United States federal contracting and pollution prevention: how award type and facility characteristics affect adoption of source reduction techniques in four manufacturing sectors

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Abstract

There is reason to believe that hazardous emissions generated by industrial actors that have been awarded government contracts have different pollution prevention action patterns compared to those that have not been awarded government contracts. This is important because pollution prevention actions are a key inroad to alleviating environmental contamination generally and related human health effects. Specifically, we find that US-based industrial polluters tend to respond to Federal incentives to reduce costs by making efficiency improvements. Using publicly available purchasing, toxics release, and pollution prevention data from 2001 to 2012 for 458,081 transactions and 9,910 facilities, we investigate the impact of contract award structure on facility environmental performance. We fit regression models to understand more about how the number of reported voluntary pollution prevention actions and reductions in total toxic chemical waste managed at each facility in terms of three types of contract awards. We find that industrial actors that have been awarded incentive contracts not only report more pollution prevention actions, but that these actions are more likely to result in significant pollution reduction. Results inform US Federal purchasing policy decisions and support earlier theoretical development at the intersection of ecological modernization, super-industrialization, and the role of government in facilitating transitions to green technology. In addition, greener purchasing decisions can have a broad impact on human health by reducing pollution in communities.

1. Introduction

Experts estimate that 10 to 20 percent of a nation’s gross domestic product (GDP) comes from government purchases (Rainville 2017). In the United States (US), government expenditure is the third largest industry, by total value added to the US economy, behind real estate and professional services and ahead of manufacturing, finance, and retail (BEA 2019). Thus, government purchasing makes up a significant portion of overall consumption, and a disproportionate, yet perhaps necessary, share of market consumption (Harris et al 2003). Government contracting is a specific type of procurement, which is regulated in the US under the US Federal Acquisitions Regulation (FAR). The main policy goals of the US Federal procurement are cost savings and competition among potential vendors (Edquist et al 2015). In addition, procurement has environmental impacts resulting from production of goods. With government being a high proportion of GDP (Audet 2001) and being a large consumer within defense, construction, shipbuilding, energy, and transportation industries (OECD 2003), government purchasing policies have environmental impacts (Testa et al 2016).
We measure the impact of US Federal purchasing by identifying the toxic chemical waste reported by contract awardee facilities using the Environmental Protection Agency’s (EPA) Toxics Release Inventory (TRI). Tracking the environmental performance of suppliers in this way has been used in studies of public procurement in the past (Handfield et al 2002, Hill et al 2020). Such associations found toxic releases produced by firms that have been awarded US Federal Government contracts, which they fulfilled at their respective facilities (hereafter contractors), was higher than non-contractors and that this trend sustained over time (Hill et al 2020). By linking US Federal purchasing and toxic chemical waste disclosure data, we assess whether facility waste management practices are linked with the type of contract award. For example, US Federal Government contractors can be paid via three primary methods: a fixed-price contract, a cost-plus contract, or an incentive contract. The last method, the incentive contract, links the fee for the product or service to the efficiency of the contractor; if the contractor is more efficient and comes in under budget, they receive a portion of the residual as additional profit and if they come in over budget, the contractor must pay a portion of the overage (FAR 2020c). Government agencies cannot observe the actual activity of the firm, therefore, the metric for success is the change in cost of the activity being funded. Lower costs indicate greater efficiency of the contractor, which leads to lower costs for the agency and the earning of an award bonus for the firm. Higher costs indicate inefficiency and lead to extra fees passed onto the contractor. By linking the fee to the performance of the contractor, the incentive contract encourages cost reduction and efficient operation (Lewis and Bajari 2014).

Our hypothesis is that firms fulfilling contracts with incentives for cost reduction will have more voluntary pollution prevention technology because the additional incentive provides motivation for changing their operating practices and these firms include environmental performance changes as a way to lower costs. We test this by examining whether contractors with incentive contracts are different regarding the number of waste management practices implemented (measured via reported pollution prevention actions) than other contractors and noncontractors. One way to conceptualize this difference is ecological modernization theory where the government, via regulation and green purchasing, moves the private sector from higher to lower pollution. Government does this by using capitalist practices, such as business incentives, to alter firm environmental performance.

The objective of this paper is to test for an association between one method of government guidance, namely incentives in contracting, and more sustainable environmental performance through greater installation of voluntary pollution control technology. Our paper begins with a discussion of contracting types and connects the incentive contract to ecological modernization theory proposing a mechanism for why incentives in government contracting might alter activity of polluting facilities. Then we present our analysis using US TRI data on reported pollution prevention technology at privately owned contract facilities. Our paper ends with a discussion of the results and connections to the theoretical literature and potential policy implications of our results.

2. Background

2.1. US Federal Government purchasing and incentive contracts

The three types of contracts used in the US are cost-plus, fixed-price, and incentive (FAR 2020a). Cost-plus contracts are when the government agrees to pay the base price for the contracted goods or services plus any overage of unexpected costs; this type is used for high-risk endeavors and for research and development (Legal Information Institute 2020). In a fixed-price contract, the government pays the base price plus a fixed fee, which is the profit for the company; this type is used most often because it involves the least amount of upfront negotiation between vendors and the contracting agency, and it is ideal for most ‘off the shelf’ purchases (FAR 2020b). Finally, incentive contracts are when the government and contractor enter a cost-sharing agreement (FAR 2020c). The government will cover a percentage of the overage if the contractor is over budget; however, if the contractor comes in under budget, they may keep a percentage of the residual added to their fee as additional profit. The percentages are based on a pre-negotiated formula. The potential for additional profit ‘[provides] motivation for excellence in contract performance’ (FAR 2020c). The US Federal Government does not observe contractor costs, but the contractor can report a cost underrun. Cost underruns demonstrate efficiency, which the US Federal Government awards by sharing a portion of this underrun with the contractor (FAR 2020c, McAfee 1988). The incentive contract is designed to encourage efficient operation of contractors (Väliä 2020). Understanding the differences in contract type can lead toward identifying ways that facilities receiving US Federal Government incentive contracts might be different from other recipients.

Public procurement focuses on ‘delivery of quality and timely services to citizens through public programs and projects’ (Khan 2018, p 1). Cost savings and competition are the primary goals of US Federal procurement policy (Edquist et al 2015) and are the reasons why incentive contract options were developed (McAfee 1988, Scherer 1964). Incentive contracts balance efficiency and competitive fairness against essential contractor
profitability. Incentive contracts result in several benefits including reduced spending costs of the US Federal Government and increased economic efficiency of the producer; these benefits support the growing advocacy of using incentive contracts (Kendall 2014, 2015, Thomas 2019). While incentive contracts focus on the economic efficiency of the firm using cost to measure performance, firms receiving these types of awards might consider their environmental performance when seeking ways to lower costs. Contractors fulfilling incentive contracts might lower their costs through reduction of material inputs, including hazardous materials, and reduction of waste that often involves costly management (Gray and Shadbegian 1995). According to the US Census Bureau’s Annual Survey of Manufacturers, in 2018, the cost of refuse removal services (including hazardous waste from toxic chemicals) topped four billion dollars for electronic products sectors (DOC 2020). The cost savings of reducing material inputs can be achieved through practices that minimize waste and maximize efficiency in material use (Wong et al 2020). Less spending on waste removal and the earnings through incentives are reasons that these types of contractors might be more environmentally efficient. We conceptualize the connection between economic cost savings from reducing material inputs and lowering of waste releases using ecological modernization theory.

2.2. Ecological modernization theory and voluntary pollution prevention

Ecological modernization theorists envision the advancement of cleaner industrial production through the integration of good business practices, ecological concerns, and capitalist practices (Mol and Sonnenfeld 2014). Proponents find this theory plays out in highly capitalized, internationally oriented industries that face pressure from overseas markets with environmental consumers (Mol and Sonnenfeld 2014). The antithesis to this argument comes from treadmill of production theorists who argue that economic activity occurs on a never-ending conveyance of resources that degrades the environment (Schnaiberg et al 2002). According to treadmill theorists, halting environmental degradation requires a fundamental change in the capitalist system (Schnaiberg 1980). Ecological modernization theorists argue that capitalism can be reformed, at least in part, through green industrialism (Gibbs 2006). Industrial structures and processes need to change while market relations and liberal democratic institutions can remain (Spaargaren and Mol 1992). These ecologically modernizing transformations can arise through super-industrialization with support from environmentally oriented government decision making, and cleaner production technology (Buttel 2000).

Super-industrialization, the continued expansion of economies and industries, through increased use and integration of information systems, closed-loop systems, and dematerialization, will lead to less resource intensive production processes (Buttel 2000). As society and technology advance, competitive industries must reduce pollution and natural resource strain by producing more efficiently with cleaner production technology (Spaargaren and Mol 1992). Huber (2004) states that the intent is not to use less but to make industrial metabolism compatible with natural metabolism at optimum efficiency. Implementation of technology for pollution prevention is a key part of industry’s progress toward an ecologically modern production process, as this allows producers to operate with greater efficiency and reduced impact on the environment (Hart 1995, Hart and Dowell 2011). Pollution reduction technology can be implemented voluntarily or as a response to incentives and other government policy.

Ecological modernization includes government actors as an essential component of the push toward an economy with reduced environmental impact through: green purchasing (Hausknost 2020, Heinrichs 2019, Heinrichs and Laws 2014), technical assistance (Bartholomew et al 2008, Bierma and Waterstraat 2008), grants (Galli and Fisher 2016), incentives (Xie et al 2019), and regulatory pressure focused on changing purchasing practices rather than end-of-pipe pollution release standards (Zhu et al 2012). Facility owners sometimes preemptively invest in pollution prevention technology ahead of proposed legislative or policy changes to give them a competitive advantage (Millimet et al 2009), and advances in clean technology can also occur voluntarily by the facility (Kanashiro 2020). While facilities may be induced to implement clean technology by government oversight (Shimshack and Ward 2005), ecological modernization stresses that the government is a guide in this process encouraging voluntary behavior instead of mandating it.

Corporate environmental voluntarism is ‘voluntary management and/or process changes adopted by [industrial actors] to reduce or mitigate environmental impacts arising from manufacturing’ (Press 2007, p 318). In the US, one law encouraging voluntary action is the Pollution Prevention Act (PPA) of 1990 (EPA 2020c). Pollution prevention, as defined by the PPA, is ‘any practice that reduces, eliminates, or prevents pollution at its source, also known as source reduction’ (EPA 2020c). Under the PPA, any activity that is a source reduction undertaken at a TRI facility must be reported if the action occurs on a chemical that the TRI covers. Such activities include, but are not limited to, technology modifications, process modifications, substitution of chemicals or component materials, and updates to inventory control (EPA 2020c). Corporate environmental voluntarism results from decisions to reduce waste based on internal factors such as influence from corporate owners and shareholders (Prechel and Istvan 2016) as well as environmental management...
plan adoption, which many firms implement to improve operating practices (Wong et al. 2012). These organizational influences are conceptualized most often by organizational political economy theorists, with studies examining firm and facility characteristics (Lenox and Nash 2003, Prechel 2021). While organizational theory helps explain some variation in firm environmental activity, ecological modernization is uniquely situated to further elaborate upon the role of economic incentives and their influence on firm decisions to implement pollution prevention.

Private sector implementation of green technology and pollution prevention can happen voluntarily, but state funded programs and incentives that increase green technology offerings can also result in increased technology innovation and implementation (Lemprière 2016). A moderating factor is that industrial actors are limited in their ability to implement new technology based on their environmental management capability; in other words, their ability to improve performance on environmental issues (Wong et al. 2012). Environmental management also improves when government incentives are offered (Zhang et al. 2020) and benefits include reductions in pollution (Xie et al. 2019). Firm environmental management is often technological with process modifications improving sustainability and leading to the ecological modernization outcome of sustainable production (Guo et al. 2019). While the benefits of incentives are clear, there is evidence that command and control policy is more effective in some scenarios (Li 2014) making incentive-based policy ideal for some situations but not all (Wong 2012). Ecological modernization supports the government having a toolbox of appropriate mechanisms to address environmental issues using economic incentives as a preferred option over regulatory pressure (Jaffe et al. 2004). Private sector implementation of green technology and pollution prevention can happen voluntarily, but state funded programs and incentives that increase green technology offerings can result in increased implementation (Lemprière 2016). Thus, government policy can complement the advance toward super-industrialization through incentive-type policies that lead to pollution reduction.

Pollution prevention is important because of its ability to reduce impacts on human health and save operators money on materials and waste management by reducing the use of a chemical at its source (Moss 2008, Zarker and Kerr 2008). Pollution prevention actions at TRI facilities are voluntary, unless required by a different regulation, but if an action is undertaken, it is required that the action be reported. Though voluntary actions have been critiqued as ‘greenwashing’ because there is limited accountability for industry to meet stated reduction targets (Ramirez Harrington 2013), there are several examples of success (Ranson et al. 2015). Clelland and colleagues (2000) found that waste minimization practices have immediate and long-term operational benefits for facility owners. In addition, substitution of inputs with less toxic components can reduce hazardous waste from toxic chemicals (Johnson et al. 2008). Benefits of cost savings are also felt by facilities as their productivity increases because of reduced waste management costs associated with disposal of hazardous materials (Garcia-Marco et al. 2020). Other studies have found pollution prevention can result in reductions of toxic releases by up to 50 percent per chemical (Harrington et al. 2014) and on average a reduction of 9–16 percent during the implementing year (Ranson et al. 2015).

Gains have been made in some sectors such as automotive manufacturing (Gaona et al. 2020). One potential problem of the PPA and other laws regulating reduction of chemical releases is the focus on specific media; sometimes reductions in air pollution result in a shift of pollution from air to land or water releases (Bi 2017). Thus, successes in pollution prevention should be marked by reduction in total production related waste for a chemical (Ranson et al. 2015) and we took this consideration into account in our analyses. Super-industrialization, role of government, and corporate voluntarism all play a role in facility-level decisions to implement pollution prevention technology. Studying influences on a manufacturing facility’s implementation decisions regarding voluntary pollution prevention practices can provide valuable insights into the effectiveness of various policy tools, such as those encouraging voluntary action, and can contribute to theory and rulemaking.

2.3. Research question and hypotheses
To understand how different types of US Federal Government contract payment might be impacting firm environmental performance through changes in voluntary waste management implementation, we ask: do facilities that receive incentive contracts have greater investment in voluntary pollution control technology than facilities that do not receive incentive contracts? We hypothesize that facilities fulfilling contracts with incentives for cost reduction will have more voluntary pollution prevention technology because they will be looking at the entirety of their operating costs to find ways to reduce expenditures. This will include reducing expenditures on material costs and waste management which can be accomplished by implementing pollution prevention actions. Facilities are incentivized to reduce costs to increase profits and therefore will increase investment to minimize or more efficiently utilize material inputs and reduce waste. Capitalist actions resulting in environmental benefit are a key part of ecological modernization and we discuss the implications our analysis has on this theory.
Table 1. Case sub-sectors and the number of facilities of each contract type.

| Subsector                                          | Cost-plus | Fixed-price | Incentive | No contracts |
|----------------------------------------------------|-----------|-------------|-----------|-------------|
| Chemical manufacturing                             | 13        | 349         | 16        | 3034        |
| Fabricated metal manufacturing                     | 11        | 507         | 15        | 2942        |
| Computer and electronic component manufacturing    | 59        | 364         | 41        | 1064        |
| Transportation equipment manufacturing              | 23        | 259         | 39        | 1174        |
| Total                                              | 106       | 1479        | 111       | 8214        |

3. Methods

3.1. Toxic chemical waste data
This study obtains data on toxic chemical waste from the US EPA TRI for the years 2001–2017. The TRI includes annually reported chemical management data from qualifying facilities that manage, release, or otherwise use a listed chemical above a specific threshold (EPA 2019). Each of these chemicals is known or suspected to pose potential hazards to human health or the environment. We include chemical waste for all possible disposal methods reported under TRI (e.g., recycling, air releases, landfill disposal). The database is mandated by the Emergency Community Planning and Right to know Act (EPCRA) and includes information on reported pollution prevention activities (process modifications, chemical substitutions, etc) on the reported chemicals; this information is known as pollution prevention or P2 data. Not all TRI facilities are government contractors, so we use two other datasets to narrow our sample to subsectors with contractors.

3.2. Facility business statistics
The first dataset for government contract and other facility level business statistics we use is the National Establishment Time Series (NETS), which is a proprietary time-series dataset with facility level characteristics for individual facilities across the US (see Walls and Associates (2015) for more information). We purchased a license for use of the data, and it came with a TRI facility ID to Duns number crosswalk that allows pairing of TRI to NETS data. Merging the data results in a 92.7 percent match success. Researchers have shown the effectiveness of this data for longitudinal studies of the TRI because of its ability to provide facility-level covariates for size and ownership (Berchicci et al 2012, Collins et al 2020, Hill et al 2020). In addition, a field in the data indicates if the facility received government contracts and narrows the sample of facilities from all TRI subsectors to subsectors with contractors.

3.3. Contract award data
A public dataset provides information on government contracts and comes from the US General Services Administration public facing website USAspending.gov, which provides access to a time-series collection of all US Federal transactions from 2001 up to the present (USAspending 2020). Data are at the award transaction level per year and using the list of TRI facilities and their Duns numbers, we identify the facilities that receive government contracts. We use transaction data from 2001 to 2012 and sum to the award-year level based on award ID. Though data exists outside these years, we limit our analysis to this timeframe because USAspending data do not begin until 2001 and the NETS data version we use ends in 2012.

3.4. Sample selection and case subsectors
Data are merged at the facility-year level following established protocols for TRI/NETS data cleaning laid out by Collins et al (2020), which includes checking for duplicate records, to ensure the greatest disaggregation of data for facility level characteristics from the TRI and the NETS data. Four subsectors from the three-digit North American Industry Classification System (NAICS) are part of this study: chemical manufacturing (NAICS 325), computer and electronic product manufacturing (NAICS 334), fabricated metals manufacturing (NAICS 332), and transportation manufacturing (NAICS 336). These subsectors are selected for the following criteria: each subsector had contractors of all three types for all study years, the highest contractor-to-noncontractor ratio (see table 1) and provide products to several different agencies.

Chemical manufacturing includes the formation of products through the transformation of organic and inorganic raw materials through a chemical process (EPA 2020a). Industries in the computer and electronic product manufacturing subsector include manufacturers of computers, computer peripherals, communications equipment, and similar electronic products, and makers of components for such products. The design and use of integrated circuits and the application of highly specialized miniaturization technologies are common elements in the production technologies of the computer and electronic subsector (BLS 2020a). Industries in the fabricated metal product manufacturing subsector transform metal into intermediate or end products,
other than machinery, computers and electronics, and metal furniture, or treat metals and metal formed products fabricated elsewhere. Important fabricated metal processes are forging, stamping, bending, forming, and machining, used to shape individual pieces of metal; and other processes, such as welding and assembling, used to join separate parts together (BLS 2020b). Industries in the transportation equipment manufacturing subsector produce equipment for transporting people and goods. Establishments in this subsector utilize production processes like those of other machinery manufacturing establishments—bending, forming, welding, machining, and assembling metal or plastic parts into components and finished products. However, the assembly of components and subassemblies and their further assembly into finished vehicles tends to be a more common production process in this subsector than in the machinery manufacturing subsector (BLS 2020c). The final dataset contains 109,844 facility-years and 9,910 total TRI facilities. Of these, 1,696 are contractors and 8,214 never receive any contracts during the study years (table 1).

3.5. Pollution prevention success indicators
We include all pollution prevention (P2) actions reported at facilities from 2001–2012 as a variable for the total number of actions. We also calculate three additional indicators to determine if pollution prevention activity is successful. First, we determine whether a reduction in total pounds of production related waste of the chemical occurs one year after the reported action. Production related waste includes all waste streams of the toxic chemical at the facility (e.g., recycling, air releases, landfill disposal). Reductions in production related waste indicate a decrease in the total waste associated with the production process that uses the chemical at the facility. We normalize the change in total production related waste using the reported production ratio for each chemical. The production ratio is the level of increase or decrease from the previous year of the production process or activity that the chemical is used. We utilize the normalization formula provided by Gaona (2018) determining if a net reduction occurs at the facility. The reason we normalize by production ratio is because after a pollution prevention action occurs, production output may change at a facility changing the intensity that the chemical is used. Normalization controls for this potential change. The formula for a one-year reduction takes the following format:

\[
1 \text{ year reduction} = \text{Production waste}_t - \left(\frac{\text{Production waste}_{t+1}}{\text{Production ratio}_{t+1}}\right)
\]

(1)

where \(t\) is the base year when the pollution prevention action is reported, and production waste is the total production related waste for the chemical that the action is completed for at the facility. The production ratio is a chemical specific ratio.

Second, whether the reduction is sustained is tested by comparing the TRI pounds for the chemical five years after the action is implemented to see if the reduction continues. The formula for a five-year reduction is:

\[
5 \text{ year reduction} = \text{Production waste}_t - \text{Ratio adj prod waste}_{t+5}
\]

(2)

where the ratio adjusted production waste is determined by:

\[
\text{Ratio adj prod waste}_{t+5} = (\text{Ratio}_t * \text{Ratio}_{t+1} * \ldots \text{Ratio}_{t+5}) * \text{Prod waste}_{t+5}
\]

(3)

To obtain the adjusted production waste for \(t + 5\) years after a pollution prevention action, the cumulative product of the ratios is multiplied by the production waste \(t + 5\) years after the action as described by Gaona (2018).

Also, some reductions can be small, so to determine if an action is of greater success, reported actions that resulted in a 25 percent reduction or more in TRI pounds after five years are included as an indicator of success. The formula for calculating the 25 percent reduction is:

\[
25 \text{ percent reduction} = 5 \text{ year reduction} - (0.25 * \text{production waste}_t)
\]

(4)

For each of the indicators, a net decrease is indicated by a negative value, and a net increase in production related waste is indicated by a positive value. The total number of actions with a net decrease for each indicator is aggregated for each facility from 2001 to 2012. To test for reductions, we include production related waste data from 2013 to 2017; pollution prevention actions reported during this later period are not included in the sample.

3.6. Predictors and covariates
The main predictor variable for our analysis is the type of contract the firm fulfills which has three categories: incentive, cost-plus, and fixed-price. Our main predictor variable, the incentive contract type, is contextulized using ecological modernization theory, but we also draw variables from other fields of study to more
robustly understand the association between incentive contracts and facility environmental activity. Other covariates from the government procurement and green purchasing literature are obtained from USA Spending (USASpending 2020) include the agency that issued the contract; in this case we use a bivariate dummy variable for department of defense (DOD) contractors or non-DOD as defense contracts sometimes come with exemptions to meeting environmental statutes in the US (Legal Information Institute 2019). We also use the average number of bidders each facility competed against for awards received from 2001–2012 as a proxy for competition. In addition, two green purchasing covariates indicative of ecological modernization and green purchasing are included from the USA spending data. The first is the average annual proportion of contract dollars from 2001–2012 the facility receives that require use of EPA designated products. EPA publishes a list of products that awarding agencies may require the vendor to use when they fulfill the award and include things like using recycled paper and Energy Star products (EPA 2020c). The second variable is the average proportion of annual award dollars from 2001–2012 and that also includes clauses for sustainability. This variable indicates whether the award includes certain requirements for resource conservation and recovery minimizing waste and other hazardous materials.

Several covariates derived from organizational political economy are also included. From the NETS data, we include both corporation size and facility size. Corporation size, which has been observed to impact a facility’s environmental activity (Wong et al 2012), is measured as the number of establishments that report the same parent company as the facility (see Lenox and Nash 2003, Lannelongue et al 2015 for studies using the same metric). Number of establishments owned by the managing firm is also indicative of corporation complexity which is an important component in understanding firm activity, coordination among owned plants, and environmental performance (Perrow 1986, Prechel et al 2016). Our data include 5287 facilities with parent companies and 4623 facilities that are single firm facilities. Sensitivity analysis is conducted to test if there are differences between these two groups.

Facility size, also from organizational theory and associated with management of pollution (Maung et al 2016), is measured from two variables: log adjusted average annual sales and log adjusted average employment per facility, each from 2001–2012. We use both variables because each measures something different about facility size. Sales is an indicator for ability to implement pollution prevention, while employment average estimates labor costs and potential of hazardous exposure to workers. Both variables might influence firm decisions to implement pollution control technology. Also, while these variables are correlated with one another, they are not correlated in ways that negatively impact model estimation with a variance inflation factor (VIF) of 3.43 for sales and 3.32 for employment. Both values are below the threshold of 10 indicating no multicollinearity issues with the models so each is included in each model. Ownership type has also been shown to be related to facility environmental activity (Sampson and Zhou 2018, Wang and Jin 2007) and we include bivariate variables for whether the facility is publicly or privately owned as well as one for foreign ownership status.

We also include covariates from regulatory and environmental justice scholarship. Covariates from the Enforcement and Compliance History Online include an indicator for if the facility is an EJScreen facility, which indicates the facility is in a block group of the 80th or higher national percentile of one of the primary environmental justice indexes of EJScreen, EPA’s screening tool for environmental justice (EPA 2020b). We also include whether the facility is within ten miles of a native American tribe, the number of inspections the facility had during the time frame, and whether the facility reports discharges into impaired waterways. The EJScreen and tribal proximity variables are included because research in the field of environmental justice has shown that facilities that release the most toxic waste tend to be in the most poor and vulnerable communities (Collins et al 2016, Mohai et al 2009) and that native American lands face disproportionate impact from toxic chemical releases and defense contractors (Hooks and Smith 2004). Impaired waterway discharges and inspection count are indicators of regulatory oversight, which influences firm decisions to implement pollution control technology (e.g., Millimet et al 2009, Gray and Shimshack 2011, Shimshack and Ward 2005).

An additional covariate is the number of years each facility reported information and is based on the number of years the facility reported as ‘open’ to the NETS data, which goes back to 1989 and controls for facilities reporting more actions because they reported longer. Lastly, a covariate for the number of chemicals reported controls for the greater likelihood of a facility reporting actions with the more chemicals that they manage. Descriptive statistics for all quantitative variables are listed in Supplementary table 1 and counts of factor variables are reported in Supplementary table 2 (https://stacks.iop.org/ERIS/1/025006/mmedia).

3.7. Statistical analyses
A generalized linear mixed model (GLMM) is fit to the data for each of the four dependent variables: total number of P2 actions, number of years with a P2 action that resulted in a decrease in net production related waste within one year, number of P2 actions that resulted in reduction after five years, and number of actions that resulted in a 25 percent or more reduction after five years. The data are over-dispersed with the variance
Figure 1. Number of facilities over time by subsector. There has been a decline in number of TRI facilities reporting each year.

Figure 2. Number of contractors over time. Fixed-price contractors are the most common type in each subsector and in general, the number of contractors per year is stable.

being much higher than the mean violating the assumption of a traditional Poisson regression and so we use a quasi-Poisson model. The model statement is:

$$ Y_{it} \sim \text{quasi-Poisson}(X_{it}\beta_{it} + \theta_t + \epsilon) $$

where $Y$ is an integer response variable for the $i$th observation (facility) for each $t$ subsector. $X_{it}$ is the matrix of predictors for each $i$ facility in each $t$ subsector. $\beta_{it}$ is the vector of coefficients for each $i$ facility in each $t$ subsector. $\theta_t$ is the vector of random intercepts for each subsector $t$. $\epsilon$ denotes the error term.

The models are fit using a top-down approach fitting a full model first. Fixed effects for bivariate dummy variables are included for contract type. Our models include both contractors and non-contractors. We also test for influential points and goodness of fit. We fit the models excluding outliers and coefficient estimates without finding significant changes so all data are kept in the models. Lastly, we conduct a post-hoc test comparing
the estimated marginal means for the interaction of contract type and subsector in a generalized linear model where we remove the random intercept for subsector and replace it with subsector as a fixed effect. We compare the contrasts of the estimated marginal means using the Tukey HSD method from the ‘emmeans’ R package (Lenth 2020). This allows for comparison between contract types within subsector. We conduct all analyses using R statistical software version 4.0.0 (R Core Team 2020). Models are fit using the ‘lme4’ package (Bates et al 2015). The ‘car’ package is used for model diagnostics (Fox and Weisberg 2011).

4. Results

4.1. Pollution prevention and contract type

Over time, all subsectors are declining in the total number of TRI facilities per year (figure 1). While facilities with government contracts are a small subset of total subsector facilities, the number of TRI facilities that are contractors has stayed relatively constant (figure 2). In addition, total pollution prevention actions are
declining over time in the subsectors along the same pattern as the decline in number of facilities except for computer and electronic component manufacturing that has steady reporting of actions (figure 3). Contractors also report a steady number of pollution prevention actions per year with increased reporting over time in computer and electronic products manufacturing (figure 4). In addition, incentive contractors are reporting a larger number of overall actions in computer and electronic product manufacturing, and in transportation manufacturing relative to the total number of facilities in those subsectors (figures 2 and 4). This suggests an association between incentive contractors and their pollution prevention reporting in these sectors.

Sensitivity tests reveal no influential points, constant error variance, and no multicollinearity with no predictors with a VIF above 10. No significant differences are observed between single facility firms or multi-facility firms, so all data are included in the models. We find support for greater reporting of pollution prevention by incentive contract awardees in our GLMM results. We find that if a facility receives incentive contracts, they report 2.28 times as many actions ($\beta = 0.822, p < 0.001$) as non-contractors from 2001 to 2012 (figure 5) and this result is statistically significant (table 2). Facilities that receive incentive contracts are 2.17 times ($\beta = 0.773, p < 0.01$) more likely than non-contractors to report actions with a net reduction in production related waste of the chemical after one year (figure 5) and this result is statistically significant (table 2). Incentive contractors also report 1.96 times ($\beta = 0.675, p < 0.05$) as many actions as noncontractors that have sustained net reductions after five years and they report 1.99 times ($\beta = 0.690, p < 0.05$) as many actions that have net reductions of 25 percent or more after five years (figure 5). These results are also statistically significant (table 3).

For the other contract types, we find that cost-plus contractors on average report 1.58 times ($\beta = 0.463, p < 0.05$) as many pollution prevention actions as noncontractors (figure 5) but the effect is not as strong as for incentive contractors (table 2). In addition, cost-plus contractors report more actions that achieve net reductions after five years but not more actions with reductions one year later (figure 5). We do not find that fixed-price contractors report significantly more or less pollution prevention actions than noncontractors for any of the dependent variables (tables 2 and 3).

4.2. Covariates

Variables describing procurement characteristics of TRI facilities are associated with pollution prevention reporting. If a facility receives contracts from the DOD, we find that they report on average 43.8 percent ($\beta = -0.575, p < 0.05$) fewer pollution prevention actions than non-DOD facilities with a net reduction of 25 percent or more and this is statistically significant (table 3). Of our green purchasing variables, greater award
...and more pollution prevention actions with a 25 percent net reduction after five years (figure 5). For each additional percentage of contract dollars that includes sustainability criteria, a facility reports 82 percent ($\beta = 0.598, p < 0.05$) more pollution prevention actions that are successful after five years (table 3). The proportion of award dollars that require use of EPA designated products is not associated with reporting more successful pollution prevention actions (figure 5).

Organizational predictors for facility environmental activity are also associated with pollution prevention reporting. For facility size, average sales do not have any significant association with pollution prevention...
Figure 6. Results for the interaction of contract type and subsector. Significant differences in the reporting of pollution prevention are observed in computer and electronic products manufacturing and transportation manufacturing with incentive contractors reporting more pollution prevention. No significant association is observed in the chemical manufacturing or fabricated metal manufacturing subsectors.

reporting, however, average employment does with a greater number of employees being associated with greater number of pollution prevention actions and more successful actions (figure 5, tables 2 and 3). Corporation size and complexity is associated with reduced reporting of pollution prevention actions that are successful after five years; with each additional establishment owned by the corporation, the facility reports 1.7% fewer actions with a 25 percent reduction after 5 years ($\beta = -0.018, p < 0.05$). Number of reporting years is associated with more pollution prevention reporting; with each additional year a facility is operating, they report 1.5 percent more actions ($\beta = 0.015, p < 0.01$) (figure 5). Longer reporting facilities also report 2.1 percent ($\beta = 0.021, p < 0.05$) more actions with a net reduction after one year (table 2) and 2.4 percent ($\beta = 0.024, p < 0.05$) more actions that have sustained reductions over five years for each additional year they have been reporting (table 3).

Lastly, regulatory and environmental justice characteristics of facilities are associated with variation in pollution prevention reporting. We do find an association between EJScreen facilities and reduced reporting of pollution prevention actions with EJScreen facilities reporting 10.3% fewer actions than non-EJScreen facilities ($\beta = -0.108, p < 0.05$) (figure 5). There is no difference found for the effectiveness of actions and EJScreen status except for actions with a 25 percent reduction after 5 years; EJScreen facilities report 12% fewer actions in this model and the estimate is significant at $\alpha = 0.1 (\beta = -0.137, p < 0.1)$. Facilities that report more chemicals report more pollution prevention actions (figure 5) and more successful actions (table 2). Lastly, facilities that are inspected more often report more actions and more successful actions (figure 5) and this association is statistically significant at $\alpha = 0.05$ for all our models (tables 2 and 3). For each additional inspection, a facility reports 2.7 percent ($\beta = 0.027, p < 0.001$) more pollution prevention actions (table 2) and 3.25 percent ($\beta = 0.032, p < 0.01$) more actions that result in net reductions in production related waste in their first year (table 2). In addition, for each additional inspection, a facility reports 4.2 percent ($\beta = 0.041, p < 0.001$) more actions that resulted in a net reduction after five years (table 3) and 4.1 percent ($\beta = 0.04, p < 0.001$) more actions that resulted in a net decrease of 25 percent or more after five years (table 3).

4.3. Subsector results
In chemical manufacturing, these facilities are most often awarded fixed-price contracts for paint, dope, varnish and related products, preservative and sealing compounds, laboratory equipment and supplies as well as drugs and biologicals. Cost-plus contracts are most often awarded to research and development as well as exploratory biomedical and fuel products. In addition, results of the post-hoc marginal mean comparison for
Figure 7. Marginal pairwise outcomes for number of P2 actions within each sector. As employment increases, more P2 is implemented with incentive contractors more likely to report more P2. The association is strongest in computer and electronic product manufacturing and transportation manufacturing subsectors.
this subsector (marginal mean = 0.841, p < 0.05). Fixed-price contractors report half as many (49.5 percent, marginal mean = −0.703, p < 0.05) total actions than incentive contractors with no difference in number of successful actions reported at α = 0.05 in this subsector (figure 6). Lastly, this subsector also exhibits greater pollution prevention implementation as labor costs increase with incentive contractors also implementing more actions than other facilities of similar size (figure 7).

5. Discussion

Our analysis indicates that US Federal contract payment methods are associated with sustainable manufacturing practices. In two of the four manufacturing subsectors, facilities respond to incentives contracts, in part, with pollution prevention strategies. Incentive contractors report on average more than two actions for every action reported by noncontractors and, within computer and electronic products manufacturing, report more than three actions for every action reported by noncontractors and two actions for every one reported by fixed-price contractors, holding all other variables constant. Within transportation manufacturing, incentive contractors report more than two actions for every one reported by noncontractors. These results suggest that manufacturing facilities with US Federal incentive contracts may be implementing pollution prevention actions as part of their approach to lowering their costs to earn the incentive bonus. This association indicates that industrial processes are changing at these firms’ facilities in a market-based context without regulatory pressure. Incentive contractors are implementing more pollution prevention actions than fixed-price recipients and noncontractors suggesting that the difference might be linked to the added cost incentives built into the contracts.

Ecological modernization theorists argue that when waste is reduced, there are economic and environmental benefits including cuts in production and waste costs and reduction in hazards associated with waste disposal (Gibbs 2006, Mol and Sonnenfeld 2014). These economic benefits to firms implementing such changes demonstrate that capitalist practices can lead to positive environmental outcomes. US Federal incentive contracts focus on production costs when the contract is negotiated, and the results in our study suggest that facilities with incentives to reduce costs might be looking at their hazardous material inputs and waste, in addition to other factors, when determining ways to reduce expenses. This is akin to how green taxes can lead to positive environmental outcomes (Andersen 1994) and how government can encourage technological advancement (Huber 2004). These technological advances are leading to less resource intensive production processes which is indicative of super-industrialization and corporate environmental voluntarism.

In addition, actions reported by incentive contractors are more likely to be successful at reducing production related waste of toxic chemicals in the years following. Overall, incentive contractors on average report nearly two (figure 5) pollution prevention actions for every action reported by noncontractors with reductions of 25 percent or more. In computer and electronic product manufacturing, this value increases to more than three actions for every one reported by noncontractors and more than two for every action reported by fixed-price contractors. This is important evidence showing the advancement of these industries and that they are incorporating environmental concerns into the core of their operating practices, a key factor in ecological modernization theory. In summary, voluntary pollution prevention actions undertaken by incentive contractors are implemented more frequently, are more effective, and support the advancement of production processes toward more harmonious industrial activity. The evidence supports an association between incentive contracts, changes in firm environmental behavior and public health outcomes. Increasing adoption of pollution prevention practices has direct implications for public health. Pollution prevention actions, on average, lead to an immediate drop in targeted chemical toxic releases by 9%–16% and last up to five years (Ranson et al. 2015). Decreasing TRI toxic chemical releases, especially air pollutant emissions, have been linked to reductions in county child mortality rates (Agarwal et al. 2010). Earlier research noted that 13% of TRI facilities have been government contractors at some point from 2001–2012, suggesting the changes in contracting would affect a limited number of TRI facilities (Hill et al. 2020). While not a panacea for addressing risk from industrial toxin exposure, incentive contracts may be an important multiplier in leading to more adoption and effectiveness of source reduction activities, making these types of contracts a practical method to incentivise firm environmental innovation with measurable public health outcomes for Federal contractors.

Regarding our procurement covariate findings, defense contractors report fewer pollution prevention actions. This might be a signal that the special treatment that defense contractors receive under various US Federal regulations, including exemptions for environmental statutes (Ramos et al. 2007, Zippel 2013), is hampering the potential advancement that could be made through environmental innovation, which we saw in the incentive contractors. We also find evidence that TRI facilities that are contractors and receive awards with sustainability criteria report more pollution prevention actions. There could be a coordinated impact of combining incentive contracting and green purchasing by US Federal agencies; looking more closely at how these two
interact could benefit green purchasing policies going forward. Future work on this may enhance our understanding of how the government can play an active role in ecological modernization through procurement decisions (Heinrichs and Laws 2014).

Of our organizational theory covariates, our findings for facility size support concepts of economies of scale being related to technology advancement regarding pollution prevention. Also, the finding that facilities employing more people are correlated with greater pollution prevention could indicate that facilities with higher labor costs are implementing more P2 to reduce operating costs and perhaps to reduce the risk employees face when working with hazardous materials (figure 7). In addition, our findings for facility reporting years indicate that facilities reporting longer report more pollution prevention actions. The finding could be indicative of mechanization of industry and the modernization of technology at TRI facilities with those operating longer adopting more green alternatives (Hart and Dowell 2011, Huber 2004).

Our finding for EJScreen facilities doing potentially fewer pollution prevention actions is concerning, and these facilities should be encouraged to do more pollution prevention to reduce their impact on vulnerable communities. Incentive contracting might be a way to move these facilities from extensive hazardous material inputs and waste toward better performance. Finally, the role of government oversight continues to play an important role in encouraging facilities toward voluntary reduction as we also find that more inspections lead to greater pollution prevention (Gray and Shimshack 2011).

When looking within subsectors, we find that the association between type of government procurement contract and pollution prevention reporting is strongest for computer and electronic product manufacturing and transportation manufacturing. We do not find any association between contract type and pollution prevention within the chemical manufacturing subsector and only weak association with fabricated metal manufacturing. The lack of association within chemical manufacturing may be related to the products they produce that are largely not end-use products but rather components and inputs for other manufacturers to use. This suggests a few possibilities including that incentive contracts do not have the same effect in each subsector. Another possibility is that there are simply not enough incentive contracts utilized in these subsectors for a significant difference to be seen in pollution prevention reporting. Incentive contracts are used infrequently and recipients of fixed-price contracts, which are the dominant form of procurement in the US, report fewer actions than incentive contractors in computer and electronic product manufacturing and transportation manufacturing. Dominant use of fixed-price purchasing, which has no significant association with greater reporting of pollution prevention, combined with exemptions or reduced green purchasing could lead to fixed-price contractors having more intensive use of hazardous material inputs. The results of this study offer support for calls to increase the use of incentive contracts (Kendall 2015, Lewis and Bajari 2014) because in addition to saving taxpayer dollars, there are potential environmental benefits to this method of procurement in line with sustainable consumption goals of policy (Hausknost 2020) both in the US and elsewhere.

There are a few limitations to our study and the extent that the results can be generalized. Incentive contracts, as mentioned above, are used far less frequently than fixed-price contracts. The contracts we include in this analysis for the incentive type represent all that could be obtained to match a TRI facility ID from 2001 to 2012 and are a subset of all contractors and all TRI facilities. This does not lessen the significance of the findings but does put into perspective the fact that the study results characterize a small portion of US Federal contractor TRI facilities (6.25 percent of our sampled contract facilities are incentive contractors). Future studies might look solely at fixed-price purchases to deduce differences relevant to environmental impacts of US Federal purchasing. In addition, the results we find are most relevant to the four subsectors that are included and may not translate to other subsectors.

The TRI does not cover all facilities or all contractors; therefore, the associations we find are most relevant to TRI qualifying facilities. Generalization beyond TRI facilities is discouraged until similar associations can be tested. Synthesizing the contract spending data with other public databases like the US National Emissions Inventory (NEI) could expand this area of research to include smaller facilities and other pollutants.

The TRI and the NEI rely on self-reported data that are often calculated by facilities using general emissions factors which adds additional uncertainty into the analysis in the form of estimation and reporting errors. The TRI also does not cover all chemicals, just management and release of certain recognized toxic chemicals, making it impossible to deduce the entire extent to which incentive contracts spur innovation in waste management for US Federal contracting facilities using just the TRI data. Additionally, the NETS data relies on establishment data from Dun and Bradstreet, a privately owned commercial business list data source maintained for marketing purposes with unknown data collection and processing. Efforts to combine data from multiple business lists and in-person validation sampling may help improve the quality of this data in future studies.

Another source of uncertainty in this analysis arises from the pollution prevention data, its quality, and its interaction with other regulations. The pollution prevention actions we study were all reported voluntarily with an unknown amount being associated with upgrades that were required by the Clean Air or Clean Water
Acts (CAA and CWA). Research designs seeking to test for similar effects of these policies on pollution prevention behavior may be useful in the future, and additional information collection from the TRI about why pollution prevention actions are initiated would help to differentiate the effects of these policies from the effect of incentive contracts.

Lastly, with voluntary reporting of pollution prevention data, there might be underreporting because of the lack of enforcement for reporting pollution prevention actions through the TRI program. It is also possible that incentive contractors are better at reporting their environmental activity and are in line with their goals of securing future incentive contracts. More in-depth qualitative studies of contractors might help illuminate this. In addition, our primary predictor is incentive type awards which is best conceptualized using ecological modernization, however, organizational characteristics of the industrial firms also play a role in the activity of the facilities they own such as size and corporation complexity. These latter characteristics relate most to other organizational scholarship (Lenox and Nash 2003, Prechel and Istvan 2016) suggesting that both ecological modernization and organizational theory are needed in this analysis to fully understand the context and nature of firm decisions to make more or fewer pollution prevention decisions. We focus our investigation and effort on ecological modernization, but the results support further work with an organizational lens. Our approach is to continue innovation in crossing disciplines to understand these complex environmental problems and strongly encourage future research using these multiple perspectives and variables. Future research can build upon our use of ecological modernization theory by considering alternative theoretical frames such as other political economy frameworks and organizational theory.

6. Conclusion

Our study has three primary conclusions. First, when incentivized by US Federal Government procurement contracts, manufacturing facilities are increasing their efficiency by implementing more pollution prevention technology. These sustainable upgrades are reported more frequently by contractors that have received US Federal incentive-type awards. The awards incentivize manufacturers to reduce their stated cost for the contract in any way they can, which may include pollution prevention strategies to save on material input costs and waste management. Such efforts by firms lead to lower operating costs and earn higher incentive bonuses. The incentive motivates the additional work by these facilities so that they can increase their profitability with marginal reductions in costs; because of the incentive bonus, the marginal savings are higher as the bonus is added to the return on investment of the pollution prevention technology. These facilities save on waste management, reduced material costs, and receive a bonus from the US Federal Government for excellent performance making it a triple win for these facilities. Incentives in government contracting are correlated with the performance of contract recipients. These incentives encourage contractors to lower their costs and are associated with increased implementation of successful waste management practices, potentially leading to higher production efficiency.

Second, results from this study support key concepts of ecological modernization theory including that governmental policy can guide industry toward positive environmental activity via incentives. This study provides evidence that industry, responding to government policies to incentivize efficient production processes, can achieve reduced material inputs and reduced waste while also meeting production demands. These voluntary actions undertaken by firms at their facilities reflect how capitalist practices can achieve positive environmental outcomes that are complementary to financial performance. In addition, sustainable consumption by US Federal agencies can have important benefits and, if combined with incentive contracting, there could be continued reductions in toxic chemical waste.

Finally, our findings support the continued expansion of US Federal Government incentive contracting because the evidence suggests that these incentives not only lead to better economic performance, but also lead to better environmental performance while also fulfilling the procurement needs of government agencies. Pollution prevention is one way firms can lower their costs, save money, and contribute toward positive environmental outcomes. Our study provides support for the benefits of linking incentives to firm economic performance and that these benefits extend beyond financial savings. They also may be leading to substantial environmental benefits and encourage firms to adopt voluntary changes in their production processes leading to less intense resource use, lower toxic chemical pollution output, and cleaner production technology.

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Data availability statement

No new data were created or analysed in this study.

Ethical statement

The authors declare they have not competing financial interests linked with this project or paper.

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