Weimer, 2006). In some product categories, such as electric and gas appliances, the private standards serve as the sole standards (Cheit, 1990).

Producers face several, but potentially limited, incentives to adopt private standards (Meidinger, 2009). First, to protect themselves from tort liability, manufacturers rely on private standards and testing programs to demonstrate their application of due care in the design and manufacture of their products (Meidinger, 2009). Retailers that control large market shares, for example, large supermarket chains, have required suppliers to adhere to stricter private standards, (Henson, 2008).[4] Second, in their underwriting process, the insurance industry has required their insured manufacturers and retailers to adhere to private standards. For example, product liability insurers require compliance with standards set by the Underwriters Laboratories which is a private standard setting and testing organization (Cheit, 1990). Indeed, the insurance industry funded the early development of the Underwriters Laboratories (Meidinger, 2009). Nevertheless, these factors may not provide sufficient incentives for producers to reduce risk to the extent recommended by the voluntary standards. For example, producers' incentives are limited under the tort system as plaintiffs face numerous challenges in establishing the causal link between a product and their injury (Buzby et al., 2001). Ultimately, the extent to which voluntary standards reduce health risks is an empirical question.

2.2 OSHA and legal exposure limits

[4]Our study of voluntary standards excludes those cases in which private standards have become incorporated into law. For example, municipal building codes have incorporated the Underwriters Laboratories' standards (Cheit, 1990). OSHA's safety regulations have adopted by reference the American National Standards Institute (ANSI) standards (Lazzara, 2004). By incorporating an ANSI standard in its regulations, OSHA converts a voluntary standard into a federal requirement.

The 1970 Occupational Safety and Health Act (OSH Act) established (i) OSHA to promulgate and enforce regulations on health and safety, and; (ii) the National Institute of Occupational Safety and Health (NIOSH) to conduct research to develop mandatory health standards (Froines et al., 1995). The permissible exposure limits (PELs), set by OSHA, serves as the legal standards. The OSH Act permitted OSHA to adopt consensus standards in the first two years of its operations, and the ACGIH's 1968 list of voluntary private standards were adopted as the legal limits.[5] Thereafter, to establish new or revised standards, OSHA must follow detailed rulemaking procedures set out in Section 6(b) of the OSH Act (Froines et al., 1995). The slow pace of standard setting by OSHA has been blamed on: (i) the unrealistic evidentiary standards required by the courts (Mendeloff, 1988), (ii) the onerous "procedural, analytical and substantive requirements to federal agency rulemaking" (Weimer, 2006; Howard, 2010), and (iii) OSHA's limited resources (Howard, 2010).

The Supreme Court decision in the Benzene case is one the key decisions pertaining to occupational health. The decision of the plurality of judges, requires OSHA to show that it *is more likely than not* that long-term exposure at the existing standard posed a *significant risk* (Mendeloff, 1988).[6] The Benzene decision has led to OSHA's increased emphasis on quantitative risk assessment. This requires several time-consuming and complex steps to complete, and the final results are often controversial (Howard, 2010). Critics argue that the court's requirement that OSHA demonstrate evidence of harm above the proposed standard instead of relying on theories and assumptions is unrealistic. Instead, in developing standards, OSHA collects workplace exposure data, which is likely to be above the regulated exposure limits, or uses animal models that are administered high doses. OSHA then extrapolates

[5] The 1968 list has been incorporated into the Walsh-Healey Public Contracts Act, which governs government contracts for manufacturing. The Act sets out health and safety standards (McCluskey, 2003).
[6] Industrial Union Department, AFL-CIO v. American Petroleum Institute, 448 U.S. 607 (1980).

mathematically from this data to set hypothetical exposures or doses corresponding to the new regulated standards (Mendeloff, 1988; Froines et al., 1995).

The 11th Circuit Court of Appeal's 1992 decision ended OSHA's multiple-substance rulemaking approach (Howard, 2010).[7] In 1989, OSHA published a final rule revising 212 existing exposure limits and establishing 164 new exposure limits. These standards were set by relying on occupational exposure limits proposed by NIOSH and others, but OSHA did not conduct its own risk assessments (Howard, 2010). The Court vacated these limits, arguing "that OSHA had failed to establish that *each* [exposure limit] reduced a significant risk to worker health and that *each* exposure limit was technologically and economically feasible for the affected industries" (Howard, 2010). Accordingly, in March 1993, OSHA reverted to enforcing the 1971 legal limits (DOL Federal Register, 1993).

2.3 ACGIH and voluntary standards

ACGIH's members are occupational health professionals from academia, industry, and government agencies. According to the ACGIH (2002), the Threshold Limit Values (TLVs), indicate "the level of exposure that the *typical* worker can experience without adverse health effects but they are not fine lines between safe and dangerous exposures." They represent "scientific opinion[s] based on a review of existing peer-reviewed scientific literature by committees of experts in public health and related sciences." The TLV committee takes the approach of adopting a less onerous scientific procedure in recommending TLVs, i.e., by undertaking a peer review of the literature, but updating these TLVs frequently (Paustenbach et al., 2011). While earlier TLV revisions account for the practicality of risk reduction (Mendeloff, 1988), current revisions do not evaluate economic and technical feasibility (ACGIH, 2002).

[7] AFL-CIO v. OSHA, 965 F.2d 962, 962, 968 (11th Cir. 1992).

The procedure to update the TLVs has become more transparent over time, in response to criticisms in the 1980s that the TLVs were insufficiently protective and failed to account for the best available scientific information. Allegations were made that the TLVs were biased due to industry influence (Castleman and Ziem, 1988; Ziem and Castleman, 1989; Roach and Rappaport, 1990). In revising a TLV, a committee member takes the lead in producing the draft document, reviews the relevant scientific literature, and revises the draft based on the comments from other members of the committee (Culver, 2005). The draft documents the basis for the decision, its limitations, and references the studies reviewed (Culver, 2005). After the ACGIH board ratifies a proposed TLV a Notification of Intended Change ("NIC") is posted in various ACGIH publications and on its website. Thereafter public comments are accepted for six months (before 2007 the period was 1 year) (ACGIH, 2008). The Board of the ACGIH then decides based on a majority vote to adopt the revised TLV (Culver, 2005).

ACGIH's publication of the TLVs has withstood a legal challenge from industry.[8] The 2005 district court ruled that ACGIH had a First Amendment right to publish its standards. Furthermore as a private entity, it is not subject to such federal statutes governing rulemaking, such as the Federal Advisory Committee Act, the Administrative Procedure Act, and the OSH Act (Karmel, 2008). The 2008 district court noted that the ACGIH expressed its opinions in publishing the TLVs and did not provide representation of facts.[9] This characterization of TLVs as opinions frees the ACGIH from a variety of lawsuits that are based on statements of facts, such as product disparagement.

2.4 Plants' incentive for adhering to the voluntary standards

[8] *International Brominated Solvents Assoc. v. ACGIH, Inc.*, 5:04-CV-00394-HL (M.D.Ga), Order at 2 (March 11, 2005).
[9] *International Brominated Solvents Assoc. v. ACGIH, Inc.*, 5:04-CV-00394-HL (M.D.Ga) (2008)

Plants face several, albeit limited incentives, to adhere to strict voluntary standards. First, firms must purchase worker compensation insurance, so that workers harmed by workplace exposure are compensated (Ruser, 1985). Firms that self-insure and the larger firms that pay experience-rated insurance premiums face an incentive to adopt standards that strike a better balance between the cost of reducing exposure and the cost of either increased premiums or the increased payouts to workers (Ruser, 1985). In turn, insurance providers, which benefit from averting claims payments, encourage insured plants to adopt more protective standards. In making recommendations on exposure controls, insurance companies consider OSHA to be the minimum standards, and compare test results from industrial hygiene sampling to both the voluntary TLVs and legal limits (Pressman, 2005). However, smaller firms' premiums may not rise substantially even if their workers file claims because their premiums are based on the claims experience of similarly sized or similar kinds of businesses (Shapiro and Rabinowitz, 2000).

Second, a few states permit workers to pursue tort claims against employers who cause *intentional* harm or whose *grossly negligent or reckless* action causes harm (Fitzpatrick, 1982; Lynch, 1983; Cheney, 1991; Gabel, 2000). Workers can point to workplace exposure that exceeds the TLV as evidence of the employer's negligence (Karmel, 2008). Conversely, employers have used the "TLV defense" (Ziem and Castleman, 1989), i.e., when exposure was below the TLV, the employer can argue that "any exposure was *de minimis* and not a proximate cause of the workers' injuries and that the employer has not acted willfully or recklessly (Karmel, 2008). However, in reality, workers face significant obstacles in proving employers' gross negligence, recklessness, or intentional harm (Gorton, 2000). Moreover, in many states, worker compensation is, by law, the exclusive remedy and workers cannot sue employers for workplace injuries (Gabel, 2000).

Third, plants face pressure to adopt stricter exposure standards from manufacturers of products used in their production processes. Manufacturers have been sued by workers under product liability laws and held liable for defective products (Cheney, 1991). In particular, workers have argued that a product which leads to exposure exceeding the TLV is a defective product (Karmel, 2008).[10] Indeed, the 1973 Fifth Circuit court, in the Borel decision, allowed employees to sue the manufacturers of asbestos, avoiding the exclusive remedy provisions of worker compensation schemes (Carroll et al., 2005).[11] Given their risk for liability, manufacturers have refused to sell to industrial users known to flaunt regulations (Allport et al., 2003). However, manufacturers may exert only limited pressure on plants, as manufacturers can discharge their duty of care, by providing adequate warning information to the chemical plants (Laughery, 2004), and by arguing that the chemical plants are 'sophisticated' users, which already possess the information necessary for the safe use of the product (Faulk, 1986).

Fourth, the 1983 OSHA Hazard Communication Standard (HCS) requires employers to provide material safety data sheets on chemical substances, including TLVs, to workers who handle those substances. While the HCS does not mandate the adoption of TLVs, knowledge among plants managers, industrial hygienists and workers about stricter voluntary standards may prompt actions to reduce exposure. Hoerger et al., (1983) writes that most companies in the chemical industry, at least the large and medium-sized ones, staffed by professional industrial

---

[10] Goidich (1992) notes a similar role for voluntary standards in product liability cases. "While standards are not conclusive on the question of negligence," manufacturers presented the information on the standard, its broad acceptance, and expert testimony on the manufacturers meeting or exceeding the standards, have met with favorable judgments. Conversely, plaintiffs who show manufacturers failed to comply with these standards have won suits.

[11] Borel v. Fibreboard Paper Products Corp., 493 F.2d 1076 (5th Cir. 1973).

hygienists who establish control programs often targeted at or below the ACGIH recommendations. However, these data sheets may not present information in ways comprehensible to workers (Fagotto and Fung, 2002) to enable their advocacy of safer workplace or their demands for compensatory wages. Moreover, even if workers do understand their risks, they may lack the bargaining power to demand for safer workplace or compensatory wages (Gray and Jones, 1991).

3. Methods

Workers' exposure to a given chemical is measured using "test results" which are compared to exposure limits. Exposure limits can be specified in three possible ways, i.e., time-weighted average, short-term exposure or ceiling limits. These test results are calculated from "test samples" collected during OSHA's inspections. The collection of these samples and the testing of samples against the PELs are necessary to establish violations of the legal exposure limits for a given chemical (Lofgren, 1996). One or more test samples for a given chemical are collected using personal monitoring devices worn by workers, which are then measured at the Salt Lake City Technical Center. The information on the chemical identity of each test sample, its concentration and the associated sampling duration are recorded in the CEHD. Using this information and OSHA's guidelines, we calculate the test results for a given chemical. Details on these calculations are in Online Appendix 1.

We ask if plants respond to TLVs by reducing workers' exposures to air contaminants. We identify plants' response by exploiting the variation in the TLVs across different chemicals and that variation for individual chemicals over time. Our analysis on plant-level exposure focuses on chemicals which have both TLVs and PELs, and specifically those 75 chemicals that make up 70%-95% of test samples or 68%-94% of the test results annually in the chemical industry. We examine only those plants in the chemical sector where inspections collect at least one test sample of the 75 chemicals in the 1984-2009 period, and as described below, our inferences can be applied directly to only this sample. We examine 1,359 inspections at 1,103 unique plants, which yield 19,504 test results from 5,298 test samples.[12]

We observe the exposure level of a chemical (among the 75 chemicals) at a plant in a given year only if a sample of that chemical has been collected at that plant in that year. This pattern of observation gives rise to sample selection at two levels. First, the plant is selected among all plants in the chemical sector for an inspection in which samples are collected. Second, the inspector collects samples for only a subset of chemicals with PELs. We collapse the discussion of all chemicals with PELs to 75 chemicals because these make up most of the test samples that are collected by OSHA in the chemical manufacturing sector.

As our research focuses on chemical-level variation in TLVs, we exclude the 14,689 inspections in the chemical sector that do not sample our 75 chemicals, because they do not provide any information on the differences in exposure to various chemicals within the same inspection. This exclusion comes at the acceptable cost of not addressing the first type of sample selection. Because OSHA targets industries and plants for which exposures are more likely to exceed the legal standards, our analysis examines those plants in the chemical sector with above average exposure levels (OSHA, 2002). Other studies that document the exposure levels across plants and over time have similarly taken this approach of focusing on the plants that are in the CEHD (Gray and Jones, 1991; Froines et al., 1986; Froines et al., 1990). While the CEHD is not a random sample, OSHA's inspection strategy and the composition of inspections have remained

[12] We also estimate an alternative model that examines any inspection between 1984 and 2009 that collects any test sample. This model examines 1,544 inspections at 1,252 unique plants, yielding 23,105 tests of 222 chemicals and 19,845 tests for the 75 chemicals. Results are qualitatively similar.

fairly similar over time (Okun et al., 2004). OSHA continues to conduct programmed inspections which are based on priorities of specific chemicals or industries, and non-programmed inspections, which are undertaken in response to referrals from other agencies, workers' complaints, accidents, or as a follow-up to previous inspections.

Our study does address the second level of sample selection. Within our sample of inspected plants, we only observe the exposure to a given chemical if that chemical is sampled at a plant in a given year. For example, if only one chemical were sampled, we would not have information on the exposure for the other 74 chemicals at that plant in that year. However, observing that the inspector chose to test one chemical, but not others may provide information as to their relative exposure levels. Whether this type of selection biases our results significantly is ultimately an empirical question. Therefore, first, we estimate the Heckman selection model, which incorporates two variables, which we argue meet the exclusion requirements. Second, we compare results from the Heckman model with corresponding results from the OLS model, to examine the extent to which selection biases our results.

Our estimation model consists of two equations:

$$Exp_{s\,k\,p\,t} = F\,(\,Z\,(X_{k\,p\,t}, PEL_{k\,t}, TLV_{k\,t}) + \varepsilon_{s\,k\,p\,t}) \qquad \text{--- Outcome/Exposure Equation}$$

$$J_{s\,k\,p\,t} = 1\,[\,Q\,(W_{k\,p\,t}, X_{k\,p\,t}, PEL_{k\,t}, TLV_{k\,t}) + v_{s\,k\,p\,t} > 0\,] \quad \text{--- Selection/Inspection Equation}$$

The first equation captures workers' exposure levels at a plant. The outcome variable, $Exp_{s\,k\,p\,t}$, is the level of exposure of workers at plant *p* to the chemical *k* at time *t* as captured in the test result *s*. Each test result *s* denotes a measure of exposure relative to the exposure limit. Plants set target exposure levels in order to maximize profits. A plant's choice of less strict exposure targets can lower its abatement costs and thus reduce its short-run production costs. However, setting such targets can raise the expected costs from OSHA's penalties for violations of the legal exposure limits or other expected costs, including higher premiums for worker compensation insurance, tort liability, and higher wages to compensate workers for undertaking more risks. Nevertheless, the literature suggests plants that expose their workers to higher levels of chemicals will face only limited increases in these costs (see section 2.2). Plants set target exposure Z based on the plant characteristics, $X_{k\,p\,t}$, the legal exposure limits, $PEL_{k\,t}$, and the voluntary exposure limits, $TLV_{k\,t}$. The actual exposure levels vary from the target exposure levels by an error term, $\varepsilon_{s\,k\,p\,t}$, due to the failure to maintain the abatement equipment or human error (Shimshack and Ward, 2007).

The second equation describes the likelihood of observing a test result s collected during an inspection. The indicator variable $J_{s\,k\,p\,t}$ takes the value 1 if an inspection collects a sample s for chemical k in plant p at time t, and is zero otherwise. Plants must adhere to the PELs for all 75 of these chemicals and therefore, inspectors can potentially sample any of these 75 chemicals in any plant in any year. Indeed, our data reveals that inspectors do collect samples for which worker exposure, as eventually indicated by the test result, is below the detectable level. The Inspectors' approach of sampling potentially any chemicals with a PEL is sensible when they have incomplete information on the chemicals to which a worker may be exposed.[13]

The sample selection problem arises because the outcome variable, $Exp_{s\,k\,p\,t}$, is observed only if an inspection $J_{s\,k\,p\,t}$ collects a sample s for chemical k at plant p in year t, leading to a correlation in the error terms in the two equations. Specifically, factors that are unobserved by

[13] We plan to estimate an alternative model which restricts the identification in a given industry to those chemicals that are sampled at least once in that industry. This specification includes the interaction of industry fixed effects and chemical fixed effects. The effects of chemicals that are never sampled in a given industry would be absorbed by the interaction terms.

the researcher may lead to the inspector collecting a sample for a chemical and the sample to have a higher test result. As our observations are conditional on a chemical being sampled, the error in the outcome equation, ($\varepsilon_{s\,k\,p\,t} \mid v_{k\,p\,t} > -Q$), may not have a mean of zero.

Our study will not address the selection of a plant among all plants in the chemical sector for the collection of test samples. Our study addresses the issue of sample selection, which arises because we observe only exposure to those chemicals that are sampled, and not the exposure to the rest of the 75 chemicals. Observing a chemical not being sampled can, however, provide the researcher with information on the likely exposure levels—if inspectors choose not to sample a chemical based on their private information then the exposure to that chemical is likely to be significantly below the legal limit. To address selection, we estimate a Heckman selection model (Heckman, 1979) using the two-step method. We first estimate the selection equation. Next, we include the predicted inverse Mills ratio as a right hand side variable in the outcome equation to account for the correlation in the errors between the two equations. The standard errors account for the fact that the inverse Mills ratio is an estimated regressor. Heckman's two-step method requires that $v_{k\,p\,t}$ has a standard normal distribution and $\varepsilon_{s\,k\,p\,t}$ is mean zero. However, it does not require any assumptions on the functional form of $\varepsilon_{s\,k\,p\,t}$. We ensure that the model is not identified based purely on functional form by applying two excluded variables.[14] The inspection process, described below, gives rise to factors that influence the likelihood that a chemical is sampled, but which do not influence the underlying level of exposure to that chemical. The exclusion restriction requires that $W_{k\,p\,t}$ affects $E\,(J \mid X, PEL, TLV)$, but that $W_{k\,p\,t}$ does not affect $E\,(\,Exp \mid X, PEL, TLV)$.

[14] The Heckman model when identified solely based on the nonlinear functional form of the inverse Mills ratio can lead to imprecise estimates in smaller samples (Sartori, 2003).

OSHA incurs costs in conducting inspections, including the fixed costs of inspectors visiting a plant to conduct the inspection. The cost to collect a sample include the tangible costs of collecting the sample and sending it to Salt Lake City for analysis, and the intangible costs associated with the loss of goodwill with the plant for conducting intrusive tests that involve employees wearing monitoring devices for up to eight hour shifts. Therefore there are likely to be diminishing marginal costs of collecting samples, as multiple chemicals may be sampled using a single monitoring device. Furthermore, once the plant must undertake sample collection, the additional burden from collecting each subsequent sample is likely to be reduced. Diminishing marginal costs leads the inspector to be more discriminate in her initial decision to collect personal samples, i.e., she would need to have a strong enough belief that the exposure to a chemical exceeds the PEL to justify the costs associated with collecting the sample. Having made the decision to collect the first sample, the inspector would be more willing to collect additional samples, given the diminishing marginal costs.

This diminishing cost for collecting additional test samples lead us to consider two excluded variables. The first excluded variable is the number of samples, other than samples for chemical *k*, which are collected during an inspection. We are more likely to see samples of a chemical when it is a part of an inspection which collects a larger number of other samples. Being a part of an inspection that collects a larger number of samples lowers the cost of taking the additional sample, therefore raising the likelihood that a given sample is collected. However, it does not directly influence the underlying level of workers' exposure to that chemical, independent of whether that chemical is sampled.[15]

[15] Alternatively, when an inspector forms the belief that one chemical has high exposure, she may expect other chemicals to have high exposures as well. If this scenario were true, we would find a positive

The second excluded variable is an indicator variable that chemical *k* is a non-target chemical collected during an inspection related to a chemical-specific emphasis program. OSHA conducts chemical specific emphasis programs in which plants whose exposure to specific chemicals would be selected for inspections.[16] Because the inspection focuses on the target chemicals, we are less likely to observe samples of non-target chemicals during chemical-specific emphasis programs. Being part of a chemical specific emphasis program simply reduces the likelihood that a non-target chemical sample is collected, but it does not directly influence the level of worker exposure.

We provide direct evidence in support of the first requirement of the valid excluded variable. As reported in section 6.2, these variables are strongly correlated with the probability that a sample is observed and these relationships are statistically significant at the 1%. While $W_{k p t}$ is correlated with the exposure level conditional on observing a sample (i.e., $W_{k p t}$ affects *E(Exp | X, PEL, TLV and J=1))*, by lowering the inspector's threshold for testing, we argue that the exclusion restriction does hold (i.e., $W_{k p t}$ does not affect *E(Exp | X, PEL, TLV))*. The larger number of samples in a given inspection does not affect the underlying exposure levels at a plant. The plant does not have information on the number of samples an inspector collects, and therefore, the plant would not consider this factor in setting its target exposure levels for different chemicals.

3.1 Regression Models

---

correlation between the number of test samples in an inspection and observed exposure levels. Instead, we find a negative correlation.

[16] Emphasis programs include national-level programs that have targeted asbestos, lead, chromium hexavalent, and silica, and local-level programs that have targeted benzene, formaldehyde, and ammonia. http://www.osha.gov/dep/neps/nep-programs.html

We ask whether plants respond to TLVs by reducing worker exposure. Our regression model consists of two equations:

$$(S_{s\,k\,p\,t}/PEL_{k\,t}) = \beta_1\,(TLV_{s\,k\,t}/PEL_{s\,k\,t} - 1) + \beta_2\,D_{s\,k\,t} + \beta_3\,P_{k\,t}$$

$$+\,\beta_4\,X_{1\,p\,t} + \beta_5\,X_{2\,p} + \beta_6\,X_{3\,t} + \varepsilon_{s\,k\,p\,t}$$ ------ Exposure equation

$$J_{s\,k\,p\,t} = 1[\alpha_1\,(TLV_{s\,k\,t}/PEL_{s\,k\,t} - 1) + \alpha_2\,D_{s\,k\,t} + \alpha_3\,P_k$$

$$+\,\alpha_4\,X_{1\,p\,t} + \alpha_5\,X_{2\,p} + \alpha_6\,X_{3\,t} + \alpha_7\,W_{k\,p\,t} + \nu_{k\,p\,t} > 0]$$ ------ Inspection equation

The dependent variable $J_{s\,k\,p\,t}$ takes the value 1 if an inspection collects a test sample *s* for chemical *k* in plant *p* at time *t*, and zero otherwise. Any chemical that is not sampled in the inspection is included as a single observation with J=0 in each inspection. In other words, even if a chemical were to have legal limits defined in three different time frames – ceiling, short-term and time-weighted limits – that chemical is represented by a single observation if it is not sampled. Our rationale is that if an inspector does not test for a chemical at a plant, she believes that the maximum exposure at the plant for that chemical is lower than all its legal limit.[17]

The two excluded variables, $W_{k\,p\,t}$, are (i) the number of samples, other than samples for chemical *k*, that are collected in an inspection, and (ii) an indicator variable that chemical *k* is a non-target chemical collected during a chemical-specific emphasis program. The control variables, $X_{1\,p\,t}$, $X_{2\,p}$ and $X_{3\,t}$ are described below.

The exposure equation is at the level of the test result *s*. Our dependent variable $E_{s\,k\,p\,t}$, is the level of exposure of workers at plant *p* to the chemical *k* at time *t* as captured in the test

[17] As a robustness check, we plan to use a balanced sample. We include only one test result for each chemical that is sampled, i.e., the test result with the highest exposure. Each chemical that is not sampled is also represented by one observation of J=0.

sample *s*. Exposure E_{skpt} is defined as the ratio of the test result to the PEL. This ratio, which provides a measure of exposure in reference to the PEL, allows us to examine exposures across chemicals (Gray and Jones, 1991; Finger and Gamper-Rabindran, 2011). The test result alone, without reference to the PEL, is less informative because the same level of exposure to different chemicals can inflict health effects that vary in their severity.

Our variable of interest, *R*, is defined as $(TLV_{skt}/PEL_{skt} - 1)$, i.e., the percent difference between the TLV and PEL for test result *s* of chemical *k* in a given year *t*, if the TLV and PEL are directly comparable. Exposure limits with smaller numerical values are more protective. *R* takes a negative value when the TLV is stricter than the PEL, and vice versa. Chemicals for which TLVs and PELs are equally strict serve as the baseline for comparison, i.e., *R* takes the value 0 for these chemicals, as well as chemicals in which the PELs and TLVs are not comparable. The variable, D_{skt}, takes the value 1 for test results in which the TLV and PEL are directly comparable with each limit is defined with the same time frame, i.e., time-weighted averages, short-term exposure, or ceiling limits. It captures the difference in exposure level between chemicals that do and do not have directly comparable TLVs and PELs. The variable, P_{kt} takes the value 1 for chemicals with PELs that have been revised during our study period.

Our specification examines the contemporaneous relationship between the percent difference between TLVs, PELs and exposure. The ACGIH widely publicizes intended changes to the TLVs in ACGIH publications, including their widely disseminated booklet on TLVs, and on their website one year prior to adopting those new TLVs. We assume that by the start of the next year, when the TLVs are adopted, plants have had one year to learn about the new TLVs and to make changes, if any, to their target exposure levels.[18]

Our first specification assumes a linear relationship between exposure and the percent difference between PELs and TLVs. The linear assumption restricts the average marginal effects to be the same whether TLVs are stricter than PELs, or vice versa. The first specification includes the variables *R* and *D*. The coefficient β_1 captures the average marginal effect of one percentage point difference between TLVs and PELs for chemicals with directly comparable limits. The result $\beta_1 > 0$ would indicate that plants respond to stricter TLVs, measured relative to the PELs, by reducing their exposure level. In this specification, the coefficient β_2 captures the effect on plant-level exposure when the TLVs and PELs are equally strict relative to the case when the TLVs and PELs are not directly comparable.

Our second specification allows for a non-linear relationship between the dependent variable and the percent difference between TLV and PEL. This specification allows for the effect of TLVs to be different when TLVs are stricter or less strict than PELs. It further allows us to examine if there are marginal benefits to increasing the stringency of the TLV, when the TLV is already stricter than the PEL. This specification includes three different indicator variables for R, i.e., TLVs are less strict than PELs, $1 (R > 1)$, TLVs are stricter than PELs but by less than 50%, $1 (-0.50 < R < 1)$, and TLVs are more than 50% stricter than PELs $1 (R < -0.50)$. Again the baseline for comparison is chemicals for which TLVs and PELs are equally strict.

Response to TLVs across the distribution of exposure

[18] We plan to estimate alternative specifications which allow for a longer time period for plants to adjust to the TLVs.

From a health policy perspective, the priority is to reduce exposure at plants with high exposure levels. The previous models, which focus on the average effects, are likely to be skewed towards low exposure plants as 50% of our test results are below 1% of the PELs. To focus on high exposure plants, we estimate quantile regressions. Our comparison of results from the Heckman and OLS models on the average effect of TLVs on exposure indicate that in practice, selection does not cause significant biases in our estimates of the coefficients on the TLV variables. This evidence provides support for our approach of estimating quantile regressions even though these do not address selection. In the future, we plan to use methods developed in Buchinsky (1998) to control for sample selection in the quantile regressions.

Control variables

Inspection-level control variables include indicators for samples collected during inspections that have occurred under the chemical-specific emphasis programs. Under these programs, OSHA targets inspections to industries where employee exposure levels for specific chemicals are potentially in excess of the PELs. Dummy variables control for the type of inspection, i.e., inspections undertaken in response to accidents, complaints or referrals from other agencies, follow-up inspections or other inspections, with programmed inspections as the omitted category.[19] Plant-level control variables include plants' union status and the regulatory pressure at the plant. For our study to be valid, we need to control for these factors, but we do not need to isolate the causal effect of these factors on exposure. Regulatory pressure is captured by the number of inspections in the previous year and in the previous two to five years. We include the log of the dollar penalties and the log of the number of violations, both for the previous year and in the previous two to five years. We include indicators for SIC-4 industries to account for

[19] Programmed inspections are planned by OSHA based on the industry classification, which in turn is based on the industry-level rates of willful violation (Lofgren, 1996).

variation in production technology that influence worker exposure. While we focus on the 29 states in which OSHA enforces the law, we also include state indicators to account for any potential variation in state environmental health policies. Time dummies account for changes in production technology that can influence worker exposure. We do not apply plant-level fixed effects because over two thirds of the inspections occur at plants that are inspected only once in our sample. Our analysis with inspection level fixed effects yield qualitatively similar results, and are available upon request.

3.2 Plants' exposure relative to voluntary standards

Our earlier analysis measure exposure using the ratio of test results to PELs. The drawback of using PELs as a reference is that several of these have not been updated to reflect scientific understanding that call for lower exposure limits. Next, we examine how the gap between voluntary and legal standards affects the likelihood of test results exceeding the TLVs. The TLVs represent exposure limits that are viewed as protective of workers' health, given the available scientific evidence at the time. Therefore, the reduction in the exceedance of TLVs provides a measure of the health benefits from plants' reduction in worker exposure, if any, in response to the gap between the voluntary and legal limits. We estimate the Heckman probit model, with the exceedance of the contemporaneous TLVs as the binary dependent variable.

3.3 Comparison of plants' responses to legal and voluntary standards

To determine whether voluntary standards can serve as substitutes to legal standards, we compare plants' responses to voluntary and legal standards. We identify the effect of PELs using the variation across chemicals and chemical variation across time, though we note that PELs have been revised for only 8 chemicals during our study period.[20] We use the 1980 PELs as the denominator (i) to normalize exposures across chemicals, and (ii) as a reference for the current PELs and TLVs. We estimate the exposure equation using OLS with the following changes: (i) the dependent variable is the ratio of test results to the 1980 PELs, (ii) we add an additional variable of interest, i.e., the percent difference between the PELs and the PELs set in 1980, $(PEL_t/PEL_{1980} -1)$, and (iii) we include the percent difference between the TLVs and the 1980 PELs. We compare the coefficient on the (i) percent difference between the PELs and PELs set in 1980 and that on the (ii) percent difference between the TLVs and PELs in 1980.

4. Data

We use Chemical Exposure and Health Data (CEHD), which has just recently been made widely available to researchers. The CEHD compiles data on chemical samples collected during plant-level inspections (Gray and Jones, 1991). The CEHD provides the following information for each inspection: an inspection specific code, the numbers of samples collected in the inspection, an indicator that the sample is a personal airborne sample, the identity of the chemical sampled, the concentration of the personal airborne sample, and the duration during which the sample was collected. Using the information on the concentration and duration for each chemical sampled during an inspection, we calculate the appropriate test results for comparison to the chemical-specific exposure limits. We link the data from the CEHD to OSHA’s Integrated Management and Inspection System (IMIS) using inspection identifiers. IMIS provides information collected during inspections on plant characteristics (the plant’s SIC-4 code and address), inspection characteristics (the date, type of inspections and a field describing the chemical-specific emphasis program, if any, under which the inspection was

[20] Chemicals with revised PELs include asbestos, benzene, butadiene, cadmium and cadmium dust, ethylene oxide, formaldehyde, and methylene chloride.

conducted) and plant's regulatory history (OSHA inspections, violations, and penalties). We assemble the OSHA PELs from Tables Z-1, Z-2, and Z-3 of the OSHA General Industry Air Contaminants Standard (29 CFR 1910.1000). We conduct further research to document the few changes in PELs over time (Mirer, 2007). We assemble the TLVs from the ACGIH's annual TLV booklets (ACGIH, 1980-2009).

5. Data description

Our study examines those plants and chemicals for which workplace exposure is of greatest concern, as the data is collected during OSHA's inspections that focus on more problematic plants and chemicals. Toluene, beryllium and lead make up the largest shares of test results (11.8%, 8.7% and 6.1%, respectively). Table 1 shows the share of chemicals for which TLVs are more strict, equally strict or less strict than PELs among these 75 chemicals. We define a chemical as having stricter TLVs than PELs in a given year if any of its TLVs, expressed as ceiling limit, short-term limit or time weighted average limits, is stricter than those for PELs, even if the TLVs and PELs are equally strict by other measures. We use the corresponding definition for a chemical with stricter PELs. We do not observe cases in which a chemical's TLV is stricter by one of these measures, but is less strict by other measures.

Among the 75 chemicals in our sample, the TLVs and PELs are comparable for 64 to 66 chemicals during our study period. The share of chemicals with stricter TLVs has grown from 44.2% of the 75 chemicals in the 1984-1990 period to 51.8% in the 2003-2009 period. In contrast, the share of chemicals with stricter PELs has declined from 8.4% to 6.5% and the share of chemicals with equally strict TLVs and PELs has declined from 35.2% to 28.0%. Our sample of 75 chemicals is likely to have a smaller share of chemicals for which TLVs are stricter than PELs when compared to the full set of chemicals with PELs. Since 1980, the PELs for eight of the 75 chemicals have been revised to become stricter. This proportion is larger than the average share of all chemicals with PELs that have been revised in the same time period.

Generally, plants in our sample have similar characteristics to those excluded from our sample, including the likelihood of being unionized, and the number of inspections and violations in the previous periods (Table 2, Panel A). The average dollar penalties are slightly lower in our sample. The inspections in our sample differ from those excluded several ways. Almost all inspections in our sample are primarily health inspections, which focus on worker exposure, while a larger share of inspections excluded from our sample are safety inspections, which focus preventing falls or limbs caught in machinery. Relative to excluded inspections, a larger share of the inspections in our sample are undertaken as a chemical emphasis inspection and in response to referrals or complaints, whereas a smaller share are programmed inspections. Inspections in our sample also differ from those inspections that collect samples for chemicals other than the 75 in our study (Table 2, Panel B). Inspections in our sample have a larger numbers of test results per inspection, higher average exposure (captured by the higher maximum ratio test results to PELs per inspection), a higher probability of at least one PEL exceedance per inspection and a larger number of PEL exceedance per inspection.

Next we focus on plants within our sample. While the majority of these plants have zero or low exposures, a minority of plants exceed the voluntary and legal standards, This pattern of zero or low exposure among the majority plants is similar to the pattern of 'overcompliance' observed by Shimshack and Ward (2008) in their study of plants' wastewater discharges into the environment. The exceedance of voluntary standards, which is the baseline for safe exposure, highlights the need for effective policies to reduce worker exposures at these plants.

About 24.8% of plants in 1984-2009 and 23.4% of plants in the more recent period (2003-2009) have at least one test result exceeding the TLV. Correspondingly, 19.4% of plants in 1984-2009 and 14.4% of plants in the more recent period (2003-2009) have at least one test result exceeding the PELs.

The skewed distribution of the test results provides the motivation for our quantile analysis. For the majority of test results, the ratio of test results to PELs (or TLVs) is zero or very low, but these values are high at the highest percentiles. The share of test results that exceed the PELs and TLVs are 4.3% and 4.5%, respectively (Table 2, Panel C). The ratio of test results to PELs is 0 at the 25th percentile, 0.0006 at the median, 0.0488 at the 75th percentile and 0.3062 at the 90th percentile, while the mean is 0.382. The ratio of test results to the TLVs is 0 at the 25th percentile, 0.0008 at the median, 0.0887 at the 75th percentile and 0.4667 at the 90th percentile, while the mean is 0.581 (Table 2, Panel C and Table 6). The exceedance of PELs and TLVs are interlinked. There is a higher share of test results exceeding TLVs among those test results that exceed the PELs (79.0%) than among those test results that do not exceed the PELs (2.4%). Noteworthy is that the average gap between the TLVs and PELs is smaller among those test results that exceed the PELs than among those test results that are below the PELs.

6. Results

To investigate plants' responses to voluntary standards, we proceed as follows. We begin by examining the plants' mean response to TLVs, and testing linear and non-linear responses to the TLVs. Next, we examine the effect of TLVs across the distribution of test results. Finally, we compare plants' responses to TLVs and PELs.

6.1 Response to TLVs at the mean of test results

First, we examine plants' *mean* response to the voluntary standards using the Heckman selection model (Table 3). Exposure is measured as the ratio of the test results to PELs in order to normalize results across chemicals and measurement types (column 1). The first specification assumes a linear relationship between exposure and the percent difference between TLVs and PELs. If plants were to reduce their exposure fully in response to TLVs, chemicals with TLVs that are 1% lower than PELs would have 1% lower ratio of test results to PELs than chemicals with TLVs and PELs that are equal. As seen in Table 3, column 1, plants, on average, reduce exposure by only a small percentage in response to TLVs. TLVs that are 1% lower than the PELs lead to a 0.054% lower ratio of test results to PELs. However, this estimate is statistically significant at the 1% level, demonstrating that TLVs do have an influence on exposure levels. The analysis of PELs exceedance yields comparable results (Table 3, column 2 and 3). We find that TLVs that are 1% lower than the PELs lead to only a 0.22 percentage point decline in the likelihood of PEL exceedance, and the estimate is statistically significant at the 1% level (Table 3, column 2). This decline in PEL exceedance is small relative to the 4.2 percentage point average PEL exceedance in the sample.

Next, we examine if the relationship between exposure and the percent difference between TLVs and PELs is, in fact, non-linear (Table 3, column 4-6). The specification includes indicator variables that capture (i) those chemicals with stricter PELs and (ii) the variation in how much stricter TLVs are relative to PELs, for those chemicals with stricter TLVs. The chemicals with equally strict TLVs and PELs serve as the baseline for comparison. Exposure is captured using the ratio of test results to PELs (Table 3, column 4). We find that TLVs that are stricter than PELs reduce exposure by a small percentage, but the extent to which TLVs are stricter than the PELs does not exert differential effects on exposure. Exposure is 27.9% lower for chemicals with TLVs that are 50% or more strict than PELs and 29.2% lower for those with TLVs that are less than 50% as strict. Both results are significantly different than 0 at the 1% level, but are not significantly different from one another. In contrast, we find that exposure is 39.4% higher for those chemicals with stricter PELs, when compared to exposure for chemicals with equally strict TLVs and PELs. The model on the likelihood of PEL exceedance yields comparable results. Chemicals with stricter TLVs, regardless of the gap in the strictness of TLVs and PELs, have a lower likelihood of PEL exceedance. The likelihood of PEL exceedance is 1.4 percentage points lower for chemicals with TLVs that are 50% or more strict than PELs, and 1.6 percentage points lower for those with TLVs that are less than 50% as strict. The likelihood of PEL exceedance is measured relative to the likelihood of chemicals with equally strict TLVs and PELs. In contrast, the likelihood of PEL exceedance is 3.0 percentage points higher for chemicals with stricter PELs.

6.2 Sample Selection

We review the extent to which selection affects our estimates, by comparing the results from the Heckman and OLS models (Table 4, columns 1 and 2). The OLS model is restricted to test results calculated using test samples that are collected during OSHA's inspections (n=19,474). The OLS model assumes that the sample is randomly generated. This implies that OSHA's inspectors do not have private information, and thus, the analysis of the inspection data does not raise sample selection issues. The coefficients on the percent difference between TLVs and PELs are 0.054 and 0.055 in the Heckman and OLS models, respectively. The similarity of these coefficients suggests that the failure to account for selection in the OLS model does not substantially bias our results related to the effect of TLVs. We rule out the possibility that poor instrument choice explains the similarity in the coefficients from these two models. We demonstrate the first requirement of valid instruments is met, i.e., there is a strong relationship between each of the excluded variables and the likelihood of observing a sample. The log of the number of other chemical samples in the inspection is positively correlated to the probability of observing a test result, and the coefficient is statistically significant at the 1% level. This is consistent with our hypothesis of diminishing marginal costs of testing. Being a non-targeted chemical in an emphasis inspection is negatively correlated with the probability of observing a test result, with the coefficient statistically significant at the 1% level. The second requirement for the valid instruments, i.e., excludability, cannot be demonstrated directly. Section 3 describes why these variables are not likely to directly affect exposure.

Our first OLS model (Table 4, column 2) makes the extreme assumption that inspectors do not have private information. Our second OLS model (Table 4, column 3) makes the other extreme assumption that inspectors have full information on the expected exposure, and they do not collect test samples when exposures are expected to be far below the PELs. Therefore, we treat the exposure as zero for chemicals that are not sampled, leading to a larger number of observations in the model (n=108,535). The coefficient on the percent difference between TLVs and PELs is 0.056 and 0.010 in the first and second OLS models, respectively, and both estimates are statistically significant at the 1% level. These two OLS models provide the upper and lower-bounds, respectively, of the average effect of TLVs in reducing exposure.

6.3 Heterogeneity in response across the distribution of exposure

The tepid response, on average, to TLVs, could be due to most exposures already being very low or at zero, making further reductions in exposures difficult or impossible. We address this issue in two ways. First, we use quantile regressions and secondly, we compare the effects of

TLVs to the effects of changes in PELs. The skewed distribution of test results, with 40% of test results having a value of zero, suggests that our analysis at the mean may obscure the variation in responses to TLVs across the distribution of test results. In particular, plants at higher percentiles of test results have greater potential to reduce their exposure, while plants with zero test results cannot reduce exposure further. We run quantile regressions to investigate the effect of TLVs on the distribution of exposures. Not accounting for selection in our quantile regressions is unlikely to cause substantial bias in our results, as seen in the comparison of Heckman and OLS models (Table 4, column 1 and 2).

Results from the quantile regressions with the ratio of test results to PELs as the dependent variable are shown in Table 5. These results indicate that the effect of TLVs vary significantly across quantiles. As expected, TLVs have very little effect on the median of the distribution of results, and the scale of the effect of TLVs increases for the upper quantiles. However, the effect of TLVs relative to PELs on the distribution of results is smaller than recommended by the TLVs, even at the highest percentiles of exposure. The 90th and 95th quantile of exposures are only 0.18% and 0.42% lower, respectively, for TLVs that are 1% lower than PELs than for TLVs that are equal to PELs. Even when the largest reductions in response to voluntary standards are observed, i.e. at the 95th quantile of exposure, the exposure reduction is only two fifths of the amount recommended by the voluntary standards. At the 90th percentile, the reduction in exposure from a 1% stricter TLV is only one-fifth of the magnitude recommended by the TLV. At lower percentiles, the effect of TLVs on exposures is smaller. For example, the 70th and 80th percentile ratio of test results to PELs for TLVs that are 1% lower than the PELs are only 0.01% and 0.04% lower, respectively, than for TLVs that are equally strict as

PELs. The null effect of TLVs below the 40th percentile is unsurprising, as many of the test results have zero exposures.

6.4 Comparison of plants' response to TLVs and PELs

We compare plants' response to TLVs and PELs in Table 6, column 1 and 2. The dependent variable is the ratio of the test results to the 1980 PELs. Given that we find plants respond to TLVs at a much lower rate than we would expect them to respond to PELs, this allows us to examine in tandem how they respond to different limits. We compare (i) the coefficient on the percent difference between PELs and the 1980 PELs, and (ii) the coefficient on the percent difference between the TLVs and PELs. As seen in Table 6, column 1, plants' reduction in exposure in response to PELs is about ten times larger than the reduction in response to TLVs. PELs that are 1% lower than 1980 PELs lead, on average, to 1.02% lower ratio of exposure to the 1980 PELs. This coefficient that is not significantly different from one, supports the idea that firms respond to reductions in legal limits with equal reductions in exposures. In contrast, TLVs that are 1% lower than 1980 PELs lead, on average, to only a 0.09% lower ratio of test results to 1980 PELs. The specification in Table 6, column 2 yields comparable results on plants' sizable reduction in exposure in response to PELs with the coefficient on the current PEL significantly greater than 0, and not significantly different 1. PELs that are 1% lower than the 1980 PELs lead on average to a 0.93% lower ratio of exposure to the 1980 PELs. Plants' larger reduction in exposure in response to PELs is unsurprising, as OSHA imposes penalties for PEL exceedance, but not for TLV exceedance. If plants' exposure had been on average just below the 1980 PELs, we expect a 1% decline in the PEL relative to the 1980 PELs to lead to a maximum of 1% decline in the ratio of test results to 1980 PELs.

Our comparison of exposure reduction in response to PELs and TLVs comes with one caveat. It is plausible that compared to the 48 chemicals with TLV revisions, the eight with PEL revisions are known to be more hazardous, enabling OSHA to successfully implement these legal standards. Therefore, the estimated exposure reduction in response to PELs may be driven by both the legal nature of PELs and plants managers' perception of the hazardous nature of these chemicals. Our comparison of reductions in PELs and TLVs may therefore overstate the exposure reduction due to the mandatory nature of the legal limits.

6.5 Exposures measured as TLV exceedance

The outcome variable of TLV exceedance allows us to better capture health benefits from reduced exposure, as TLVs are on the whole more protective than the PELs. Therefore, we examine the effect of the percent difference between PELs and TLVs on TLV exceedance (Table 6, columns 3-6). The coefficients on the percent difference between PELs and TLVs (Table 6, column 3 and 4) or the dummy variables denoting these differences (Table 6, column 5 and 6) capture two effects. The first effect is plants' possible reduction of exposures in response to TLVs, leading to a lower likelihood of TLV exceedance. The second effect is that TLV exceedance, all else equal, is more likely for chemicals with stricter TLVs.

We find the likelihood of TLV exceedance is increasing in the degree that TLVs are stricter than PELs. We also find a greater likelihood of TLV exceedance when TLVs are 50% or more strict than PELs (Table 6, column 6). These results are consistent with our earlier findings that plants reduce their exposures by smaller amounts than that recommended by TLVs. Consider the case in which PEL and TLV are equally strict in 1984 and then the TLV is made stricter in 1990, but the PEL remains unchanged. Therefore the new TLV is stricter than the contemporaneous PEL. If plants had fully reduced exposure by the amount recommended by the new TLV, we would expect no effect on the likelihood of the exceedance of the contemporaneous TLV. Instead, if plants had reduced their exposure by only a percentage of that recommended by the new TLV, we expect to see the opposite effect, with exposures not sufficiently lowered to meet the stricter recommended limit. Our results are compatible with the latter response. Surprisingly, in column 5, we also find that TLVs that are less restrictive than PELs also lead to an increased likelihood of TLV exceedance, though this effect is reverse when we include chemical fixed effects.

6.6 Other estimation issues

The identification of the effect of the percent difference between TLVs and PELs on exposure comes from (i) variation across chemicals, and (ii) variation of individual chemicals over time. One concern is if a third factor, for example, OSHA's initiation of rule-making could have contributed to both stricter TLVs and lower exposure. Our review of the literature does not find evidence that ACGIH's proposals for stricter TLVs are related closely to OSHA's rule-making. Far fewer revisions have been undertaken for PELs (8 chemicals) than for TLVs (45 chemicals). We cannot restrict our identification to within chemical variation because while several TLVs are revised to stricter levels over time, the total number of revisions to TLVs is limited.

6.7 Other variables

Chemicals for which PELs become stricter during our study period have higher exposure, as measured by the ratio of test results to PELs (Table 3, column 1). Stricter PELs, all else equal, will mechanically lead to higher ratio of test results to PELs. Exposure is higher for samples collected during referral (55.9%), follow-up (34.5%), and other inspections (56.2%) relative to those collected during programmed inspections. These results are compatible with inspections as a result of a referral from another government agency and as a follow-up to a previous inspection being undertaken at plants with problematic workplace exposure (OSHA, 2002). Exposure is 74.4% higher for samples collected during health inspections relative to those collected during safety inspections, a finding compatible with health inspections targeting plants with problematic workplace exposure.

7. Setting legal standards at the levels of the current voluntary limits

OSHA's Administrator, Dr. David Michaels, has affirmed that updating the legal standards is the agency's priority (Rosenfeld and Feng, 2011). In recent interviews conducted by the General Accounting Office, public health experts argue that "Congress should pass new legislation that would allow OSHA, through a single rulemaking effort, to revise standards … based on … the TLVs developed by the ACGIH," (GAO, 2012).[21] Similar recommendations have been made by the 1997 Presidential/Congressional Commission on Risk Assessment and Risk Management (Presidential Commission, 1997) and by the Director of NIOSH (Howard, 2010). This legislation would sidestep the procedural requirements under section 6(b) of the OSH Act or the Administrative Procedure Act and those resulting from the Benzene decision that have paralyzed the rule-making process (GAO, 2012). A precedent for such legislation is the 1970 legislation that permitted OSHA in its first two years of operations to adopt existing workplace exposure limits to serve as legal standards (McCluskey, 2003; GAO, 2012).

[21] The GAO report mentions "voluntary industry consensus standards" as an alternative basis for revision. However, that approach would not achieve a timely update for the legal standards. As noted in the GAO (2012) report, "OSHA may need to do a substantial amount of independent scientific research to ensure that [those] consensus standards are based on sufficient scientific evidence."

Our study provides three pieces of evidence in support of the one-time adoption of the exposure limits represented by the current TLVs as the legal standards. First, mandating these limits is necessary to provide sufficient incentives for high exposure plants to reduce their exposures. Our study reveals that while plants, on average, reduce their exposures to the full extent mandated by the legal standards. In contrast, even when the largest responses to the TLVs are observed, exposure declines by only two-fifths of the levels recommended by the voluntary standards. We acknowledge that our study may provide upper-bound estimates of the effect of legalizing an exposure limit, because the eight chemicals for which PELs were revised during our study period may have been more hazardous than average. Therefore policy action of legalizing the limits, which serve as the current voluntary standards, is likely to reduce exposure by less than the full amount mandated by the new legal limits.

Second, setting the legal standards to the levels of stricter voluntary limits would incentivize an important subset of plants to reduce workers' exposure. Our data show that worker exposure at this subset of plants exceeds the stricter voluntary standards, but comply with the less strict legal standards. For 18.1% of inspected plants between 2003 and 2009, workers' exposure level for at least one chemical is between the voluntary and legal standards.[22,] At the level of test results, the predictions from the Heckman model indicates that about 5.0% of the selected observations and 4.9% of non-selected observations would have exposure levels between the voluntary and legal standards. [23]

[22] These figures are restricted to those chemicals for which TLVs are stricter than PELs.
[23] We use the Heckman model which allows for a linear relationship between exposure and the gap between legal and voluntary standards (Table 3, column 1). This prediction is based on the estimated coefficients and the chemicals for which voluntary standards are stricter than legal standards.

Third, our data suggest that adopting the voluntary standards would meet the economic feasibility required of OSHA's standards.[24] According to the Supreme Court decision in the Cotton Dust case, a legal standard meets the feasibility threshold even if it imposed financial burden on firms that are laggards in health and safety standards in the industry.[25] However, the feasibility threshold would not be met if the legal standard causes the dislocation of the entire industry, adversely affected its competitiveness, or if it led to undue concentration in the industry (Nordstrom, 1983; Mendeloff, 1988). The fact that most plants in the industry already meet the voluntary standards and many of these maintain exposures far below the voluntary standards indicate that most plants in the industry would not be adversely affected by the revised legal standards. Predictions from the Heckman model suggest that for chemicals that are not sampled, exposure levels are expected to meet the voluntary limits in over 98.1% of cases.

Our study of inspected plants, with higher average exposures, can inform the potential impact of this proposed policy change on the broader chemical sector. First, the policy priority is high exposure plants, and our study shows that legalizing stricter exposure limits can reduce exposure at these priority plants. Second, compared with plants in our sample, we expect an even larger share of plants in the chemical sector to already meet the voluntary standards, and therefore to be unburdened by the policy change. Predictions from the Heckman model suggest that for chemicals that are not sampled, exposure levels are expected to meet the voluntary limits in over 98.1% of cases. By the same token though, we expect that only a small share of plants may maintain their exposures between the voluntary and legal standards, and thus would be affected by the proposed policy.

---

[24] American Textile Mfrs. Inst. v. Donovan, 452 U.S. 490, 506 (1981)

[25] The Supreme Court prohibited the use of cost-benefit analysis in setting OSHA's legal standards. A cost-benefit analysis on revising the legal standards to the levels of stricter voluntary limits is beyond the scope of this study.

8. Conclusion

Voluntary standards on exposure to contaminants from food, products, and in the work environment play an increasing role in providing safety guidelines, especially in the absence of up-to-date legal standards (Cheit, 1990). Moreover, voluntary standards can potentially respond quickly and flexibly to new technologies and new information on health risks (Weimer, 2006; Meidinger, 2009). Given the reliance on voluntary standards, we conduct the first study that tests if voluntary standards for contaminants reduce exposure to those contaminants and if these standards serve as perfect substitutes for legal standards. Specifically, we examine if plants reduce workers' measured exposure to toxic chemicals in response to voluntary workplace exposure standards and if plants respond to voluntary standards in the same way in which they respond to legal standards.

Our analysis of inspections at 1,103 chemical plants between 1984 and 2009 concludes that voluntary standards can serve as complements, but not perfect substitutes, to legal standards. First, high worker exposure at a subset of plants calls for effective policy tools to reduce exposure. Between 2003 and 2009, 14.4% of inspected plants have at least one test result exceeding the PEL and 23.4% of inspected plants have at least one test result exceeding the TLV, which indicates adverse exposure levels. Second, high exposure plants reduce their exposure, measured by the ratio of test results to legal limits, by only a ***small*** percentage in response to voluntary standards, as captured by the difference between the TLVs and PELs. At the 90^{th} and 95^{th} percentiles of exposures, TLVs that are 1% lower than PELs leads to only 0.18% and 0.42% lower ratios of test results to PELs. Noteworthy, at the 95^{th} percentile of exposures, where we observe the largest response to TLVs, the exposure reduction is only two fifths of that recommended by the voluntary standards. Third, plants reduce exposure by a greater percentage in response to legal standards than to voluntary standards. PELs that are 1% lower than the 1980 PELs lead, on average, to 0.95%-1.03% lower exposures. In contrast, TLVs that are 1% lower than the 1980 PELs lead, on average, to only 0.09% lower exposures.

Our study of inspected plants can be extrapolated with care to inform a policy that affects the broader chemical sector. Our study provides support for public health experts' call for Congress to pass legislation that would allow OSHA to update legal standards using the TLVs (GAO, 2012). This policy would contribute to reducing exposure at an important subset of plants. For 18.1% of inspected plants between 2003 and 2009, workers' exposure level for at least one chemical is between the voluntary and legal standards.[26] At the same time, this action will not impose an economic burden on the majority of plants. For 74.8% of inspected plants between 2003 and 2009, all their test results already meet the voluntary standards. Nevertheless, legalizing these stricter limits alone, without sufficient enforcement of these stricter standards, would not ensure plants achieve these stricter standards. As described, 14.4% of plants in the more recent period (2003-2009) have at least one test result exceeding the current legal standards.

Our results are compatible with plants' limited incentives to adhere to voluntary standards (Section 2.4). First, plants, other than the largest, do not pay higher premiums for worker compensation insurance even when they face increased liability from workplace exposure (Ruser, 1985). Second, in states where the worker compensation system is the exclusive remedy, employees cannot bring an action against employers for harm due to adverse workplace exposure. Moreover, when state laws permit legal action against employers for intentional harm or gross negligence, workers face significant obstacles in bringing a successful

[26] These figures are restricted to those chemicals for which TLVs are stricter than PELs.

action (Gorton, 2000). Third, workers' wages do not fully compensate for their increased risk, because workers lack bargaining power (Gray and Jones, 1991). Moreover, workers do not fully comprehend health risks, despite the mandated reporting of the voluntary limits on material safety data sheets (Fagotto and Fung, 2002).

Our results are subject to two important caveats. We plan to re-estimate in our models in two ways. First, we plan to estimate standard errors clustered on inspections. Our preliminary results find no qualitative differences when we include inspection fixed effects. Second, we plan to estimate quantile regressions that address sample selection.

Extrapolation of our results on voluntary contaminant standards for workplace exposure to the areas of food and product safety requires care. Nevertheless, our finding that high exposure plants do not fully reduce their exposure in response to voluntary standards cautions against the substitution of voluntary standards for legal standards. We expect producers to be less responsive to voluntary standards when they face only low costs in not meeting these standards, such as limited loss in market share or limited tort liability. Should data on actual exposure to contaminants become available in the food and product safety areas, it would be informative to test producers' responsiveness to voluntary standards.

References

ACGIH, 1980-2009. Threshold Limit Values (TLV) and Biological Exposure Indices (BEI) booklets. ACGIH, Cincinnati, Ohio. Annual booklets from 1980 to 2009.

ACGIH, 2002. ACGIH® Statement of Position Regarding the TLVs® and BEIs® adopted by the ACGIH® Board of Directors on March 1, 2002 Accessed on 5/14/2012 http://www.acgih.org/tlv/PosStmt.htm

ACGIH, 2008. TLV®/BEI® Development Process: An Overview. Accessed on 5/14/2012. http://www.acgih.org/TLV/DevProcess.htm

Adler, S.R., 1989. From Model Agency to Basket Case – Can the Consumer Product Safety Commission Be Redeemed. 41 Administrative Law Review. 61.

Allport, D. C., Gilbert, D. S., Outterside, S. M., 2003. MDI and TDI Usage: Responsible Risk Management, in D. C. Allport, D. S. Gilbert and S. M. Outterside (eds.) MDI and TDI: Safety, Health and the Environment. A Source Book and Practical Guide. John Wiley. Chichester, UK

Buzby, J., Frenzen, P.D., Rasco, B., 2001. Product Liability and Microbial Food-Borne Illness. Economic Research Service, US Department of Agriculture; Washington, D.C. http://www.ers.usda.gov/publications/aer799/aer799.pdf

Carol, S., Hensler, D., Gross, J., Sloss, E., Schonlau, M., Abrahamse, A., Ashwood, S., 2005. Asbestos Litigation. RAND Institute for Civil Justice. RAND Corporation.

Castleman, B.I., Ziem, G.E., 1988. Corporate influence on threshold limit values. *American Journal of Industrial Medicine.* 13(5). 531-559.

Cheit, R., 1990. Setting Safety Standards: Regulation in the Public and Private Sectors. Berkeley and Los Angeles: University of California Press.

Cheney, C.A., 1991. Not Just for Doctors: Applying the Learned Intermediary Doctrine to the Relationship between Chemical Manufacturers, Industrial Employers, and Employees. Northwestern University Law Review. 85 (2).

Culver, B. D., 2005. Herbert E. Stokinger Award Lecture 2005—Innovation for the TLV Process. Journal of Occupational and Environmental Hygiene. 2(10), 70-73.

Environmental Protection Agency. 1987. Overview Report on Unfinished Business: A Comparative Assessment of Environmental Problems. Washington, DC. Environmental Protection Agency, 000R87901.

Environmental Protection Agency Scientific Advisory Board. 1990. Reducing Risk: Setting Priorities and Strategies for Environmental Protection. SAB-EC 90-021.

Ettinger, H. J., 2005. Henry Smyth Jr. Award Lecture. Journal of Occupational and Environmental Hygiene, 2(4), D25-D30.

Fagotto, E., Fung, A., 2003. Improving Workplace Hazard Communication. Workplace Safety. EBSCO Publishing.

Falkenstein, D., 2010. Wal-Mart Imposes More Stringent Standards on Beef Suppliers. Food Poison Journal. http://www.foodpoisonjournal.com/foodborne-illness-outbreaks/walmart-imposes-more-stringent-standards-on-beef-suppliers/.

Finger, S., Gamper-Rabindran, S., 2011. Testing the effects of self-regulation on industrial accidents. Revision requested by Journal of Regulatory Economics. Center for Industry Studies. Working paper 33.

Fitzpatrick, Jr. J.J., 1982. Recent Product Liability and Regulatory Developments Affecting Trade Association Sponsored Health and Environmental Effects Research. Insurance Counsel Journal.

Froines, J.R., Wegman, D. H., Dellenbaugh, C. A., 1986. An Approach to the Characterization of Silica Exposures in U.S. Industry. American Journal of Industrial Medicine, 10, 345-361.

Froines, J.R., Baron, S., Wegman, D. H., O'Rourke, S., 1990. Characterization of the Airborne Concentrations of Lead in U.S. Industry. American Journal of Industrial Medicine, 18 (1), 17.

Froines, J., Gottlieb, R., Smith, M., Yates, P., 1995. Disassociating Toxic Policies: Occupational Risk and Product Hazards in: Gottlieb, R. (Ed.) Reducing toxics: a new approach to policy and industrial decisionmaking. Washington D.C.

Gabel, J. T. A., 2000. Escalating Inefficiency in Workers' Compensation Systems: Is Federal Reform the Answer? Workers’ Compensation Law Review 71.

GAO. General Accounting Office. 2012. Workplace Safety and Health: Multiple Challenges Lengthen OSHA’s Standard Setting. Report to Congressional Requesters. April 2012. GAO-12-330.

Gamper-Rabindran, S., Finger, S., 2012. Does self-regulation reduce pollution? Responsible Care program in the chemical industry. Journal of Regulatory Economics, accepted.

Goldich, K. A., 1982. The Role of voluntary Safety Standards in Product Liability Litigation: Evidence or cause in Fact? Insurance Counsel Journal, 320-336

Gorton, M., 2000. Intentional Disregard: Remedies for the Toxic Workplace. 30 Environmental Law, 811

Graham, J., 1991. Product Liability and Motor Vehicle Safety in: Huber, P.W., Litan, R. E. (Eds.) The Liability maze: the impact of liability law on safety and innovation. Brookings Inst. Pr.

Gray, W. B., Jones C. A.,1991. Longitudinal Patterns of Compliance with OSHA in the Manufacturing Sector. Journal of Human Resources, 26 (4), 623-653.

Heckman, J., 1979. Sample selection bias as a specification error. Econometrica 47, 153-161.

Henson, S., 2008. The Role of Public and Private Standards in Regulating International Food Markets. Journal of International Agricultural Trade and Development 4(1), 63-81, p. 71.

Howard, J., 2010. OSHA Standards-Setting: Past Glory, Present Reality and Future Hope. Chicago-Kent College of Law and Workplace Fairness. Employee Rights and Employment Policy Journal 237.

Industrial Union Dept., AFL-CIO v. American Petroleum Inst., No. 448 U.S. 607, 639, Supreme Court of the US, 1980.

International Brominated Solvents Association v. ACGIH, No. 5:04-cv-00394-HL, the US District Court for the Middle District of Georgia Macon Division, 2008. http://www.acgih.org/ACGIH_Order_Granting_Summary_Judgment.pdf

Lazzara, J., 2004. Safeguarding: Are ANSI Standards Really Voluntary? Occupational Hazards Magazine, Penton Media Inc.

Leigh, J. P., 2011. Economic Burden of Occupational Injury and Illness in the United States. Milbank Quarterly 89 (4), 728-772.

Lofgren, D. J., 1996. OSHA Compliance Issues: Targeting Industries and Work Sites for OSHA Health Inspections. Applied Occupational and Environmental Hygiene. 11 (5), 448-456.

Lynch, J. F., 1983. The Clash between Strict Products Liability Doctrine and the Workers' Compensation Exclusivity Rule: The Negligent Employer and the Third-Party Manufacturer. Insurance Counsel Journal, 35.

Lyon, T., Maxwell, J. W., 2008. Corporate Social Responsibility and the Environment: A Theoretical Perspective,” Review of Environmental Economics and Policy, 2, 240-260.

McCluskey, G. J., 2003. Occupational Exposure Limits in: Greenberg, M., (Ed.) Occupational, Industrial, and Environmental Toxicology, 2nd ed. English Book Books: 418-423.

Meidinger, E., 2009. Private Import Safety Regulation and Transnational New Governance in: Coglianese, C., Finkel, A., Zaring, D., (Eds) Import Safety. Chapter 12. University of Pennsylvania Press.

Mendeloff, J., 1988. The Dilemma of Toxic Substance Regulation: How Overregulation Causes Underregulation. The MIT Press.

Mirer, F., 2007. Have OSHA Standards Kept Up With Workplace Hazards? Hearing Before the Subcommittee on Workforce Protections. One Hundred and Tenth Congress First Session: Washington, D.C. http://www.gpo.gov/fdsys/pkg/CHRG-110hhrg34633/html/CHRG-110hhrg34633.htm

Morgenstern, R. D., Pizer, W.A., 2007. The Nature And Performance of Voluntary Environmental Programs in the United States, Europe, And Japan. Resources for the Future. Washington DC.

National Academy of Engineering, National Research Council, 2010. Interim Report on Causes of the Deepwater Horizon Oil Rig Blowout and Ways to Prevent Such Events. Washington, D.C.: The National Academies Press.

Occupational Safety and Health Administration. 1993. Air Contaminants. United States Department of Labor Final Rules RIN 1218-AB26. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=13306&p_text_version=FALSE

Occupational Safety and Health Administration, 2002. OSHA Inspections. US Department of Labor. OSHA 2098 (Revised). http://www.osha.gov/Publications/osha2098.pdf

Okun, A., Cooper, G., Bailer, A. J., Bena, J., Stayner, L., 2004. Trends in occupational lead exposure since the 1978 OSHA lead standard. American Journal of Industrial Medicine, 45, 558–572. doi: 10.1002/ajim.20008

Paustenbach, D., Cowan D., Sahmel J., 2011. The History and Biological Basis of Occupational Exposure Limits for Chemical Agents in: Rose, V.E., Cohrssen, B., (Eds). Patty's Industrial Hygiene. 6th Ed. John Wiley and Sons, Inc.

Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997. Risk Assessment and Risk Management in Regulatory Decision Making. Final Report, Vol. 2. http://www.riskworld.com/Nreports/1997/risk-rpt/volume2/pdf/v2epa.PDF

Pressman, D. M., 2005. Insurance 101 for the Safety Professional. Paper presented at the 2005 American Society of Safety Engineers Professional Development Conference. June 12-15. New Orleans, LA. Session No. 770 https://www.asse.org/practicespecialties/riskmanagement/docs/Pressmann%20Paper.pdf

Roach, S.A., Rappaport, S.M., 1990. But they are not thresholds: a critical analysis of the documentation of Threshold Limit Values. American Journal of Industrial Medicine, 17(6):727-753.

Rosenfeld, P.E., Feng, L., 2011. Risks of Hazardous Waste. 1st Ed. Elsevier.

Ruser, J.W., 1985. Workers' Compensation Insurance, Experience-Rating, and Occupational Injuries. The RAND Journal of Economics, 16 (4), 487-503.

Sartori, A.E., 2003. An Estimator for Some Binary□Outcome Selection Models Without Exclusion Restrictions. Political Analysis. 11(2), 111-138.

Schepel, H., 2005. The Constitution of Private Governance: Product Standards in the Regulation of Integrating Markets. Oxford, Hart Publishing.

Shapiro, S.A., Rabinowitz, R., 2000. Voluntary Regulatory Compliance in Theory and Practice: The Case of OSHA. Administrative Law Review, 51 (1), 91-156.

Shimshack, J., Ward, M., 2008. Enforcement and Overcompliance. Journal of Environmental Economics and Management, 55(1), 90-105.

Smith, S., 2012. GAO Chief: We Don't Know Why OSHA Standards Take So Long. EHS Today, The Magazine for Environment, Health and Safety Leaders. http://ehstoday.com/standards/osha/gao-senate-osha-standards-0419/

Walter, L., 2010. David Michaels Outlines Goals, Hopes for the Future of Occupational Safety and Health. EHS Today, The Magazine for Environment, Health and Safety Leaders. http://ehstoday.com/standards/osha/asse-david-michaels-outlines-goals-occupational-safety-health-9348/

Washington Post, 2012. WP Politics: David Michaels, Assistant Secretary of Labor for Occupational Safety and Health (since December 2009). http://www.washingtonpost.com/politics/david-michaels/gIQA1jlaAP_topic.html

Weimer, D. L., 2006. The Puzzle of Private Rulemaking: Expertise, Flexibility, and Blame Avoidance in U.S. Regulation. Public Administration Review, 569-582

Yassin, A., Yebesi, F.,Tingle, R., 2005. Occupational Exposure to Crystalline Silica Dust in the United States 1988-2003. Environmental Health Perspectives, 113 (3), 255-260.

Ziem, G.E., Castleman, B.I., 1989. Threshold limit values: historical perspectives and current practice. *Journal of Occupational Medicine.* 31(11). 910-918.

Ziperstein, R., 2011. School Food, Inc.: The Contracting of America's National School Lunch Program and its Nutritional Consequences. The Cornell Policy Review, 2(1).

Legal cases

AFL-CIO v. OSHA, 965 F.2d 962, 962, 968 (11th Cir. 1992).
American Textile Mfrs. Inst. v. Donovan, 452 U.S. 490, 506 (1981)
Borel v. Fibreboard Paper Products Corp., 493 F.2d 1076 (5th Cir. 1973).
Industrial Union Department, AFL-CIO v. American Petroleum Institute, 448 U.S. 607 (1980).
International Brominated Solvents Assoc. v. ACGIH, Inc., 5:04-CV-00394-HL (M.D.Ga), Order at 2 (March 11, 2005).
International Brominated Solvents Assoc. v. ACGIH, Inc., 5:04-CV-00394-HL (M.D.Ga) (2008)

Table 1: The share of chemicals with voluntary standards that are stricter, equally strict or less strict than legal standards					
			Years		
Share of chemicals	All years	1984-1990	1991-1996	1997-2002	2003-2008
• with stricter TLVs than PELs	46.5%	44.2%	44.4%	45.1%	51.8%
• with equally strict TLVs and PELs	32.5%	35.2%	33.3%	33.6%	28.0%
• with stricter PELS than TLVs	7.6%	8.4%	8.7%	7.1%	6.5%
• for which TLVs and PELS are not directly comparable.	13.4%	12.2%	13.6%	14.2%	13.7%

Notes: We consider the 75 chemicals, which make up 70%-95% of test samples or 68%-94% of test results annually between 1984 and 2009 in the chemical manufacturing sector. TLVs and PELs denote the voluntary and legal exposure standards respectively.

Table 2. Summary statistics						
	[1]	[2]	[3]	[3]	[4]	[5]
Panel A: Inspections between 1984-2009						
Characteristic of the inspection	Inspections that collected at least one sample of the 75 chemicals (n=1,362)			Inspections that did not collect at least one sample of the 75 chemicals (n=14,686)		
		Mean	Std. Dev.		Mean	Std. Dev.
Plant characteristics						
Dummy for unionized plants		0.338	0.473		0.300	0.458
No. of inspections in the previous year		0.273	0.714		0.257	0.705
No. of inspections between years t-2 and t-5		0.765	1.423		0.822	1.693
No. of violations in the previous year		1.404	5.472		1.503	15.308
No. of violations between years t-2 and t-5		5.130	25.476		4.870	25.685
Amount of $ penalties in the previous year		1,142	11,276		6,243	172,378
Amount of $ penalties between years t-2 and t-5		10,459	218,114		13,620	251,629
Inspection characteristics						
Dummy for at least one chemical sample is collected during the inspection		1	-		0.021	0.143
Health inspection		0.982	0.134		0.456	0.498
Inspection Type: Programmed		0.198	0.398		0.410	0.492
Accident		0.012	0.108		0.041	0.197
Complaint		0.504	0.500		0.295	0.456
Followup		0.068	0.251		0.067	0.250
Referral		0.209	0.407		0.157	0.364
Other		0.010	0.101		0.030	0.171
Dummy for Chemical Emphasis Inspections		0.070	0.255		0.021	0.144
Panel B: Inspections that collected chemical samples						
Characteristics of the inspections	Inspections that collected at least one sample of the 75 chemicals			Inspections that collected chemical samples but none of the 75 chemicals		
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
No. of test results	1,362	18.490	30.770	185	3.200	2.345
Maximum of (test results / PELs)	1,362	2.401	12.781	185	1.548	5.504
†Maximum of (test results / TLVs)	1,360	2.681	20.856	-	-	-
No. of PEL violations (for any chemicals)	1,362	0.683	2.005	185	0.368	0.930
Probability of at least one PEL violation	1,362	0.210	0.407	185	0.184	0.388
†Number of TLV violations	1,360	0.880	2.464	-	-	-
†Probability of at least one TLV violations	1,360	0.247	0.431		-	-

Notes: PELs and TLVs denote legal and voluntary standards, respectively. †The data includes TLVs for only the 75 chemicals in our study. The data includes PELs for all chemicals sampled.

Table 2 : Summary statistics (continued)									
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Panel C: Test results for the 75 chemicals in our sample									
Characteristic of the test results	Test results ≤ PELs			Test results > PELs			All test results		
Test results/PELs	18,996	0.058	0.145	849	7.641	20.474	19,845	0.382	4.504
Test results/TLVs	15,904	0.134	1.015	753	10.008	39.662	16,657	0.581	8.730
TLV/PEL - 1	18,996	0.101	1.578	849	0.612	1.818	19,845	0.123	1.592
Dummy indicating the TLVs and PELs are directly comparable	18,996	0.760	0.427	849	0.775	0.418	19,845	0.761	0.427
PEL Exceedance	18,996	0	0	849	1.000	0.000	19,845	0.042	0.201
TLV Exceedance	15,904	0.024	0.152	753	0.789	0.408	16,657	0.058	0.234
Panel D: Motivation for the excluded variables to address selection									
Characteristics of inspections	Inspections with ≤ 40 test results			Inspections with > 40 test results			All inspections		
Test results/PELs	10,471	0.588	5.925	9,374	0.198	2.637	19,845	0.382	4.504
Characteristics of inspections	Inspections with ≤ 7 test results			Inspections with > 7 test results			All inspections		
Test results/PELs	1,941	0.740	4.928	17,563	0.356	4.503	19,845	0.382	4.504
Characteristic of chemical emphasis inspections	Target chemicals			Non-target chemicals			All chemical emphasis inspections		
Test results/PELs	444	1.027	3.576	1,022	0.131	0.674	1,466	0.402	2.086

Notes: PELs and TLVs denote legal and voluntary standards, respectively. There are more observations for test results/PELs than for test results/TLVs because more legal standards are expressed as short-term limits. Therefore, each test sample can be compared with the short-term PEL, yielding many more observations of the ratio of test results to PELs. In contrast, there are relatively more TLVs that are expressed as time-weighted averages. Several test samples are used to calculate one test result for comparison to the time-weighted TLV, yielding relatively fewer observations of the ratio of test results to TLVs.

Table 3. Heckman regression of the ratio of test results to PELs on the percent difference between TLVs and PELs

	[1]	[2]	[3]	[4]	[5]	[6]
	Heckman	Heckman Probit Coefficients	Heckman Probit Marginal effects	Heckman	Heckman Probit Coefficients	Heckman Probit Marginal effects
Exposure Equation						
Percent difference between TLVs	0.054**	0.049***	0.002***			
and PELs, captured by (TLV/PEL-1)	(0.021)	(0.008)	(0.0004)			
1 [(TLV/PEL - 1) < -0.5]				-0.292**	-0.296***	-0.014***
				(0.117)	(0.071)	(0.003)
1 [-0.5 ≤ (TLV/PEL - 1) < 1]				-0.279***	-0.357***	-0.016***
				(0.096)	(0.065)	(0.004)
1 [(TLV/PEL - 1) > 1]				0.394***	0.641***	0.030***
				(0.118)	(0.051)	(0.003)
Dummy for test results for which	-0.083	-0.119**	-0.005***	-0.004	-0.113**	-0.005***
TLVs corresponds directly to PELs	(0.089)	(0.047)	(0.002)	(0.103)	(0.055)	(0.002)
Dummy for chemicals	0.296**	0.283***	0.013***	0.244**	0.110*	0.005***
with PEL changes in 1984-2009	(0.118)	(0.054)	(0.003)	(0.120)	(0.056)	(0.003)
Accident inspection dummy	0.244	0.414**		0.311	0.538***	
	(0.300)	(0.164)		(0.300)	(0.162)	
Complaint inspection dummy	0.032	0.109**		0.042	0.141**	
	(0.097)	(0.054)		(0.097)	(0.055)	
Followup inspection dummy	0.345*	0.255***		0.347*	0.228**	
	(0.187)	(0.091)		(0.187)	(0.094)	
Referral inspection dummy	0.559***	0.388***		0.566***	0.400***	
	(0.111)	(0.061)		(0.111)	(0.061)	
Other inspection dummy	0.562*	0.517***		0.567*	0.587***	
	(0.295)	(0.127)		(0.294)	(0.132)	
Health inspection dummy	0.744***	0.397***		0.717***	0.350**	
	(0.246)	(0.148)		(0.246)	(0.150)	
Chemical emphasis inspection dummy	0.064	0.471***		0.060	0.466***	
	(0.166)	(0.080)		(0.166)	(0.082)	

Notes: PELs and TLVs denote legal and voluntary standards, respectively. The Heckman regression consist of (i) the exposure equation, whose variables are listed fully in the table, and (ii) the inspection/selection equation. Variables included in the selection equation, but excluded from the exposure equation, are listed in the table. Other control variables in the selection equation (not listed in the table) are similar to control variables in the inspection equation. The marginal effects for the Heckman Probit model (column 3 and 6, respectively) are calculated using the coefficients from that model (column 2 and 5, respectively) and the values in the sample. The marginal effects for the variables of interest are listed in the table. Statistically significant at the ***1%, **5% and *10% levels.

Table 3 (continued). Heckman regression of the ratio of test results to PELs on the percent difference between TLVs and PELs						
	[1]	[2]	[3]	[4]	[5]	[6]
	Heckman	Heckman Probit Coefficients	Heckman Probit Marginal effects	Heckman	Heckman Probit Coefficients	Heckman Probit Marginal effects
Exposure Equation (continued)						
No. of inspections in the previous year	0.059	-0.010		0.054	-0.037	
	(0.083)	(0.041)		(0.083)	(0.042)	
No. of inspections between years t-2 and t-5	-0.014	-0.059**		-0.012	-0.058**	
	(0.042)	(0.023)		(0.042)	(0.023)	
Log (no. of violations in the previous year)	0.076	0.056		0.076	0.037	
	(0.119)	(0.060)		(0.119)	(0.063)	
Log (no. of violations between years t-2 and t-5)	0.047	-0.021		0.044	0.021	
	(0.086)	(0.044)		(0.086)	(0.044)	
Log ($ penalties in the previous year)	-0.069*	-0.030		-0.071*	-0.025	
	(0.037)	(0.019)		(0.037)	(0.019)	
Log ($ penalties between years t-2 and t-5)	-0.001	0.043***		-0.001	0.027**	
	(0.026)	(0.013)		(0.026)	(0.013)	
Unionized plant dummy	-0.034	-0.027		-0.031	0.008	
	(0.084)	(0.045)		(0.084)	(0.046)	
Inverse Mills Ratio	0.385***			0.370***		
	(0.080)			(0.080)		
Rho (Correlation in the error terms in the exposure and inspection equations)	0.0890***	0.340***		0.084***	0.289***	
	(0.018)	(0.046)		(0.018)	(0.043)	
Excluded Variables in Selection Equation						
Log (no. of other test results in the inspection)	0.532***	0.527***		0.532***	0.533***	
	(0.005)	(0.005)		(0.005)	(0.005)	
Dummy for non-targeted chemicals in the chemical emphasis inspection	-2.151***	-2.029***		-2.159***	-2.113***	
	(0.080)	(0.077)		(0.080)	(0.081)	
Obs.	108,535	108,535		115,438	115,438	

Notes. Variables included in the selection equation, but excluded from the exposure equation, are listed in the table. Other control variables in the selection equation (not listed in the table) are similar to control variables in the inspection equation. Only the marginal effects for the variables of interest are listed in the table. Statistically significant at the ***1%, **5% and *10% levels.

Table 4: Comparison of OLS and Heckman regressions of the ratio of test results to to legal standards on the percent difference between voluntary and legal standards.

	[1]	[2]	[3]
Model	Heckman	OLS	OLS
Percent difference between TLVs and PELs	0.054**	0.056***	0.011***
captured by (TLV/PEL-1)	(0.021)	(0.021)	(0.003)
Dummy for test results for which	-0.083	0.102	-0.074***
TLVs corresponds directly to PELs	(0.089)	(0.080)	(0.019)
Dummy for chemicals	0.296**	0.348***	0.103***
with PEL changes in 1984-2009	(0.118)	(0.118)	(0.022)
Rho (correlation between error terms in the	0.089***		
exposure and selection equations)	(0.018)		
No.obs.	108,535	19,474	108,535
R-sqr		0.021	0.003

Notes: The PELs and TLVs represent legal and voluntary standards, respectively. In column 1, the OLS model includes only observations with test results. In column 3, we assume that chemicals that are not sampled (among the 75 chemicals) have zero exposure. Statistically significant at the ***1%, **5% *10% levels.

Table 5: Quantile regressions of test results/PEL on the percent different between TLVs and PELs

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Percentile	10	25	50	60	70	80	90	95
Panel A: Summary statistics: Values at various percentiles								
test results/PELs	0	0	0.0007	0.008	0.030	0.089	0.314	0.833
test results/TLVs	0	0	0.005	0.020	0.054	0.135	0.410	1.016
(TLV/PEL - 1)	-0.8	-0.5	0	0	0	0	1	2
Panel B: Regression coefficients								
Percent difference between TLVs and PELs	0	0	-6×10^{-12}***	-2×10^{-12}***	0.011***	0.043***	0.178***	0.422***
captured by (TLV/PEL-1)	0	0	(4×10^{-20})	(1×10^{-17})	(0.00003)	(0.0002)	(0.001)	(0.002)
Dummy for test results for which	0	0	-0.00004***	4×10^{-11}***	0.005***	0.021***	0.086***	0.180***
TLVs correspond directly to PELs	0	0	(2×10^{-19})	(6×10^{-17})	(0.0001)	(0.001)	(0.004)	(0.010)
Dummy for chemicals	0	0	0.002***	0.029***	0.072***	0.152***	0.284***	0.565***
with PEL changes in 1984-2009	0	0	(3×10^{-19})	(8×10^{-17})	(0.0001)	(0.001)	(0.006)	(0.015)

Notes: The TLVs and PELs represent the voluntary and legal standards respectively. No. obs.=19,474. About 40% of the observations have test results with the value zero. Therefore, the null effect of TLVs below the 40th percentile is unsurprising. Boostrap standard errors are estimated. Statistically significant at the ***1% level.

Table 6: Other questions: The impact of legal standards on the ratio of test results to PELs (columns 1-2) and the effects of voluntary standards on the ratio of test results to TLVs (columns 3-6)

	[1]	[2]	[3]	[4]	[5]	[6]
Dependant variable	test result/PEL in 1980		1 (test result>TLV)			
Model	Heckman		Heckman Probit			
			Coefficents	Marginal effects	Coefficients	Marginal effects
Exposure Equation						
Percent difference between TLV and PELs	0.088***		-0.0513**	-0.003***		
captured by (TLV/PEL-1)	(0.024)		(0.014)	(0.001)		
1 [(TLV/PEL - 1) < -0.5]		-0.346***			0.400***	0.022***
		(0.114)			(0.046)	(0.003)
1 [-0.5 ≤ (TLV/PEL - 1) < 1]		-0.288***			0.0328	0.002
		(0.096)			(0.044)	(0.002)
1 [(TLV/PEL - 1) > 1]		0.502***			0.229***	0.012***
		(0.126)			(0.053)	(0.003)
Percent difference between TLV and PELs	1.025***	0.931***				
captured by (PEL/PEL_{1980}-1)	(0.234)	(0.238)				
Dummy for test results for which	-0.0408	0.0521	-0.113**	-0.006**	-0.234***	-0.013***
TLVs correspond directly to PELs	(0.089)	(0.102)	(0.046)	(0.002)	(0.050)	(0.003)
Dummy for chemicals	0.556***	0.616***	0.542***	0.029***	0.400***	0.022***
with PEL changes in 1984-2009	(0.156)	(0.158)	(0.050)	(0.003)	(0.052)	(0.003)
Rho (correlation in the errors terms in the	0.085***	0.082***	0.381***		0.374***	
inspection and exposure equations).	(0.018)	(0.018)	(0.041)		(0.042)	
Excluded Variables in Selection Equation						
Log (no. of other test results	0.529***	0.530***	0.519***		0.519***	
in the inspection)	(0.005)	(0.005)	(0.004)		(0.004)	
Dummy for non-targeted chemicals in	-2.143***	-2.157***	-2.211***		-2.186***	
the chemical emphasis inspection	(0.080)	(0.080)	(0.079)		(0.079)	
Obs.	108,535	108,535	111,818		111,818	

Notes: The PELs and TLVs represent legal and voluntary standards, respectively. The Heckman regression consists of (i) the exposure equation and (ii) the inspection/selection equation. Variables included in the selection equation, but excluded from the exposure equation, are listed in the table.The marginal effects for the Heckman Probit model (column 4 and 6, respectively) are calculated using the coefficients from that model (column 3 and 5, respectively) and the values in the sample. The marginal effects for the variables of interest are listed in the table. Statistically significant at the ***1%. **5%, and *10% levels.

Appendix I: Calculation of test results

Exposure limits for a given chemical are defined in one or more of three different measures, i.e., the time-weighted average, short-term exposure and ceiling limits. Ceiling limits are typically specified as an instantaneous measure or as an average over 5 or 15 minutes; short-term exposure limits are typically specified as an average over 15 minutes, and time-weighted averages are typically specified as an average over 8 hours.

The CEHD provides information on the samples for each chemical collected during an inspection, i.e., the concentration of the sample and the duration of sampling. Using this information and OSHA’s instructions on the calculation of test results, we calculate the test results for comparison to the time weighted averages, short-term and ceiling limits, respectively.

Consider a chemical with ceiling limits of c ppm measured over 5 minutes, short-term exposure limits s ppm measured over 15 minutes, and time-weighted average of t ppm measured over 8 hours. The following samples of that chemical are collected duration an inspection.

Sample no.	Concentration in ppm	Duration of sampling
1	r1	5 minutes
2	r2	10 minutes
3	r3	15 minutes
4	r4	6 hours
5	r5	8 hours

Consider test results for ceiling limits. The first sample can be directly compared with the ceiling limits. OSHA permits the assumption that the average concentration for the second sample is at least r2 ppm for a given 5 minute period, given the average concentration is r2 ppm for a period longer than 5 minutes. The analogous assumptions hold for the third, fourth and fifth samples. Each of these five concentrations is compared individually with the ceiling limit, yielding 5 test results.

Consider test results for the short-term limits. The third sample can be compared directly to the short-term limit. The fourth and fifth sample can be compared individually to the short-term limits based on the OSHA permitted assumption that the average of those samples are at least r4 and r5 ppm, respectively, for a given 15 minute period. The samples that are less than 15 minutes are used to calculate a composite test result, by assuming, per OSHA instructions, that there is zero exposure during the remaining time. The composite test result (based on the first and second samples) is

$$= \frac{[\text{r1 ppm x 5 min. + 0 ppm x (15-5) min. }] + [\text{r1 ppm x 10 min. + 0 ppm x (15-10) min.}]}{\text{max (sum of the duration of the first and second sample, or 15 minutes)}}$$

In total, there are four test results for short-term limits in this example.

Consider the test results for time-weighted averages. The fifth sample can be compared directly to the time-weighted limits. The composite test result (based on the 1^{st} through 4^{th} samples) is

$$= \frac{\text{r1 x 5 min + r2 x 10 min + r3 x 15 minutes + r4 x 6 hours x 60 min per hour}}{\text{max (sum of the duration of the } 1^{st}, 2^{nd}, 3^{rd} \text{ and 4 samples, or 8 hours).}}$$

In total, there are two test results for time-weighted averages in this example.