Preemptive Corporate Environmental Investment: Evidence from Toxic Releases

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Abstract

Do firms preemptively invest in environmental quality in the anticipation of competitive threats? Exploiting manufacturing plant location contests, we show that incumbent plants reduce on-site toxic releases by 9.3% following entry announcements, with no reduction in off-site transfers and no loss of economic output. These firms invest in process and production modifications, the capital-intensive and irreversible category of abatement activity. We find results are driven by anticipated labor market threats, instead of regulatory pressure or investor scrutiny. The incumbent firms, which reduced toxic releases, experience lower wage growth and worker turnover ratio. Our findings demonstrate that firms use irreversible abatement investment as a pre-commitment device, motivating for environmental improvement beyond external regulatory or market constraints.

Keywords: Pre-emptive Investment; Investment Irreversibility; Entry Threats; Corporate Environmental Investment; Labor Market Competition; Toxic Releases;

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1 Introduction

In 2023, only 8% of facilities adopted new source reduction measures as abatement initiatives (Environmental Protection Agency, 2025). The finance literature attributes these abatement activities as a cost to be minimized under regulatory or market constraints, rather than an investment undertaken strategically.[1] A key feature of many abatement investments is their irreversibility,[2] which makes environmental investment a potential commitment device analogous to other forms of irreversible capital expenditure (Dixit, 1980; Pindyck, 1988; Dixit and Pindyck, 1994). When an anticipated shift in competition threatens a firm's essential inputs, it can deploy a cleaner production process as a credible pre-commitment to retain those resources, with credibility derived from its cost irreversibility and public verifiability. In this paper, we provide the first evidence of preemptive investment in environmental quality by firms in response to expected changes in conditions of competition.

Using announcements of large plant openings as a quasi-natural experiment, we show that incumbents, anticipating increased market competition, significantly reduce their toxic releases. These environmental improvements are driven by abatement investments in production modifications, which are costly and irreversible, with no corresponding reduction in economic output. Our findings identify the anticipated intensified local labor market competition as the main channel behind this strategic response, effectively excluding other potential explanations such as increased regulatory oversight or changes in product market competition. We find that by preemptively improving workplace environmental quality, incumbent firms secure their workforce and experience limited long-term wage increases, typically triggered by a major new entrant in the labor market.

[1] For example, regulatory enforcement raises the cost of non-compliance (Greenstone, 2002; Akey and Appel, 2021; Duchin et al., 2025), investor scrutiny lowers the cost of capital for cleaner firms (Dyck et al., 2019; Hsu et al., 2023), and supply-chain demands transmit environmental standards through production networks (Flammer, 2015).

[2] For example, installing emissions control equipment, such as catalytic reduction systems or industrial scrubbers, requires substantial capital expenditure, is physically embedded in the plant, and cannot be profitably redeployed elsewhere.

The optimal response of an incumbent firm to an entry announcement is not obvious ex ante. Anticipating local economic growth, a firm may rationally prioritize capital investment, other than abatement, accepting higher toxic releases as a byproduct of expanded production.[3] Countervailing this, large plant openings intensify competition for workers, placing upward pressure on local wages and tightening the supply of skilled labor (Greenstone and Moretti, 2003; Moretti and Thulin, 2013; Kim, 2020).[4] Facing this tightening, an incumbent can preemptively improve workplace environmental quality. Under the framework of compensating wage differentials (Rosen, 1974; Colonnelli et al., 2025; Krueger et al., 2025), this non-pecuniary amenity provides direct utility to workers, effectively substituting for the higher pecuniary compensation they would otherwise demand. Unlike flexible wage premiums that a firm can easily reverse, irreversible and publicly verifiable abatement investments signal a credible, permanent commitment to environmental quality, successfully locking in the labor supply.

To empirically test how incumbent plants optimally respond to anticipated labor-market competition, we use an identification strategy that compares counties that ultimately won the competition to host a new manufacturing plant (*winner* counties) with those that were serious contenders but did not (*loser* counties). The central identifying assumption is that winner and runner-up counties are similar in unobservable characteristics that affect both economic and environmental outcomes, conditional on observables. This setting offers a unique advantage for isolating strategic decision-making. By focusing on the announcement period rather than the actual opening, we disentangle forward-looking strategic adaptations from the direct operational effects of the new entrant. The announcement serves as a pure information shock regarding future labor scarcity, allowing us to identify how firms proactively adjust their environmental profile to position themselves for the increasing competition.

[3]Large plant openings generate positive spillovers for incumbent firms through agglomeration economies, knowledge diffusion, and input-output linkages (Moretti and Thulin, 2013; Kline and Moretti, 2014; Bloom et al., 2019).

[4]Large plant openings alter the competitive landscape by boosting local earnings, particularly for high-skilled workers (Greenstone and Moretti, 2003; Moretti and Thulin, 2013). Kim (2020) further shows that entry reduces labor market frictions, amplifying competitive pressure on incumbents.

We assemble a stacked panel dataset of 235 such plant siting competitions between 2002 and 2018, where we observe both the winning and at least one closest losing county for each deal.[5] This structure allows us to estimate difference-in-differences regressions that capture how environmental outcomes, captured by toxic releases reported under the Toxics Release Inventory (TRI), change for incumbent plants in winner counties relative to those in loser counties, before and after the announcement of the new plant.

We find that the announcement of large manufacturing plant openings leads to a significant immediate decrease in on-site toxic emissions by incumbent plants in the same county. Specifically, toxic releases decreased by about 9.3% for incumbent manufacturing facilities within the next 3 years. This reduction is mainly coming from incumbent plants in the manufacturing industries. Importantly, these reductions occur without sacrificing economic performance, as sales remain steady and employment slightly increases. Instead, it is associated with increased abatement efforts, primarily through high-cost process modifications.

We rule out alternative explanations of the main findings mainly in three ways. First, we find that the incumbent plants do not significantly reduce off-site emissions, and the reduction in on-site emissions is mainly focused on the air emissions. These results imply that the reduction in emissions is not driven by demand from stakeholders other than employees, such as customers, suppliers, or outside investors. Second, the effect emerges soon after the announcement and grows over time, indicating forward-looking environmental strategies and is less likely to be driven by knowledge spillovers, as the new plant has yet to open. Lastly, the environmental regulatory enforcement after the announcement does not change significantly, ruling out the potential of government enforcement to change incumbent plants' emission policies.

Next, to investigate whether labor market tightening operates as a mechanism, we analyze how these results vary across different labor market characteristics. First, we find that the

[5]We combine the list of large plant opening events from Bloom et al. (2019), Kim (2020), and Slattery and Zidar (2020). For each event, we manually search local newspapers to identify the year of announcement for new plant openings, rather than their actual opening year.

environmental response is especially higher in winning counties with low unemployment rates and in counties with lower employer concentration. We then measure the expected labor market competition for incumbent firms by assessing the similarity of the required skill sets of workers between incumbent and new plants' industries. Incumbent plants would anticipate greater labor competition if they share the same pool of labor with similar skills, which would incentivize them to adjust their environmental behavior in anticipation of the change after a new plant opens. We use OEWS data to estimate the average required skill elements for jobs in each industry and calculate the Mahalanobis distance between the skill sets of incumbent and new plants' industries, using either 5- or 4-digit NAICS codes. We find that incumbent plants in winning counties are more likely to reduce their toxic releases when their skill composition is similar to that of the new plants.

Consistent with prior research showing that firms adjust non-wage attributes, such as working conditions or corporate social responsibility initiatives, to attract and retain talent, particularly in high-skill industries,[6] we find that incumbent firms in high-skill sectors exhibit larger emission reductions. Similarly, we find that incumbent firms preemptively reduce more toxic emissions in deals when the winning county is more pro-environment. This suggests that incumbent firms strategically enhance their environmental performance to compete for skilled workers and in locations with an environmentally conscious population.

We then document heterogeneity in these results across new plants' environmental characteristics. The theoretical strategic framework suggests that incumbent firms should reduce emissions to remain competitive in the labor market if the new entrant is expected to offer a cleaner environment. Expected emissions are estimated using the average emissions over the past three years of median firms in the new plants' 6-digit NAICS industry. We compare this value with the incumbent firm's average emissions in the past three years. Our analysis reveals a greater reduction in emissions for incumbent plants in winning counties that had

[6] e.g., Flammer (2015), Burbano (2016), Schauf and Schoonjans (ming), Colonnelli et al. (2025), Krueger et al. (2025)

higher emissions than the new plant's expected levels.

Next, we examine whether incumbent plants that improved environmental performance remained competitive in the labor market following the entry of new plants. Our analysis focuses on two key outcomes: wages and worker retention. We find that high-skilled workers experience approximately 2.8% higher weekly earnings in counties that attracted new plants, consistent with Greenstone et al. (2010) and Moretti and Thulin (2013), reflecting increased labor market competition. However, this wage increase is concentrated among industries that did not reduce emissions. Industries that improved environmental performance show significantly smaller wage increases, suggesting they successfully used environmental quality as non-pecuniary compensation rather than competing solely on wages.

To distinguish the labor market mechanism from alternative explanations, such as reducing total environmental footprint to signal corporate responsibility to new supply chain partners, including new plant or investors, we examine whether emission reductions are concentrated in on-site releases that affect local environmental quality versus off-site transfers that reflect total corporate environmental footprint. Workers directly experience on-site toxic releases like air emissions, water discharges, and land contamination through their daily exposure at the workplace and residence in the local community. In contrast, off-site waste transfers, such as toxic materials shipped to other facilities for treatment or disposal, do not affect local environmental amenities but do contribute to the firm's overall environmental footprint. However, we find no significant change in off-site waste transfers. Further, we find air emissions, which the most visible and directly experienced form of pollution, derives the results, while water and land emissions show no reductions. This differential response is inconsistent with mechanisms driven by supply chain formation, investor pressure, or corporate environment concerns, all of which emphasize total environmental footprint regardless of type and location.

We rule out other alternative mechanisms, such as regulatory pressure and knowledge

spillovers, as primary drivers of the observed emission reductions. Since reductions begin before the new plants become operational, knowledge transfer is unlikely, and analysis shows no increase in EPA enforcement or changes in non-attainment status, suggesting no tightening of environmental regulation. Product market competition is also an unlikely driver, as new plants tend to operate in tradable industries that do not directly compete with local incumbents for customers.

Related literature First, we extend the "Million Dollar Plant" (MDP) literature by examining environmental spillovers through strategic firm behavior. While previous studies focused on productivity spillovers (Greenstone et al., 2010) or negative health effects (Currie et al., 2015), we reveal a positive environmental spillover: incumbent firms strategically reduce emissions in anticipation of labor market competition. Our findings challenge the maintained assumption of the compliance literature that environmental improvement requires an external trigger. Prior work identifies regulatory enforcement (Greenstone, 2002; Akey and Appel, 2021), investor pressure (Hsu et al., 2023; Dyck et al., 2019), and supply-chain demands (Flammer, 2015) as the primary drivers of abatement. We show that anticipated labor market competition generates the same outcome through a wholly different mechanism: forward-looking firms exploit the commitment value of irreversible abatement investments to preempt wage competition, without any external monitor imposing costs.

Second, we contribute to the literature on irreversible investment and strategic commitment (Dixit, 1980; Pindyck, 1988; Dixit and Pindyck, 1994). While prior work establishes that irreversible capital expenditures can serve as credible commitment devices in product market competition (Spence, 1977; Dixit, 1980; Milgrom and Roberts, 1982; Cookson, 2018), we provide the first evidence that firms deploy irreversible environmental investment as a commitment device in labor market competition. Because abatement investments are costly to reverse and publicly verifiable through mandatory TRI disclosure, they constitute a credible commitment that shapes the terms on which competition occurs in a way that flexible operational adjustments would not.

Third, we contribute to the literature on how labor markets shape corporate decisions. Building on compensating wage differential theory (Rosen, 1974) and recent evidence that workers accept lower wages at environmentally responsible firms (Colonnelli et al., 2025; Krueger et al., 2025), we provide causal evidence that labor market competition drives preemptive environmental investment. Our framework formalizes environmental quality as a strategic substitute for wages, extending Matsa (2010) and Kim (2020), who show that firms use financial policy to manage labor costs, to a previously undocumented instrument: irreversible environmental investment.

2 Empirical strategy

To understand how incumbent plants optimally respond to anticipated labor-market competition, we utilize the announcement of a large plant opening in a given geographic area. The siting of large new plants is a strategic decision made by firms, often influenced by local labor supply, infrastructure, tax incentives, and regulatory conditions. As such, counties that receive new plants may systematically differ from those that do not, making it difficult to disentangle the effects of economic growth from pre-existing differences. In this paper, we use the openings of large plants as a shock to the local labor market. Previous research shows that the entry of a new plant expands the labor market and heightens competition for high-skilled workers (see Greenstone, Hornbeck, and Moretti (2010); Currie, Davis, Greenstone, and Walker (2015); Kim (2020)). Specifically, we exploit detailed information on large plant siting competitions, where firms considered multiple potential locations before selecting a final site. The previous literature already established that the counties that won the competition to open a new plant and the counties that slightly lost the deal are fundamentally comparable before the competition to win the plant ended. We can compare changes in toxic releases between plants whose fundamentals would not have changed had it not been for anticipated changes in their local labor market by comparing plants in winner counties

with those in loser counties after the opening announcements of a large plant in the county.

Another difficulty is that environmental decisions of plants are forward-looking and require a long time to adjust through planning, investment, and coordination. If we study the changes in environmental outcomes after the new plant becomes operational, the effect may be confounded with preemptive responses that occurred following the announcement. Therefore, in this paper, we focus on the changes in environmental outcomes after announcement dates, so that we can more clearly identify preemptive adaptations and avoid conflating them with responses to the materialized new plant opening. The announcement of a major new plant represents a significant information shock, signaling potential shifts in the local economy, such as increased labor market competition.

The empirical regression we mainly conduct in this paper is as follows:

$$\log(E(T_{i,c,d,t})) = \alpha + \beta Winner_{c,d} \times Post_{c,d,t} + X_{c,t} + \kappa_{i,d} + \eta_{t,d} + \varepsilon_{i,c,d,t} \tag{1}$$

Given that the main dependent variable, toxic releases, is a non-zero and positively skewed variable, we use Poisson regression for the main analysis (Cohn, Liu, and Wardlaw, 2022). We estimate stacked difference-in-differences, where we stack treated and control samples for each new plant opening event following previous literature (Bloom et al. (2019); Kim (2020); Slattery and Zidar (2020); Giroud et al. (2024)). $T_{i,d,t}$ is the total *on-site* toxic releases of a plant i for large plant opening event in the same county c for each deal d at time t. $Winner$ is the indicator which is 1 if a large new plant decided to be opened in the county c and 0 if the county narrowly lost the deal for deal d. $Post$ is the indicator which is 1 if it is on or after the *announcement* new plant opening (t) in county c and 0 before for each deal d. We focus on on-site total releases because workers directly experience on-site toxic releases like air emissions, water discharges, and land contamination through their daily exposure at the workplace and residence in the local community. We restrict the sample period to be between -3 to +3 years, including the announcement years. Vector

X includes county-level control variables, including GDP growth$_t$ and the previous year's GDP$_(t-1)$. Main regressions include fixed effects of plant-by-deal ($\kappa_{i,d}$) and year-by-deal ($\eta_{t,d}$) considering the heterogenerous treatment effects (Gormley and Matsa (2011)) for each plant. We cluster standard errors at the county level.

3 Data and descriptive statistics

The two main datasets we use are 1) a list of large plant opening events and 2) the Toxics Release Inventory (TRI) Program from the US Environmental Protection Agency. First, we combine the list of large plant opening events from Bloom et al. (2019), Kim (2020), and Slattery and Zidar (2020). For each event, we manually search local newspapers to identify the year of announcement for new plant openings, rather than their actual opening year. Next, we merge this list with the TRI data, which contains mandatory self-reported toxic chemical releases by facilities in the US. EPA audits and actively punishes misreporting based on Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA). There has been limited evidence of systematic measurement error in this self-reported data (Brehm and Hamilton (1996), Bui and Mayer (2003)). The reporting requirements have been changing over time, mostly expanding their coverage on sectors and chemicals. During our sample period (2002-2018), there was only one deletion of a chemical in 2015 and three additions of chemicals. We provide robustness test results excluding newly added chemicals in subsubsection 4.1.2. As shown in Table IA.1, we have a total of 235 large plant opening events, of which 108 are in the manufacturing industry.

We further combine other EPA-generated datasets: Pollution Prevention (P2) for abatement activities of establishments, Integrated Compliance Information System (ICIS) for environmental regulatory enforcement by EPA, and Greenbook for attainment status of counties. Financial information is from National Establishment Time-Series data (NETS) for establishment-level and Compustat for publicly listed parent firm-level. Other county-

level information, including GDP growth and unemployment ratio, is from the Bureau of Economic Analysis (BEA) and County Business Patterns (CBP), respectively. We additionally use Scorecard for the votes on environment bills at the House and Senate levels, and combine ONET and OESM to get the average skill level of the industry. Summary statistics of variables are reported in Table 1.

4 Main results

4.1 Impact of announcement of large plant openings on incumbent plants' on-site toxic releases

4.1.1 Plant-level analysis

In Table 2, we report the plant-level analysis of the changes in environmental outcomes around large plant opening announcements, comparing incumbent plants in the winning and losing counties using the regression equation Equation 1. The results show that incumbent manufacturing plants in the winning counties reduce *on-site* total toxic releases by about 9.3% compared to those in the loser counties, as shown in column (2). Economic magnitude of this reduction in toxic releases is around 4,000 pounds. When it comes to nitrogen oxides (NO_x), it is equivalent to the annual pollution from nearly 100 mid-size SUV cars per year. The results are qualitatively and quantitatively similar after controlling for time-varying industry-level characteristics. Note that we focus on incumbent plants that are in manufacturing industries. The announcements of the opening of new manufacturing plants affect incumbent plants in the same industry, as they compete in the same labor market, consistent with previous literature (Greenstone et al. (2010), Bloom et al. (2019), Kim (2020)). These results show that incumbent plants also adapt their environmental behaviors in anticipation of local economic change due to the opening of a new plant.

Consistent with that the announcement of new manufacturing plant opening informs the incumbent manufacturing plants of the increase in future market competition in the common inputs, those plants react less significantly to the opening new non-manufacturing plants. In column (4), the incumbent plants' toxic releases do not change significantly differently with the control group. The aggregate effect of new plant openings announcements, regardless of industry, on toxic release decisions by incumbent plants is significant (columns (5) and (6)). In Table IA.2, we further conduct analysis using Equation 1 with non-manufacturing incumbent plants as a sample. Consistent with non-manufacturing incumbent plants not significantly affected by new plant openings, we find insignificant changes in toxic releases.

Dynamic analysis To understand the timing of adaptation of environmental behaviors, we conduct dynamic analysis on the total toxic releases by plants after the announcement of new plant openings. We conduct empirical analysis similar to Equation 1, but replacing *post* with variable *time*, which is relative time around the announcement year. For example, if it is on the announcement year, $time = 0$, and if it is a year before, $time = -1$. One year before the new plant opening announcement is the base year, where we compare the changes in plant-level total toxic releases. As shown in Figure 1, we observe a significantly bigger drop in toxic releases of plants after a year of the announcement, which intensifying effect over time.

4.1.2 Robustness tests

We first rule out the potential of local economic and environmental factors to explain the main result. One might question that fundamental differences in local economics and environmental conditions between winner and runner-up counties could explain the changes in toxic releases decisions by incumbent plants. In Figure IA.1, we regress a winner dummy on various county-level economic and environmental variables. We find that the coefficient for none of these key local metrics significantly differs from zero. Results show that the

winner and runner-up counties are not fundamentally different in terms of both economic and environmental aspects before the announcement of the plant openings.

In Table IA.3, we next conduct robustness tests to address potential econometric concerns on the selection of control variables. The results are consistent after dropping any control variable (column (1)), after controlling for pre-event county-level characteristics (column (2)), after restricting to sample with publicly listed parent firms (column (3)), after controlling for the financials of public parent firms, including lagged total assets and leverage ratio (column (4)), after controlling for additional firm financial characteristics, e.g., lagged cash holdings divided by total assets, lagged capital expenditure, and lagged tangibility (column (5)), after controlling for deal-year-parent firm level fixed effect (column (6)), and after controlling for plant-level size information, i.e., sales and employees (column (7)).

Next, we conduct robustness tests to clarify that counties with multiple large plant opening events do not distort the main results in Table 2. In Table IA.4, we (1) exclude deals in counties with another deal within the past 5-year window, (2) exclude runner-up counties that had won a deal in the past 5-year window, (3) exclude deals whose winner counties had a past deal within the past 5-year window, and (4) include deals whose winner counties experience the win for the first time. The results are qualitatively the same as the main results, yet with bigger economic magnitudes, which implies that multiple opening events mitigate new plants' impact on the local labor market.

As we use toxic releases reported following EPA regulations, one might worry that the main results are being distorted by the changes in reporting requirements. We conduct robustness tests excluding the chemicals that were newly added during our sample period (Bromopropane in 2015, Hexabromocyclododecane in 2016, Nonylphenol in 2014). As shown in Table IA.5, the negative effect of new plant opening announcements on toxic release decisions of incumbent plants is not driven by changes in reporting requirements by EPA. We observe that a limited number of plants (866 plants) have reported newly added chemicals

in our sample period.

4.1.3 Methods of emission reduction

The empirical analyses thus far indicate that incumbent manufacturing plants proactively revise their environmental strategies in anticipation of heightened input market competition following the entry of new facilities. We now further investigate whether environmental investments serve as a strategic pre-commitment tool. Because capital investments in pollution abatement are largely irreversible, incumbents can exploit this sunk-cost nature to credibly commit to their post-entry production structures. If this pre-commitment strategy holds, incumbent plants should be observed undertaking costly abatement efforts while actively defending their current economic scale.

Abatement Abatement efforts are a key method through which plants reduce toxic releases. We examine whether these plants intensify abatement activities, particularly those that fall under the categories of two: 1) process or production modification, and 2) operation, inventory, or material management. Process or production modifications are relatively more costly pollution prevention activities, such as substituting raw materials. Examples of operating, inventory, or material management include adjustments to production schedules aimed at minimizing equipment and feedstock changeovers.

In Table 3, we repeat Equation 1, replacing the dependent variable with the number of pollution prevention activities. As shown in columns (1) and (2), incumbent plants in winner counties increase their abatement efforts after the announcement compared to the plants in the losing counties, both in the short and long term. Such efforts tend to focus on more costly abatement strategies, as shown in columns (3) and (4), compared to less expensive operative adjustments in columns (4) and (6). These results are consistent with our conceptual framework, in which firms make a long-term environmental commitment to remain competitive in the face of expected changes in labor market competition.

One caveat is that abatement efforts often unfold gradually over time. Meaningful changes in environmental behavior require time to plan, finance, and implement to modify production processes or restructure operating practices. Immediate responses may be limited to low-cost, incremental adjustments, whereas more substantial abatement efforts tend to materialize over extended periods. To account for the time the abatement efforts take, in columns (2) and (4), we extend the sample period to 5 years after the announcement of new plants. Results show that abatement efforts intensify with a longer period for both adopting good operating practices and process modifications. This trend further supports the interpretation that firms are engaging in forward-looking environmental strategies.

Economic outcomes We next examine whether the observed changes in environmental behavior among incumbent plants are accompanied by changes in their economic performance, particularly in terms of sales and employment. This analysis helps assess whether the reduction in toxic releases reflects a strategic response to anticipated changes in the local economic environment following the announcement of a new plant. Note that these environmental adjustments occur after the announcement but before the actual opening of the new facility. At this stage, the new plant has not yet influenced local product or labor markets directly. Thus, we would not expect the economic performances of incumbent plants to be directly affected by new plants.

If we observe reductions in toxic releases without any corresponding decline in sales or employment, it suggests that incumbent plants had the capacity to reduce emissions without economic sacrifice. This would imply that they were previously choosing cost-saving strategies, such as marginally complying with environmental regulations without extra investment, but are now adjusting their behavior in anticipation of future changes in the local economy. Conversely, if emissions reductions are accompanied by declines in sales or employment, it may indicate that firms are facing competitive pressures that force difficult trade-offs between environmental performance and economic growth.

To empirically test whether the economic performances of plants were affected after the announcement new plant openings, in Table IA.6, we conduct OLS regression putting logged sales and number of employees as dependent variables. We use the sales as a proxy for plant production, given the data limitation. The results in columns (1) and (2) show no statistically significant change in sales among incumbent plants located in winning counties relative to those in losing counties. Interestingly, we observe a modest but statistically significant increase in employment at incumbent plants following the announcement of the new plant openings in columns (3) and (4).

In the last two columns, we examine whether incumbent plants' parent firms raise a debt-ratio, which might be used for additional abatement effort. As pointed out by Kim (2020), the entry of a large plant can reduce firing frictions by expanding external employment options, effectively lowering the cost of workforce adjustments for incumbent firms. This greater flexibility may make it easier for firms to reallocate resources toward forward-looking strategies, such as improving environmental practices.

Taken together with the earlier finding of reduced toxic releases, this pattern suggests that firms are making strategic adjustments that improve environmental performance while maintaining or even enhancing labor capacity. These findings are consistent with forward-looking behavior, either as preparation for anticipated competition or in expectation of agglomeration benefits associated with the new entrant. In the later section, we explore what are the mechanisms to trigger incumbent plants to take pre-emptive strategic environmental behavior.

4.2 Mechanism

4.2.1 Conceptual framework

Having established that incumbent plants proactively intensify their environmental investments, we conceptualize this strategic pre-commitment as a response to anticipated local labor market competition. Because large plant entries create significant localized labor supply constraints (Greenstone and Moretti, 2003; Moretti and Thulin, 2013; Kim, 2020), incumbents face pressure to secure essential human capital. Under the framework of compensating wage differentials (Rosen, 1974; Colonnelli et al., 2025; Krueger et al., 2025), irreversible environmental investments act as a credible pre-commitment to superior non-wage amenities. This preemptive improvement in workplace environmental quality enables firms to attract and retain workers without matching the steep wage premiums demanded in a tightening market. In this conceptual framework, we discuss how the pre-emptive environmental investments could be a compensating differential of pecuniary wages for workers in the heightened labor market competition. We discuss the detailed model and results in Appendix Section A.1 and summarize them in this section.

We consider a two-stage game between an incumbent firm i and a potential entrant firm n competing for workers in the same labor market. When a new plant announces its entry (Stage 1), the incumbent firm makes a strategic choice of environmental investment, so that the lowered pollution emissions could serve as non-pecuniary benefits to attract and retain workers, instead of them competing purely on wages, as labor market competition occurs in Stage 2.

We assume that workers' utility consists of both pecuniary wages and the non-pecuniary benefits of a clean working environment. In this framework, environmental quality serves as a strategic substitute for wage payments. Workers value reduced toxic exposures for both

health and environmental reasons,[7] creating a compensating differential mechanism. As a result, firms that emit fewer toxins can attract workers while offering comparatively lower wages.

Assume a unit mass of workers is allocated between firms according to linear demand functions in labor share L_i and L_n:

$$L_i = \frac{1}{2} + \alpha[(w_i - w_n) + \theta(\tau_n - \tau_i)] \tag{2}$$

$$L_n = \frac{1}{2} + \alpha[(w_n - w_i) + \theta(\tau_i - \tau_n)] = 1 - L_i \tag{3}$$

These equations imply that two identical firms would initially split the available workforce evenly, giving each a baseline 50% share of the market. A firm increases its share above this baseline by setting wages and toxic levels to provide a higher utility than its competitor. This can be achieved either by paying higher wages ($w_i - w_n > 0$) or by maintaining lower toxic emission levels ($\tau_n - \tau_i > 0$). The actual number of workers a firm attracts depends on the specific sensitivity of workers to these differences (α) and how strongly they value environmental quality (θ), implying that a cleaner firm can attract workers even with slightly lower wages when environmental preference is sufficiently high.

In this setting, incumbent plants choose an environmental investment level ($C(\tau_i)$) in stage 1 to maximize total payoff realized after new plants open in stage 2, where they can maximize profits without increasing wages indefinitely. The total payoff (Π) to incumbent plants is the profit (π) the firm knows it will get when the labor market competition is realized in stage 2, given the emission levels, minus the abatement cost ($C(\tau_i)$) incurred in stage 1. In this model, the firm's profit maximization is driven by wage cost savings, which are exclusively achieved by the environmental investment by firms. Therefore, incumbents select the optimal toxic release level to balance the cost of abatement against the future

[7] Workers value reduced toxic exposures for several reasons, such as: (1) health concerns and risk aversion regarding toxic exposure; (2) environmental preference intensity; (3) proximity to emission sources; and (4) community environmental quality concerns. Workers are willing to accept lower wages at firms with lower toxic releases because reduced exposure provides direct health benefits and improved environmental quality.

benefit of lower wage bills.

Solving for the equilibrium yields the optimal abatement level for incumbent plants:

$$a_i^* \equiv \bar{\tau} - \tau_i^* = \frac{3\theta}{9\gamma - 2\alpha\theta^2} \tag{4}$$

This result confirms that strategic abatement is strictly positive provided that workers value environmental quality ($\theta > 0$). The equation reveals that the incumbent's incentive to reduce emissions (a_i^*) exists specifically because it allows them to compete for labor share against the entrant. The theoretical model predicts that incumbent firms will strategically reduce toxic releases when facing anticipated labor market competition. This theoretical prediction is consistent with our main results that incumbent plants reduce toxic releases after announcement of large new plant openings.

To understand whether the labor market competition threats are driving factors, we further examine the determinants of this strategic response through comparative statics. First, optimal abatement (a_i^*) is strictly increasing in the sensitivity of labor supply to utility differences (α) and the intensity of workers' environmental preferences (θ). Second, the incumbent abates more aggressively when it faces a cleaner entrant (lower τ_n). Intuitively, the marginal benefit of abatement is rises relative to the cost when the labor market is competitive, workers are environmentally conscious, and the rival firm is expected to offer a greener alternative. Based on this theoretical predictions, we conduct empirical tests to examine whether expected labor market competition is a driving factor of firms' environmental investment decisions after the announcement of large new plant openings.

4.2.2 Labor market competition channel

We start with exploring potential mechanisms through expected changes in competition in the local labor market. Following the entry of a new plant, incumbent firms may face increased pressure in local labor markets, both from agglomeration effects and from direct

competition for workers. Prior research has shown that large-scale plant openings can enhance labor market competition by raising local wage floors, increasing demand for skilled workers, and reducing worker availability for existing firms (Greenstone et al. (2010), Kline and Moretti (2014)).

In response, incumbent firms may adjust their environmental performance strategically. On one hand, increased labor competition may incentivize firms to become more emission-efficient to bolster their reputation as desirable employers, particularly in a tighter labor market where worker preferences for environmental responsibility may matter (Flammer (2015), Colonnelli et al. (2025), Rice and Schiller (2023)). On the other hand, some firms may respond by increasing output to remain competitive, potentially at the cost of higher emissions.

In this section, we examine whether potential labor market tightening following new plant openings affects the environmental behavior of incumbent plants, and whether these responses vary depending on the local labor market context. In Table 4, we perform cross-sectional heterogeneity analyses based on the main results presented in Table 2. To be specific, this is done by estimating Poisson regressions using Equation 1, replacing 'Winner' with a different treatment variable, which varies by measurement of labor market competition. We define different level of expected labor market competition in four ways: existing labor market competition, and skill and job similarity between incumbent and new plants.

First, we examine whether the positive environmental impact of large new plant announcements depends on the level of labor market concentration in the industry that the new plant is expected to affect. When a new plant is announced in an industry with an already competitive local labor market, it may signal an impending tightening of labor supply once the plant becomes operational. In response, incumbent plants may preemptively adjust their environmental practices in anticipation of heightened labor competition, aiming to attract and retain workers.

In column (1), we categorize new plant entry events based on the labor market concentration, measured by the Herfindahl-Hirschman Index (HHI), within the same NAICS 4-digit industry at the county level in the year prior to the entry. Specifically, we calculate the labor HHI for each entry announcement, defined as the concentration of employment among firms in the same 4-digit NAICS industry within the county. We then split the large plant opening events into 'high' and 'low' labor market concentration groups, where 'high' indicates HHI values above the annual median and 'low' indicates values below the median. The results show that incumbent plants in the winning counties are more likely to reduce toxic releases when the new plant is announced to open in an already competitive local labor market. The coefficients of 'Winner$_{high}$ × Post' and 'Winner$_{low}$ × Post' are statistically significantly different at a 95% confidence level.

Next, we try to capture more specific labor market competition incumbent plants are expected to face by using the similarity of the labor pool with the new plants. First, we measure the expected labor market competition by incumbent firms by measuring the similarity of the job composition of workers between incumbent and new plants' industries. Incumbent plants would expect a higher labor competition if they share the same pool of labor, which would incentivize those plants to adjust their environmental behavior to prepare for such a change after new plants open. We divide the incumbent plants in winning counties into three equal groups based on job composition similarity. As shown in column (2), incumbent plants in winning counties are more likely to reduce their toxic releases if they share a similar job composition with the new plants. Coefficients of 'Winner$_{high}$ × Post' and 'Winner$_{low}$ × Post' are statistically significantly different at a 95% confidence level. We observe a bigger divergence between 'Winner$_{high}$' and 'Winner$_{low}$' in regression results using the similarity of high-skilled job composition in column (4), which supports our assumption that high-skilled workers have higher environmental preferences than low-skilled workers.

Second, as an alternative to job composition similarity, we use the similarity of required skill sets to measure expected labor market competition by incumbent firms. This is under

the assumption that workers may switch jobs if the skill sets are similar to each other, e.g., academic researchers and data scientists. Similar to what we did in column (2), in column (4), we take the composition and proportion of each occupation in each industry from OESM and calculate the Mahalanobis distance of the job composition of incumbent and new plants' industry in either 5- or 4-digit NAICS codes. We take average required skill elements for jobs in each industry from OESM and calculate the Mahalanobis distance of skill sets of incumbents and new plants' industry in either 5- or 4-digit NAICS codes. We divide the incumbent plants in winning counties into three equal groups based on skill similarity. The results show that the effect of large plant opening announcement on incumbent plants with high skill similarity of new plants is higher and statistically more significant than the ones with low similarity.

One might wonder why incumbent plants choose to allocate more resources toward improving environmental performance, albeit starting with relatively low-cost abatement efforts in the early years, instead of simply offering higher wages. This question becomes especially relevant given that large plant openings intensify competition for skilled labor (Greenstone et al. (2010)) and they can be attracted by positive environmental practices by firms (Flammer (2015), Schauf and Schoonjans (ming)). To explore this, we further examine whether the incumbent plants' environmental decisions differ depending on the skill level of their employees. The new plant often requires a highly skilled workforce to operate, paying above-average wages, for which incumbent plants need to respond competitively to retain their skilled workers. Besides higher wages, for which it is already often high for skilled workers, enhanced working conditions have been proved to be a tool for plants to attract skilled workers (Flammer (2015), Colonnelli et al. (2025)).

In columns (3), we divide incumbent plants by their NAICS 4-digit average skill level. We define incumbent plants belong to industries that belong to a higher- or lower-than-annual national median one year before the announcement. Skill level of the industry is the weighted average of skill level in each job in the industry. We observe plants with higher

proportion reduce the toxic releases significantly unlike the ones with lower proportion. The coefficients of 'highest × post' and 'lowest × Post' are statistically significantly different in 95% confidence level.

Overall, the results show that when a new plant is announced, it can tighten the local labor market, prompting existing firms to adapt. To attract and retain workers, especially in already competitive or low-unemployment areas, incumbent firms often improve their environmental performance by reducing toxic emissions. Overall, the findings suggest that heightened labor market pressure motivates firms to become greener as a way to stay competitive for talent.

4.2.3 Workers' environmental preferences channel

In this section, we test whether incumbents' environmental decisions vary with workers' environmental preferences. Consistent with our conceptual framework, we hypothesize that incumbent plants strategically reduce toxic releases in anticipation of heightened labor market competition, particularly when their workforce values a clean environment. By committing to a cleaner environment, firms can offer a form of non-pecuniary compensation, allowing them to remain competitive in the labor market without indefinitely increasing wages. To capture worker preferences, we rely on two proxies: the worker skill mix and congressional voting records on environmental bills.

First, following previous literature,[8] e use worker skill level as a proxy, assuming that high-skilled workers value quality of life and environmental amenities in addition to pecuniary earnings. If incumbents' actions are strategic, we expect to find larger reductions in toxic releases at plants with a higher proportion of high-skilled workers. To test this, we examine the differential reactions of incumbent plants in winner counties based on their dependence

[8] Flammer (2015), Burbano (2016), Schauf and Schoonjans (ming), Colonnelli et al. (2025), Krueger et al. (2025)

on high-skilled labor. We divide plants into a 'low-skill' group (industry-level proportion of high-skilled workers $< 10\%$) and a 'high-skill' group (proportion $> 50\%$)

As shown in the left panel of Figure 2, the relative reduction in toxic releases (comparing winner to runner-up counties) is significantly larger for incumbent plants in the high-skill group. Conversely, the relative reduction for plants in the low-skill group is smaller. The difference between these two relative reductions is statistically significant at the 90% confidence level.

Next, we employ a more direct measure of local environmental preferences: congressional voting outcomes on environmental bills. Assuming that representatives' voting records reflect the preferences of their constituents,[9] we define counties as having 'high pro-environment voting' if their population-weighted proportion of pro-environmental votes in the prior year exceeds the national median. We hypothesize that incumbents' pollution reduction will be greater in deals where the winning county is more pro-environment.

Panel (b) of Figure 2 supports this hypothesis. We find a larger relative reduction in toxic releases for incumbent plants located in winning counties with high pro-environmental voting outcomes. This difference in environmental response, compared to plants in low-preference counties, is statistically significant at the 90% confidence level.

4.2.4 Green competition channel

In this subsection, we examine the differential reactions of incumbent plants in winning counties, conditional on the expected environmental performance of the new entrant. Consistent with our conceptual framework, we hypothesize that incumbents are more likely to strategically use a clean environment as non-pecuniary compensation if the new plant is expected to be a clean competitor (i.e., have lower emissions than their own). A cleaner working environment at the new plant increases its substitutability for the incumbent, strengthen-

[9] We take the crosswalk between counties and congressional districts from Ferrara et al. (2024).

ing its ability to attract workers in the anticipated heightened labor market competition. Therefore, we expect incumbent plants to reduce toxic emissions more substantially when they anticipate competition from a cleaner new plant.

To measure incumbents' expectations of the new plant's emissions, we use two proxies: industry-level and parent-firm-level. First, under the assumption that incumbents expect the new facility to have an emissions profile similar to its industry peers, we use the median emissions of the new plant's industry during the three years pre-announcement. We classify incumbents as 'expecting a cleaner new plant' if their own average emissions over the past three years are higher than this industry-level median. Incumbents whose emissions are already below this median are classified as 'expecting a browner new plant'. As shown in panel (a) of Figure 3, incumbent plants that expect a cleaner competitor demonstrate a larger relative reduction in toxic releases (compared to their counterparts in runner-up counties) after the announcement.

Second, we use a parent-firm-level proxy to refine this expectation. We identify all other plants (sister plants) belonging to the new facility's parent firm and calculate the median of their average emissions during the three years prior to the announcement. We again define incumbents as 'expecting a cleaner new plant' if their own past three-year average emissions exceed the median emissions of these sister plants. Panel (b) of Figure 3 confirms this finding. We observe a larger reduction by incumbents expecting cleaner new entrants. Furthermore, this effect is statistically significantly larger than the reduction observed for incumbents expecting a browner new plant (at the 95% confidence level).

4.3 Impact on wages and worker-turnover after new plant opening

In this section, we discuss whether incumbent plants were successfully competitive in the labor market if they changed environmental behaviors after new plants opened. We test this in two ways: compensation and separation of workers. In the heightened labor market

competition, instead of increasing wages indefinitely, plants would use good environmental conditions as a non-pecuniary compensation to workers. If the reduction in toxic releases were successful for incumbent plants to be competitive in the labor market, they are not expected to experience a significant increase in wages and not a leave by workers to the new plants. This tendency is mainly expected in high-skilled employees, given that they are the ones who are more expensive and who care about the quality of life, besides the wage incomes relative to those of low-skilled workers.

4.3.1 Impact on wages

We study how the labor costs change in winning counties compared to losing counties of deals after new large plants are supposedly opened. To capture the changes in labor costs after the realization of labor market change, we analyze the compensation firms pay to employees between four and seven years after the announcement of deals, compared to three years before the announcement. In Table IA.7, we first test the average change in labor costs after the openings of new plants. To be specific, this is done by estimating Poisson regressions using Equation 1, replacing the dependent variable with total compensation by each individual and the 'Post' dummy with a variable that captures the years after the openings of new plants. We observe that the total compensation of employees increases on average, but such an increase is highly concentrated among the high-skilled workers. Total compensation of high-skilled workers in incumbent plants in winning counties increased by about 5.4% relative to those in the runner-up counties. We note that the data has a better coverage of high-skilled workers rather than low-skilled workers, which allows us a better estimation of high-skilled workers, who value both pecuniary and non-pecuniary compensations (Krueger et al. (2025), Colonnelli et al. (2025)).

To understand the financial implications of corporate environmental investments in anticipation of entry threat, we next test the differential effect of environmental adaptation following announcement of new plant openings on compensation changes after the opening

of large new plants. We define plant-level average change in toxic releases before and after three years of the deal announcements, and define plants as 'emission reduction' if the average amount of toxic emissions before the deal is less than that after the deal. To be specific, this is done by estimating Poisson regressions using Equation 1, replacing 'Winner' with a different treatment variable that varies by adaptation of toxic releases after announcements, and replacing the dependent variable with total compensation by each individual. We divide incumbent plants in winning counties into those that reduced toxic releases and the rest of the plants.

As shown in column (1), Table 5, we find that plants that did not adapt their environmental behaviours after announcements of new plant openings experience an increase in labor costs for employees by about 7.1% compared to incumbent plants in runner-up counties. On the other hand, the incumbent plants that reduced toxic emissions do not show a significant change in labor costs for new hires or positions. The difference between the coefficients of 'Emission-non-reduction × Post' and 'Emission-reduction × Post' is statistically significant at 90% confidence level (p-value=0.051). The results imply that incumbent plants that made strategic investments in environmental quality successfully avoided a significant increase in labor costs after the new entrants started operating in the locality.

We next study the differential effect of environmental behaviors by incumbent plants on labor costs by the type of workers. In columns (2) and (3), we repeat the specification in column (1) while sample individuals are divided depending on high- and low-skilled ones, following the ONET classification of roles in five zones, where jobs above zone 3 are defined as high-skilled. The result shows that the increase in compensation is mainly focused on high-skilled workers, where the effect of emission-reduction is statistically significant at 95% confidence interval (p-value=0.046). The results support the argument that incumbent plants successfully defended their bargaining power in the labor market after the new plant openings.

To address a concern of the limited coverage on Revelio Lab,[10] we conduct robustness test using industry-level average annual wage information using Quarterly Census of Employment and Wages (QCEW). The analysis in Table 5 is repeated in industry-level. Accordingly, we divide incumbent plants depending on its industry's proportion of high-skilled workers in the year before the announcement. In Table IA.8, we find a consistent result that average annual pay increases particularly for industries who did not reduce emissions after the announcement. Such tendency is mainly focused on industries with higher proportion of high skill workers.

4.3.2 Impact on worker retention

Next, we move on to study whether incumbent plants were successful in retaining their workers by improving environmental conditions. The purpose of this analysis is to make sure the low wage growth is not due to plants losing good employees. We repeat the same specifications as in Table 5, replacing the dependent variable with a dummy variable which is one if a person leaves the company in the next year. As shown in Table 6, we observe that incumbent plants in winning counties experience an increase in turnover ratio of workers after new plants open; however, such an effect is concentrated in firms that did not successfully reduce emissions after the announcement. A differential effect on turnover ratio is distinctively larger for high-skilled workers than for low-skilled workers. This is consistent with our assumption that the high-skilled workers are more likely to take a clean working environment as non-pecuniary amenities, relative to low-skilled workers.

These results show that the incumbent plants successfully retain their talented workers by adjusting environmental behaviors. Such pre-emptive adjustment provided a signal of long-term commitment to workers. Incumbent plants used this precautionary environmental investment as non-pecuniary compensation to attract high skilled workers so that they could

[10]This tracts individual workers via LinkedIn, which by nature contains a significantly higher number of high-skilled workers than low-skilled workers.

stay competitive in the labor market.

4.4 Alternative explanations

So far, the results suggest that incumbent plants reduce their toxic releases as a forward-looking strategy in anticipation of changes to the local economy following the entry of new plants. In this subsection, we explore the alternative mechanisms that may drive these strategic environmental decisions. Specifically, we examine three potential channels: tightening product market competition, knowledge spillovers from the incoming plants (Bloom et al., 2019), and increased regulatory stringency.

Other stakeholders' preferences Given that new plant openings have an agglomeration effect in the local economy (Greenstone et al. (2010)), one might question whether the reduction in toxic releases is a by-product of the incumbent plants' endeavor to reduce general environmental footprint for stakeholders other than employees, for example, to signal corporate responsibility to new supply chain partners or as a result of investor pressure. To test whether this alternative explanation holds, we examine off-site releases by incumbent plants after plant opening announcements instead of on-site emissions. If incumbent plants reduce toxic releases for labor market competition, we expect to see a marginal reduction in off-site emissions, unlike for on-site emissions. Workers directly experience on-site toxic releases like air emissions, water discharges, and land contamination through their daily exposure at the workplace and residence in the local community. In contrast, off-site waste transfers, the toxic materials shipped to other facilities for treatment or disposal, do not affect local environmental amenities but do contribute to the firm's overall environmental footprint. We repeat Equation 1 by replacing the dependent variable with off-site releases and report regression results in column (1), Table 7. We find no significant change in off-site waste transfers.

Furthermore, we decompose on-site emissions by medium: air, land, and water. As shown

in columns (2)-(4) in Table 7, we divide on-site emissions by medium and repeat the same specification as in Equation 1. Air emissions, which is the most visible and directly experienced form of pollution by employees, show the largest decline (14.8%), while water and land emissions show more modest reductions. This gradient by visibility further supports workers' environmental preferences as the driving force. Overall, this differential response is inconsistent with mechanisms driven by supply chain formation, investor pressure, or corporate environment concerns, all of which emphasize total environmental footprint regardless of location.

Knowledge spillover effect Another potential mechanism for the observed environmental improvements is knowledge spillovers from the incoming plant, such as the diffusion of cleaner technologies or best practices Bloom et al. (2019). However, in this setting, the new facility has not yet begun operations at the time when incumbent plants begin adjusting their environmental behavior. As a result, direct knowledge spillovers are unlikely to be driving these early changes, since the new plant has not yet introduced new technologies, practices, or workforce dynamics into the local industrial environment.

Regulatory enforcement Expectations around future environmental regulatory enforcement may affect toxic release decisions of incumbent plants. On one hand, the entry of a large plant could increase future enforcement within the county, as such facilities undergo environmental review by the EPA to assess their potential regional impact. Anticipating stricter oversight, incumbent firms may respond by reducing emissions. On the other hand, the fact that large plants are often attracted through local tax incentives and subsidies, despite their potential negative impact on the local environment, may signal regulatory leniency. In this case, incumbent firms may expect looser enforcement and thus feel less pressure to reduce emissions, or may even increase them.

In Table 8, columns (1) and (2), we conduct Equation 1, dividing deals depending on the non-attainment status of winner counties. Non-attainment status is a federal designation

by EPA when the county has air pollution levels that exceed the National Ambient Air Quality Standards (NAAQS) for one or more criteria pollutants (like ozone, PM2.5, NO2), which requires the counties to have State Implementation Plan (SIP) to reduce excessive air emissions. Empirical results show that the toxic releases decisions by incumbent plants do not differ depending on the regulatory environment of counties. The coefficients of 'Post $\times$ Winner' of column (1) and (2) are statistically insignificant (t-statistics of -0.787).

Next, in columns (3) and (4) of Table 8, we test whether the environmental regulatory enforcement changes after the announcement of new plant openings. We run Equation 1 by replacing the dependent variable with the number of EPA enforcement actions for a plant i. These enforcement actions are not related to TRI reporting compliance, but instead reflect federal administrative or judicial cases filed under major environmental statutes.[11] The results show no statistically significant change in enforcement for incumbent plants in winning counties relative to those in losing counties, even when firms increase toxic releases. This suggests that the observed reduction in toxic releases is not driven by increased regulatory pressure. This further supports the interpretation that incumbent plants reduce toxic releases not in response to direct regulatory pressure, but as a forward-looking strategy to prepare for anticipated changes in the labor market competition. The absence of formal non-attainment reclassification or increased EPA enforcement reinforces the conclusion that firms acted preemptively rather than reactively.

[11]Environmental statutes include the Clean Air Act (CAA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), the Emergency Planning and Community Right-to-Know Act (EPCRA) Section 313, the Toxic Substances Control Act (TSCA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund), the Safe Drinking Water Act (SDWA), and the Marine Protection, Research, and Sanctuaries Act (MPRSA).

5 Conclusion

This paper investigates whether firms engage in preemptive investment in environmental quality in response to expected changes in the conditions of competition. Utilizing announcements of large plant openings as a quasi-natural experiment, we provide the first empirical evidence that incumbent plants use irreversible abatement investments strategically as a credible pre-commitment device. Specifically, we show that in anticipation of a new entry, incumbent manufacturing plants in winning counties reduce their on-site toxic releases by 9.3%, doing so through capital-intensive and irreversible process and production modifications without suffering a loss in economic output.

Our findings isolate anticipated, intensified local labor market competition as the primary channel driving this strategic response, effectively excluding alternative explanations such as regulatory pressure or product market competition. Because large plant openings threaten a firm's essential inputs by tightening the supply of skilled labor and placing upward pressure on local wages, incumbents face a critical need to retain their workforce. Under the framework of compensating wage differentials, these firms deploy a cleaner production process to provide a non-pecuniary amenity that directly substitutes for the higher pecuniary compensation workers would otherwise demand. Crucially, unlike flexible wage premiums that a firm can easily reverse, these abatement investments are costly, irreversible, and publicly verifiable. This allows them to function as a credible, permanent commitment to workplace environmental quality, successfully locking in the labor supply.

Consequently, we observe that incumbents making these preemptive environmental improvements successfully secure their workforce while experiencing the limited long-term wage increases that are typically triggered by a major new entrant in the labor market. The reduction in emissions successfully prevents high-skilled worker departures, indicating that environmental quality is an effective tool for talent retention.

Ultimately, this research demonstrates that abatement activities need not be viewed merely as a cost to be minimized under external regulatory or market constraints. Instead, the competition for human capital acts as a powerful market-based mechanism, where firms strategically optimize their private benefits through voluntary environmental improvements. This preemptive corporate environmentalism shows that economic development and labor dynamics can organically align firm competitiveness with broader environmental goals.

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Appendix

A.1 Conceptual Framework

We develop a theoretical framework to analyze strategic toxic release decisions under labor market competition. We model a two-stage game where incumbent firms anticipate entry and choose emission levels before competing for workers who value environmental quality. Our key innovation lies in treating toxic releases as directly observable characteristics that allow firms to economize on wage costs through compensating differentials, a mechanism grounded in labor economics theory but not previously applied to emission strategy. We focus on toxic release levels because emissions data from mandatory reporting systems like the EPA's Toxics Release Inventory (TRI) provide objectively verifiable measures of environmental performance. Through public databases, workers can directly observe this information and assess its impact on their well-being.

Our theoretical framework provides a specific mechanism, labor cost savings through lower toxic releases, that can explain observed correlations between environmental performance and firm outcomes.[1] The compensating differentials literature examines how non-wage job characteristics affect worker sorting and wage determination (Rosen, 1974). Classical theory predicts that workers will accept lower wages in exchange for superior non-pecuniary job attributes, including lower exposure to toxic chemicals and cleaner work environments. We extend this framework to strategic competition where firms choose both wages and emission levels, demonstrating how lower toxic releases can serve as a strategic substitute for wage payments.

Setup and Model Assumptions

We consider a two-stage game between an incumbent firm i and a potential entrant firm n competing for workers in the same labor market. The timeline is as below:

1. **Stage 1 (Emission Decision):** The incumbent observes an entry announcement by firm n with emission level τ_n and chooses its own toxic release level $\tau_i \in [0, \bar{\tau}]$ at abatement cost $C(\tau_i)$, where $\bar{\tau}$ represents baseline emissions with no abatement.

2. **Stage 2 (Labor Competition):** Both firms simultaneously compete for workers by setting wages (w_i, w_n), given emission levels (τ_i, τ_n).

[1] Our model operates in partial equilibrium, focusing exclusively on the strategic interaction between emission choices and wage competition. This allows us to isolate the compensating differential mechanism. However, we abstract from general equilibrium effects documented in the literature, particularly aggregate wage increases driven by agglomeration externalities from new plant entry (Greenstone et al., 2010). In our empirical predictions, we explicitly account for this distinction: our model predicts *relative* wage differences between cleaner and dirtier firms, not absolute wage levels. When a large new plant enters, all wages may rise due to agglomeration, but within that aggregate increase, cleaner firms should experience smaller wage growth than their dirtier competitors.

In this setup, we show that firms share an equal amount of labor if they pay the same wages and emit the same amount of pollution. On the other hand, if a firm makes a smaller amount of emissions, it can use that as compensation for pecuniary wages. In this section, we explain the model assumptions in detail.

Assumption 1 (Linear Labor Demand with Compensating Differentials). A unit mass of workers is allocated between firms according to linear demand functions, where both wages and a clean environment as factors of labor supply. Incumbent and new firms have a labor share (L):

$$L_i = \frac{1}{2} + \alpha[(w_i - w_n) + \theta(\tau_n - \tau_i)] \tag{A.1}$$

$$L_n = \frac{1}{2} + \alpha[(w_n - w_i) + \theta(\tau_i - \tau_n)] = 1 - L_i \tag{A.2}$$

where $\alpha > 0$ captures wage sensitivity, i.e., elasticity of labor supply with respect to total compensation differences between the incumbent firm and the new entrant. $\tau_k \geq 0$ represents firm k's toxic release level (lower values indicate cleaner firms). $\theta > 0$ represents the compensating differential rate which is the wage reduction a firm can offer while maintaining the same attractiveness to workers when its toxic releases are one unit lower than competitors. For the market stability condition, a slight increase in τ or α does not instantly capture the entire labor pool ($\alpha\theta < \frac{1}{2}$). $\alpha\theta$ represents the intensity of environmental competition, where higher labor market competitiveness amplifies the strategic value of lower emissions, and abatement incentives increase with both worker mobility and environmental preferences.

In this labor demand function, compensating differentials exist where pecuniary wages can be compensated by the non-pecuniary benefits of a clean environment. To be specific, workers are willing to accept lower wages at firms with lower toxic releases because reduced exposure provides direct health benefits and improved environmental quality.[2] Therefore, the labor demand specification implies that if firm i has lower toxic releases than firm n (i.e., $\tau_i < \tau_n$), then $\theta(\tau_n - \tau_i) > 0$, which increases firm i's labor supply at any given wage differential.

Assumption 2 (Production Technology). Each firm has a linear production function $q_k = A_k L_k$ where $A_k > 0$ is productivity and L_k is labor input. Output sells at unit price (normalized to 1). Also, $A_i, A_n > \frac{1}{2\alpha}$. This ensures positive wages.

Assumption 3 (Abatement Cost). The cost of achieving toxic release level τ_i is given by:

$$C(\tau_i) = \frac{\gamma(\bar{\tau} - \tau_i)^2}{2} \tag{A.3}$$

where $\bar{\tau} > 0$ represents baseline emissions with no abatement and $\gamma > 0$ represents the cost parameter. This specification captures: (1) zero cost at baseline: $C(\bar{\tau}) = 0$; (2) increasing marginal

[2]This captures various reasons for workers to value a clean environment provided by the firms, such as health concerns and risk aversion regarding toxic exposure in workplaces, proximity to emission sources in workplaces, or general environmental preference intensity for the community.

cost of abatement: $C'(\tau_i) = -\gamma(\bar{\tau} - \tau_i) < 0$ for $\tau_i < \bar{\tau}$; and (3) convex costs: $C''(\tau_i) = \gamma > 0$. Further, we assume $\gamma > \frac{2\alpha\theta^2}{9}$. This ensures the concavity of the abatement problem.

Equilibrium Analysis

Based on the model assumptions discussed above, we solve for the sub-game perfect Nash equilibrium by backward induction in this section. In Stage 2, firms engage in Bertrand competition for workers given emission levels (τ_i, τ_n). In Stage 1, the incumbent anticipates Stage 2 outcomes and chooses the optimal toxic release level.

- Stage 2: Labor Market Competition

  Given toxic release levels (τ_i, τ_n) from Stage 1, firms simultaneously choose wages to maximize profits:

$$\max_{w_k} \pi_k = (A_k - w_k)L_k(w_i, w_n; \tau_i, \tau_n) \tag{A.4}$$

  Theorem 1 (Labor Market Equilibrium). The unique Nash equilibrium in Stage 2 features wages:

$$w_i^*(\tau_i, \tau_n) = \frac{2A_i + A_n}{3} - \frac{1}{2\alpha} - \frac{\theta(\tau_n - \tau_i)}{3} \tag{A.5}$$

$$w_n^*(\tau_i, \tau_n) = \frac{A_i + 2A_n}{3} - \frac{1}{2\alpha} + \frac{\theta(\tau_n - \tau_i)}{3} \tag{A.6}$$

  Equilibrium labor allocations are:

$$L_i^*(\tau_i, \tau_n) = \frac{1}{2} + \frac{\alpha}{3}[(A_i - A_n) + \theta(\tau_n - \tau_i)] \tag{A.7}$$

$$L_n^*(\tau_i, \tau_n) = \frac{1}{2} + \frac{\alpha}{3}[(A_n - A_i) - \theta(\tau_n - \tau_i)] \tag{A.8}$$

  Equilibrium profits are:

$$\pi_i^*(\tau_i, \tau_n) = \frac{[L_i^*(\tau_i, \tau_n)]^2}{\alpha} \tag{A.9}$$

$$\pi_n^*(\tau_i, \tau_n) = \frac{[L_n^*(\tau_i, \tau_n)]^2}{\alpha} \tag{A.10}$$

  The equilibrium demonstrates the compensating differential mechanism for toxic releases. In the symmetric case ($A_i = A_n$), when firm i has lower toxic releases than firm n (i.e., $\tau_i < \tau_n$), it pays wages that are $\frac{2\theta(\tau_n - \tau_i)}{3}$ lower while attracting more workers. Lower toxic exposure directly substitutes for wage payments, moderated by competitive forces. Workers accept lower wages in exchange for cleaner, healthier work environments with reduced toxic exposure.

- Stage 1: Strategic Toxic Release Decision

Anticipating Stage 2 outcomes, the incumbent chooses toxic release level to maximize total payoffs:

$$\max_{\tau_i \in [0,\bar{\tau}]} \Pi_i(\tau_i) = \pi_i^*(\tau_i, \tau_n) - C(\tau_i) \tag{A.11}$$

Theorem 2 (Optimal Toxic Release Level). In the symmetric case ($A_i = A_n$, $\tau_n = \bar{\tau}$, where the entrant has baseline emissions), the incumbent's optimal toxic release level is:

$$\tau_i^* = \bar{\tau} - \frac{3\theta}{9\gamma - 2\alpha\theta^2} \tag{A.12}$$

Equivalently, the incumbent's optimal abatement (reduction from baseline) is:

$$a_i^* \equiv \bar{\tau} - \tau_i^* = \frac{3\theta}{9\gamma - 2\alpha\theta^2} \tag{A.13}$$

Results

Labor market competition alone drives voluntary toxic release reduction through the compensating differentials mechanism. Firms reduce emissions not because of regulatory mandates, but because doing so allows them to attract workers at lower wages. This bring us to the first proposition.

Proposition 1 (Voluntary Emission Reduction). When workers have preferences for environmental quality ($\theta > 0$), the incumbent optimally reduces toxic releases below baseline ($\tau_i^* < \bar{\tau}$) even without environmental regulation.

The incumbent's optimal toxic release level τ_i^* depends on the environmental preferences of workers and the wage-emission sensitivity of workers. Firms emit less (lower τ_i^*) when workers care more about the environment and when labor markets are more competitive. This leads us to the following proposition:

Proposition 2 (Comparative Statics of Toxic Releases) The incumbent's optimal toxic release level τ_i^* is:

1. Decreasing in environmental preference intensity: $\frac{\partial \tau_i^*}{\partial \theta} = -\frac{27\gamma + 6\alpha\theta^2}{(9\gamma - 2\alpha\theta^2)^2} < 0$
2. Decreasing in wage sensitivity: $\frac{\partial \tau_i^*}{\partial \alpha} = -\frac{6\theta^3}{(9\gamma - 2\alpha\theta^2)^2} < 0$

Proposition 3 (Green Competition). Incumbents strategically reduce toxic releases when facing cleaner entrants. Specifically, the incumbent's optimal emission level responds positively but incompletely to the entrant's emission level:

$$\frac{d\tau_i^*}{d\tau_n} = \frac{2\alpha\theta^2}{9\gamma - 2\alpha\theta^2} \in (0, 1) \tag{A.14}$$

This partial response implies that when the entrant becomes cleaner (lower τ_n), the incumbent reduces its own emissions (lower τ_i^*), but the emission gap $G = \tau_n - \tau_i^*$ narrows rather than remains constant:

$$\frac{dG}{d\tau_n} = \frac{9\gamma - 4\alpha\theta^2}{9\gamma - 2\alpha\theta^2} > 0 \tag{A.15}$$

This result reveals the strategic nature of environmental competition in labor markets. When a cleaner competitor enters the market, the incumbent faces increased pressure to reduce emissions because: (1) the cleaner entrant becomes more attractive to environmentally-conscious workers, reducing the incumbent's labor market share; (2) each unit of incumbent abatement generates greater competitive advantage when the competitor is cleaner; and (3) the marginal benefit of emission reduction increases as the emission gap widens. However, the incumbent's response is incomplete ($\frac{d\tau_i^*}{d\tau_n} < 1$) because abatement costs are convex—as the incumbent reduces emissions further, the marginal cost of additional abatement increases. The optimal response balances the strategic benefit of narrowing the emission gap against rising marginal abatement costs.

Given the compensating differentials between wages and emissions, the lower toxic releases enable relative wage cost savings. The wage differential

Proposition 4 (Toxic Releases and Relative Wage Costs). In the symmetric case, the wage differential is:

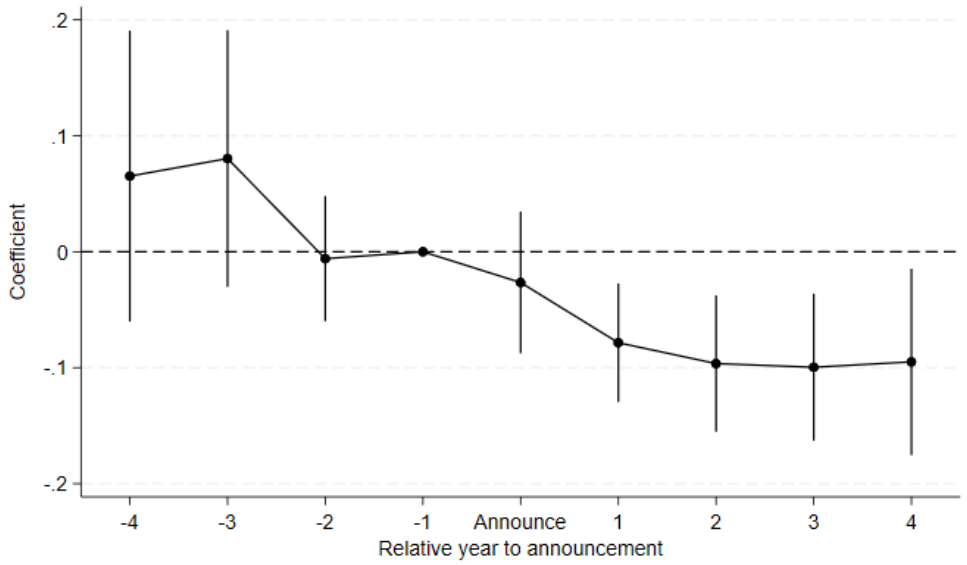
$$w_n^* - w_i^* = \frac{2\theta(\tau_n - \tau_i)}{3} > 0 \tag{A.16}$$

If firm i has toxic releases $\tau_i < \tau_n$, it pays wages that are $\frac{2\theta(\tau_n - \tau_i)}{3}$ lower than a competitor with higher emissions while maintaining the same labor market share.

This formalizes the compensating differentials mechanism: lower toxic releases directly substitute for wage costs, providing a clear economic incentive for voluntary pollution reduction. Workers rationally accept lower wages in exchange for reduced toxic exposure, which provides direct health benefits and improved environmental quality.

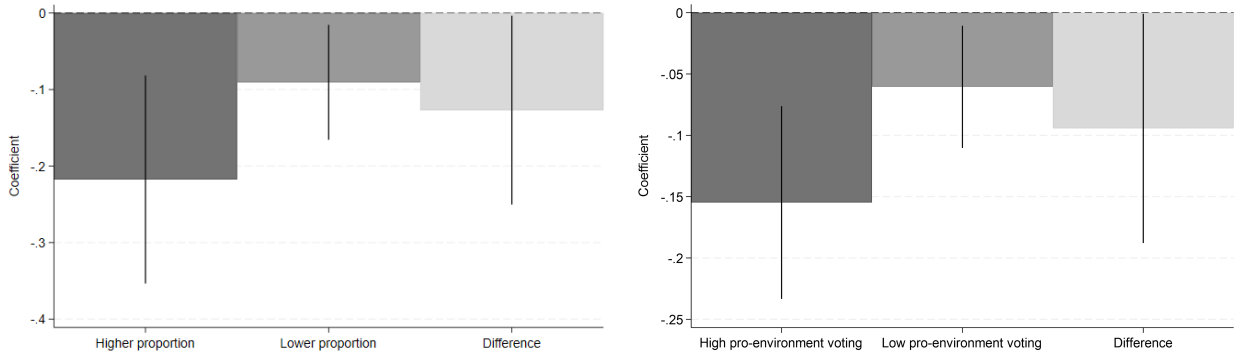
Figures

Figure 1: Impact of Announcement of Large Plant Openings on Incumbent Plants' On-site Toxic Releases



Notes: This figure plots the estimated coefficients of Treated $\times$ time$_t$ regressed to total toxic releases, where time$_t$ refers to the relative year to one year before the year of the announcement of the new plant opening. Vertical lines show 90% confidence interval of the point estimations shown in dots. We estimate the dynamic version of stacked-DID regressions, where we include fixed effects of deal-by-year and deal-by-plant. Total toxic release is the summation of all the on-site toxic releases reported to the Toxic Releases Inventory each year per facility. Control variables include GDP growth and the lagged real GDP of the county. GDP growth is the GDP of the county where the facility is located in that year minus that of the previous year, divided by that of the previous year. The sample includes the facilities in manufacturing industries and deals of new plants in manufacturing industries. Standard errors are clustered at the county level, and t-statistics are presented in parentheses.

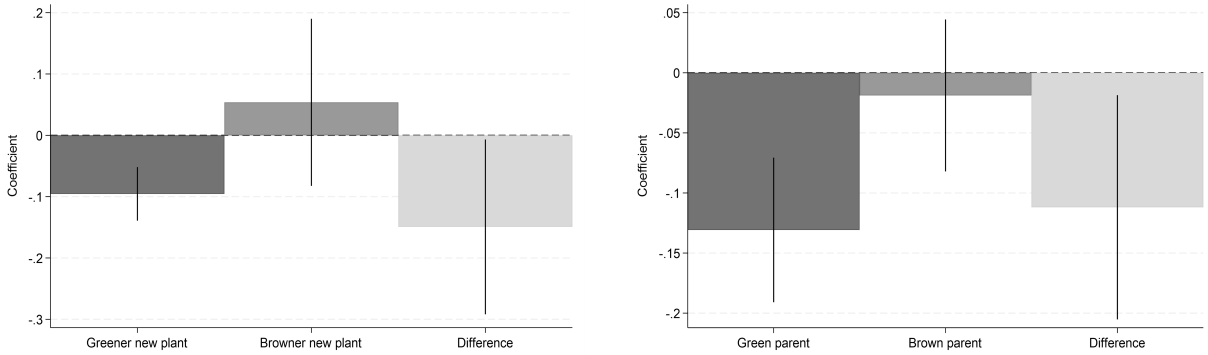
Figure 2: Heterogeneity Based on Environmental Preferences



((a)) Proportion of high-skilled workers **((b))** Pro-environmental voting

Note: This figure reports the coefficients of regressions Equation 1, replacing 'Winner' with a different treatment variable, which varies by measurement of environmental preferences. Bars refer to the point estimations, and vertical lines refer to the confidence interval at the 90% level. 'Higher proportion' refers to the group of incumbent plants in winner counties with their industry-level (NAICS 5-digits) proportion of high-skilled workers being higher than the median within the county in one year before the announcement of the new plant opening. 'Low proportion' refers to the rest of the incumbent plants in the winning counties. 'High pro-environment voting' refers to the winning counties in which the proportion of votes for environmental bills is higher than the median in the year before the announcement of the new plant openings. The rest of the winning counties are defined as 'Low pro-environment voting'. The dependent variable is total toxic releases, which is the summation of all the facilities' toxic releases of the year. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. Fixed effects of deal-by-reporting year and deal-by-plant are included. Standard errors are clustered at the county level.

Figure 3: Heterogeneity based on Expected Toxic Releases of Entrant Plant



((a)) by industry **((b))** by parent firm

Note: This figure reports the coefficients of regressions Equation 1, replacing 'Winner' with a different treatment variable, which varies by measurement of expected emissions of new plants. Bars refer to the point estimations, and vertical lines refer to the confidence interval at the 90% level. 'Greener new plant' refers to the group of incumbent plants in winner counties whose past 3-year average emission is higher than the median plants' past 3-year emission in the same industry as the new plant one year before the announcement. 'Browner new plant' refers to the rest of the incumbent plants in the winning counties. 'Green parent' refers to the group of incumbent plants in winner counties whose past 3-year average emission is higher than the median subsidiaries' past 3-year emission of the parent firm of the new plants one year before the announcement. 'Brown parent' refers to the rest of the incumbent plants in the winning counties. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. Fixed effects of deal-by-reporting year and deal-by-plant are included. Standard errors are clustered at the county level.

Tables

Table 1: Summary statistics

	N	Mean	SD	p10	p25	Median	p75	p90
Total toxic releases (million ton)	129,871	0.04	0.177	0	0	0.001	0.007	0.045
Total air toxic releases (million ton)	129,871	0.024	0.105	0	0	0	0.005	0.031
GDP growth	129,871	0.018	0.042	-0.026	0.001	0.02	0.038	0.06
Real GDP (million)	129,871	100.030	92.543	8.952	25.408	70.231	164.500	278.000
Total population (million)	129,871	1.307	1.612	0.135	0.333	0.628	1.540	3.550
Unemployment ratio of county	129,804	6.819	2.32	4.3	5.1	6.2	8.3	10.2
Non-attainment status of county	129,871	0.69	0.463	0	0	1	1	1
Sales of establishment (million)	10,747	14120	36020	29.3	130.5	1432	8411	36140
Employees of establishment	10,747	550.73	1323.426	0	29	150	450	1329
Sales / Employees of establishment	9,638	177.000	927.900	0.258	1.030	6.914	32.564	155.500
Labor HHI	32,841	3269.119	2855.873	159.6	1131.588	2383.775	4839.848	8391.039
Sales HHI	32,841	4709.56	3118.037	458.24	2336.104	4604.586	6491.715	9971.032
Total compensation (K)	66,258	91.044	74.120	37.868	52.676	77.572	102.794	149.517

Notes: This table reports the summary statistics of the main variables. Total toxic releases is the summation of all the toxic releases reported to the Toxic Releases Inventory each year. Total air toxic releases is the summation of all the air toxic releases reported to the Toxic Releases Inventory each year. Abatement-Operation is the number of abatement activities on good operating processes, and Abatement-Process is the number of abatement activities on process modification of the facility in each year. GDP growth is the GDP of the county where the facility is located in that year minus that of the previous year, divided by that of the previous year. Real GDP, total population, and unemployment ratio are for each of the counties where the facility is located. Non-attainment status is an indicator variable that is one if the county where the facility is located is designated as a non-attainment status by the EPA in the year and 0 otherwise. Labor HHI is the Herfindahl index of the number of employees hired by facilities within the same county a year before the large new plant opening announcement. Sales HHI is the Herfindahl index of total sales by facilities within the same county a year before the large new plant opening announcement.

Table 2: Impact of Announcement of Large Plant Openings on Incumbent Plants' On-site Toxic Releases

Dependent Variable:	Total on-site toxic release					
Deal:	Manufacturing		Non-manufacturing		All deals	
Winner × Post announcement	-0.089***	-0.098***	-0.062**	-0.017	-0.076***	-0.059***
	(-3.448)	(-3.295)	(-2.098)	(-0.438)	(-3.904)	(-2.617)
Observations	48,804	45,512	65,428	61,460	113,451	106,036
Pseudo R^2	0.976	0.982	0.976	0.983	0.976	0.983
County-level controls	YES	YES	YES	YES	YES	YES
Deal × Plant FE	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	NO	YES	NO	YES	NO
Deal × NAICS3 × Year FE	NO	YES	NO	YES	NO	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large plant opening announcements on total on-site toxic releases at the plant-level for all, manufacturing (NAICS codes 31-33), and non-manufacturing (other NAICS codes) new plants. Total toxic releases are the summation of all the facilities' toxic releases of the year. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3: Pollution prevention activities

	Total number of activities		Process or production modification		Operation, inventory, or material management	
Sample period:	[-3,3]	[-3,5]	[-3,3]	[-3,5]	[-3,3]	[-3,5]
Post announcement × Winner	0.074	0.119*	0.286***	0.275***	0.040	0.099
	(1.153)	(1.774)	(3.160)	(2.687)	(0.515)	(1.237)
Observations	16,599	22,625	8,242	11,450	13,881	18,910
Pseudo R^2	0.489	0.477	0.334	0.326	0.490	0.476
County level control	YES	YES	YES	YES	YES	YES
Deal × Plant FE	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	YES	YES	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large new manufacturing plant opening announcements on yearly abatement efforts of incumbent manufacturing plants. The estimated time window is -3 to +3 years around the plant opening announcement in columns (1), (3), and (5). The post-treatment period is with a time window of -3 to +5 years around the plant opening announcement in columns (2), (4), and (6). County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 4: Heterogeneity Based on Labor Market Characteristics

	Labor market competition	Similarity of job composition with new plants	Similarity of high-skill job composition with new plants	Similarity of skill composition with new plants
Dependent Variable:	Total on-site toxic releases			
Winner_{High} × Post announcement	-0.161**	-0.164***	-0.187***	-0.198***
	(-2.141)	(-3.545)	(-3.645)	(-3.976)
Winner_{Medium} × Post announcement	0.097	-0.098*	-0.054	-.045
	(0.709)	(-1.727)	(-0.636)	(-0.785)
Winner_{Low} × Post announcement	-0.046	-0.064	-0.042	-0.025
	(-0.385)	(-1.288)	(-0.843)	(-0.419)
Observations	13,536	42,892	42,906	42,629
Pseudo R^2	0.597	0.977	0.977	0.977
County-level controls	YES	YES	YES	YES
Deal × Plant	YES	YES	YES	YES
Deal × Year	YES	YES	YES	YES
P-value of Winner_{High}-Winner_{Low}	0.057	0.038	0.044	0.136

Notes: The table presents results from Poisson regressions analyzing the heterogeneous impact of large manufacturing new plant opening announcements on pollution at the plant-level for manufacturing plants (NAICS codes 31-33). Total toxic releases are the summation of all the facilities' toxic releases of the year. The estimated time window is -3 to +3 years around the plant opening announcement. In Panel A, the incumbent plants in the winner counties are divided into the bottom, middle, and top terciles of the Mahalanobis distance of skill and job composition from the new plants' 4- or 5-digit (whichever granular available) NAICS codes in the year before the announcement. Skill composition is the level of each skill weighted by the proportion of workers in each occupation for each NAICS code. Job composition is the proportion of workers in each occupation for each NAICS code. In Panel B, the incumbent plants' are divided into the bottom, middle, and top terciles of the proportion of low-skilled workers in the same NAICS code, with the ONET's education category with less than 3, and labor market competition, which is the Herfindahl-Hirschman Index (HHI) of the number of employees within the same NAICS 4-digit industry at the county level in the year before the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 5: Wage-Emission Tradeoff: Impact on Wages After New Plant Opening

Dependent variable:	Total compensation		
Sample individuals:	All	High skill	Low skill
Emission-reduction × Post opening	-0.004	0.007	-0.048
	(-0.111)	(0.191)	(-1.343)
Emission-non-reduction × Post opening	0.069***	0.096***	-0.033
	(2.694)	(2.844)	(-1.044)
Observations	66,258	51,405	13,668
Pseudo R^2	0.611	0.563	0.659
Individual-level controls	YES	YES	YES
Deal × County	YES	YES	YES
Deal × Plant	YES	YES	YES
Deal × Role	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large manufacturing new plant opening announcements on individual-level total compensations. Emission-reduction refers to plants whose average toxic releases during the three years on or after the announcement of new plant openings are lower than those of the three years prior. Emission-non-reduction firms are the remaining firms. Individuals are defined as 'high' skill if their roles are at job zone of 4 and 5 according to ONETS. Individual-level controls include predicted gender, predicted ethnicity, the highest degree earned, and tenure within firm. The sample period includes 3 years before the announcement and 4 to 7 years after the announcement. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 6: Worker Turnover

	Plant-level		Individual-level	
	Turnover ratio		Leave next year	
	High-skilled	Low-skilled	High-skilled	Low-skilled
Emission-reduction × Post opening	-0.098	0.176	0.148	0.210*
	(-0.866)	(1.571)	(1.294)	(1.715)
Emission-non-reduction × Post opening	0.184*	0.212**	0.276***	0.048
	(1.885)	(2.034)	(2.872)	(0.364)
Observations	11,896	13,823	258,601	97,414
Pseudo R^2	0.108	0.101	0.104	0.129
Individual-level controls	NO	NO	YES	YES
Deal × Individual	NO	NO	YES	YES
Deal × Plant	YES	YES	YES	YES
Deal × Year	YES	YES	YES	YES

Notes: The table presents results from OLS regressions analyzing the impact of large manufacturing new plant opening announcements on firm-level turnover ratio and individual-level tendency the next year. Turnover ratio of high-skilled workers is the number of high-skilled workers who leave the company in the next year divided by the total number of high-skilled workers in the current year. The Turnover ratio of low-skilled workers is defined analogously. 'Leave next year' is a dummy variable that is one if an individual leaves the company in the next year. Emission-reduction refers to plants whose average toxic releases during the three years on or after the announcement of new plant openings are lower than those of the three years prior. Emission-non-reduction firms are the remaining firms. Individuals are defined as 'high' skill if their roles are at job zone of 4 and 5 according to ONETS. Individual-level controls include predicted gender, predicted ethnicity, the highest degree earned, and tenure within firm. The sample period includes 3 years before the announcement and 4 to 7 years after the announcement. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 7: Alternative Mechanism: On-site versus Off-site Toxic Releases

Dependent Variable	Off-site	On-site air	On-site land	On-site water
		total toxic releases		
Winner × Post announcement	0.002	-0.060**	-0.218	-0.032
	(0.030)	(-2.308)	(-1.536)	(-0.824)
Observations	32,787	43,541	4,886	10,785
Pseudo R^2	0.898	0.974	0.950	0.974
County-level controls	YES	YES	YES	YES
Deal × Plant FE	YES	YES	YES	YES
Deal × Year FE	YES	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large plant opening announcements on off-site, air, land, and water emissions at the plant-level for manufacturing (NAICS codes 31-33) new plants. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

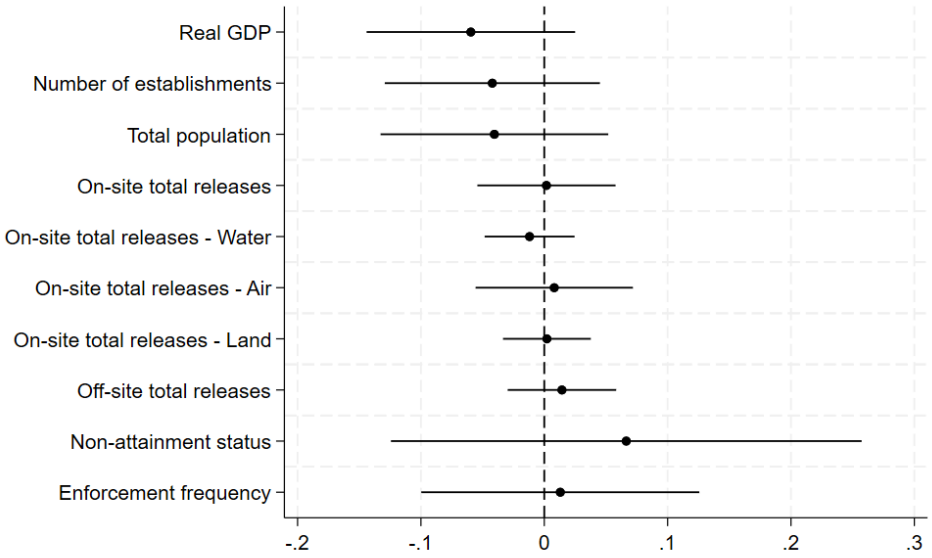
Table 8: Alternative Mechanism: Regulatory Enforcement

Dependent variable:	Total toxic releases		Enforcement frequency	
Sample:	Attainment status	Non-attainment status	Full	
Winner × Post announcement	-0.104***	-0.110***	-0.191	-0.261
	(-2.804)	(-2.587)	(-1.148)	(-1.379)
Winner × Post announcement × Toxic release$_{t-1}$				0.349
				(0.712)
Observations	18,676	29,339	5,254	5,254
Pseudo R^2	0.972	0.979	0.123	0.125
Innate interaction terms	YES	YES	YES	YES
County level controls	YES	YES	YES	YES
Deal ×Year FE	YES	YES	YES	YES
Deal × Plant	YES	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large new manufacturing plant opening announcements on toxic releases depending on the county-level environmental regulatory status (columns (1) and (2)) and on EPA enforcement of incumbent manufacturing plants (columns (3) and (4)). The estimated time window is -3 to +3 years around the plant opening announcement. Attainment status is a yearly designation of counties by the Environmental Protection Agency that violate National Ambient Air Quality Standards (NAAQS). Enforcement frequency is the annual frequency of EPA enforcement at a given plant. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

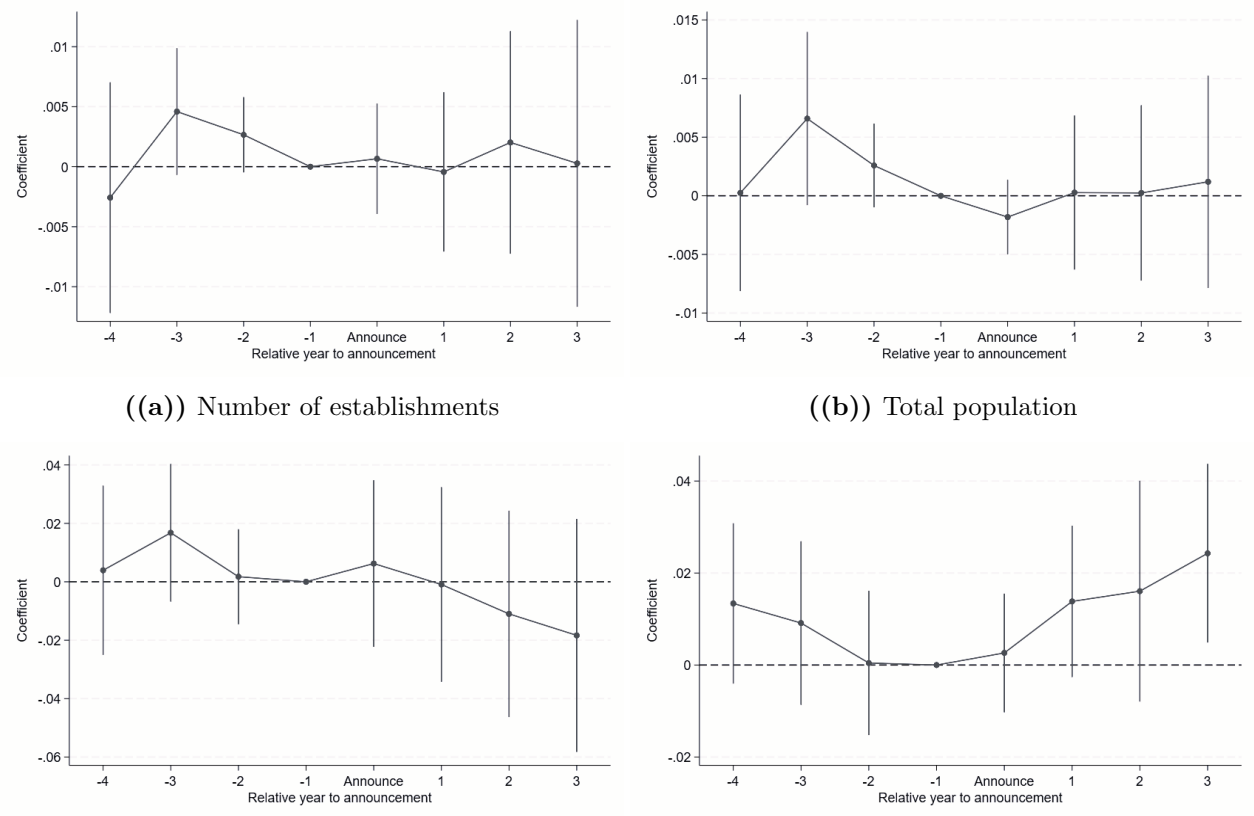
Internet Appendix

Figure IA.1: Selection of winning counties



Notes: This figure plots the estimated coefficients of each county-level regression regressing each variable on a dummy variable of 1 if the county is a winner county of the deal and 0 otherwise in the previous year of the announcement of new plant openings. Horizontal lines show 90% confidence interval of the point estimations shown in dots. Real GDP, total population, and unemployment ratio are for each of the counties where the facility is located. On-site total toxic release is the average of total toxic releases by facilities within a county. On-site release - Water is the average of toxic release via water of the facilities in a county. On-site release - Air and On-site release - Land are defined analogously. Off-site release is the average of toxic releases off-site by facilities in a county. Non-attainment status is the number of chemicals that the Environmental Protection Agency has designated a county to be in non-attainment status. Enforcement frequency refers to the total number of enforcement activities done on the facilities in a county. All the variables are logged except for the dependent variable. The sample includes the deals of new plants in manufacturing industries. Fixed effect of deal-by-year is included and standard errors are clustered at the county level.

Figure IA.2: Dynamics changes in local economic outcomes



((a)) Number of establishments

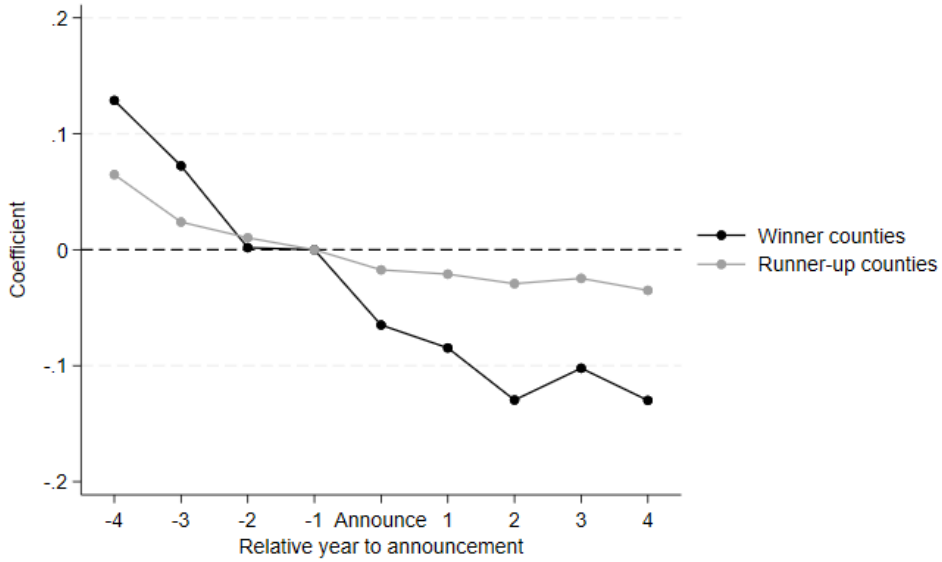
((b)) Total population

((c)) Total employment

((d)) GDP growth

Note: This figure reports the estimated coefficients of time_t regressed to each county-level dependent variable, where time_t refers to the relative year to one year before the year of the announcement of the new plant opening in the county-level regression. Vertical lines show 90% confidence interval of the point estimations shown in dots. GDP growth is the GDP of the county where the facility is located in that year minus that of the previous year, divided by that of the previous year. All the dependent variables are winsorized at 1% in each tail. Fixed effect of deal-by-county and deal-by-year is included. Standard errors are clustered at the county level, and t-statistics are presented in parentheses.

Figure IA.3: Dynamic changes in toxic releases: winner vs runner-up counties



Notes: This figure plots the estimated coefficients of time_t regressed to total toxic releases, where time_t refers to the relative year to one year before the year of the announcement of the new plant opening. Vertical lines show 90% confidence interval of the point estimations shown in dots. Total toxic release is the summation of all the toxic releases reported to the Toxic Releases Inventory each year per facility. Control variables include GDP growth and the lagged real GDP of the county. GDP growth is the GDP of the county where the facility is located in that year minus that of the previous year, divided by that of the previous year. Real GDP, total population, and unemployment ratio are for each of the counties where the facility is located. The sample facilities include those in manufacturing industries. The sample includes the deals of new plants in manufacturing industries. Fixed effect of deal-by-county is included and regression controls for linear time trend in each deal. Standard errors are clustered at the county level, and t-statistics are presented in parentheses.

Table IA.1: Large plant opening events

NAICS 2-digit	Industry	Number of events
21	Mining, Quarrying, and Oil and Gas Extraction	6
22	Utilities	10
23	Construction	1
31-35	**Manufacturing**	**108**
42	Wholesale Trade	13
44-45	Retail Trade	12
48-49	Transportation and Warehousing	14
51	Information	9
52	Finance and Insurance	16
53	Real Estate and Rental and Leasing	2
54	Professional, Scientific, and Technical Services	18
55	Management of Companies and Enterprises	16
56	Administrative and Support and Waste Management and Remediation Services	5
62	Health Care and Social Assistance	1
71	Arts, Entertainment, and Recreation	1
72	Accommodation and Food Services	2
Total		235

Notes: This table shows the number of large plant opening events matched to TRI data from 2002 to 2018 in each NAICS 2-digit code.

Table IA.2: Impact of Large Plant Openings on Pollution - Non-manufacturing plants

	Total releases							
Deals:	Non-manufacturing		Manufacturing deal		All deals		All deal	
Sample:	non-manufacturing		non-manufacturing		non-manufacting		all plants	
Post announcement × Winner	-0.092	-0.063	0.053	0.044	-0.008	0.009	-.054***	-0.037
	(-1.288)	(-.74)	(-0.857)	(0.685)	(-.174)	-0.172	(-2.857)	(-1.644)
Observations	9,526	7,781	6,452	5,142	15978	12917	129,871	119,053
Pseudo R^2	0.635	0.632	0.649	0.652	0.641	0.64	0.589	0.588
County level controls	YES	YES	YES	YES	YES	YES	YES	YES
Deal × Plant FE	YES	YES	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	NO	YES	NO	YES	NO	YES	NO
Deal × NAICS3 × Year FE	NO	YES	NO	YES	NO	YES	NO	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large plant opening announcements on pollution at the plant-level for all, manufacturing (NAICS codes 31-33), and non-manufacturing (other NAICS codes) new plants on non-manufacturing incumbent plants. Total toxic releases are the summation of all the facilities' toxic releases of the year. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.3: Impact of Large Plant Openings on Pollution - Robustness

	Total on-site toxic release						
Sample:	Full		Plants by public firms				NETS coverage
Post announcement × Winner	-0.054*	-0.069*	-0.114***	-0.129***	-0.127***	-0.165**	-0.256***
	(-1.726)	(-1.738)	(-3.101)	(-4.292)	(-3.598)	(-2.134)	(-4.088)
Observations	51,729	63,922	11,220	10,899	10,386	3,245	8,438
Pseudo R^2	0.974	0.969	0.563	0.566	0.572	0.534	0.585
County level control	NO	NO	YES	YES	YES	NO	YES
County level control$_{time=-1}$	YES	YES	NO	NO	NO	NO	NO
Firm level controls	NO	NO	NO	YES	NO	NO	NO
Additional firm level controls	NO	NO	NO	NO	YES	NO	NO
Facility level controls	NO	NO	NO	NO	NO	NO	YES
Deal × Plant	YES	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	YES	YES	YES	YES	NO	YES
Deal × Year × Firm FE	NO	NO	NO	NO	NO	YES	NO

Notes: The table presents results from Poisson regressions analyzing the impact of large plant opening announcements on pollution at the plant-level for all, manufacturing (NAICS codes 31-33), and non-manufacturing (other NAICS codes) new plants. Total toxic releases are the summation of all the facilities' toxic releases for the year. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of a given year and the previous year, divided by the GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. The sample is restricted to plants owned by public firms in columns (3) through (6) and plants covered in NETS (National Establishment Time-Series data) in column (7). Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.4: Robustness tests: Multiple treatments

Sample:	Non-overlapping deals	Toxic releases Runner-up counties without past winning		Single winning	First win
Post announcement × Winner	-0.128***	-0.103***	-0.106***	-0.111***	-0.113**
	(-2.995)	(-3.514)	(-2.998)	(-3.337)	(-2.408)
Observations	16,145	41,206	38,528	9,827	24,940
Pseudo R^2	0.979	0.976	0.983	0.977	0.976
Deal × Plant FE	YES	YES	YES	YES	YES
Deal × Year FE	YES	YES	NO	YES	YES
Deal × NAICS3 × Year FE	NO	NO	YES	NO	NO

Notes: The table presents robustness test results from Poisson regressions analyzing the impact of large plant opening announcements on pollution at the plant-level for manufacturing (NAICS codes 31-33) new plants. Robustness tests are conducted by 1) including counties that do not experience deals (either by winning or losing) more than once in a 5-year window, 2) excluding deals of which the runner-up counties were past winner in a 5-year window, 3) including deals of which the winning counties win only once in the sapmle period between 2002 and 2018, and 4) including deals of which the winning counties win deals for the first time withint the sample period. Total toxic releases are the summation of all the facilities' toxic releases of the year. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.5: Robustness - Total releases without newly added chemicals

	Toxic releases					
Deal:	Manufacturing		Non-manufacturing		All deals	
Post announcement × Winner	-0.089***	-0.098***	-0.066**	-0.017	-0.076***	-0.059***
	(-3.440)	(-3.284)	(-2.255)	(-0.451)	(-3.905)	(-2.615)
Observations	48,792	45,500	64,641	60,518	113,433	106,018
Pseudo R^2	0.976	0.983	0.976	0.983	0.976	0.983
Deal × Plant FE	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	YES	YES	YES	YES	YES
Deal × NAICS3 × Year FE	YES	YES	YES	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large plant opening announcements on pollution at the plant-level for all, manufacturing (NAICS codes 31-33), and non-manufacturing (other NAICS codes) new plants. Total toxic releases are the summation of all the facilities' toxic releases of the year, except for three chemicals that were newly added during the sample period (Bromopropane, Hexabromocyclododecane, Nonylphenol). The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.6: Economic outcomes

		Logged			Leverage	Leverage
	Sales	Sales	Employees	Employees		
Post announcement × Winner	-0.057	-0.038	0.038	0.046*	0.042**	0.039**
	(-1.150)	(-0.563)	(1.266)	(1.743)	(2.360)	(2.266)
Observations	10,747	9,362	9,537	8,173	13,168	13,023
Adjusted R^2	0.947	0.955	0.966	0.965	0.07	0.07
County level controls	YES	YES	YES	YES	YES	YES
Deal × Plant FE	YES	YES	YES	YES	YES	YES
Deal × Year FE	YES	NO	YES	NO	YES	NO
Deal × NAICS3 × Year FE	NO	YES	NO	YES	NO	YES

Notes: The table presents results from OLS regressions analyzing the impact of large new manufacturing plant opening announcements on sales and employment of incumbent manufacturing plants. Both plant-level sales and the number of employees are in terms of natural logarithms. The estimated time window is -3 to +3 years around the plant opening announcement. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.7: Wage-Emission Tradeoff: Impact on Wages After New Plant Opening

Dependent variable:	Total compensation		
Sample individuals:	All	High skill	Low skill
Winner × Post opening	0.035	0.054**	-0.040
	(1.623)	(2.021)	(-1.591)
Observations	66,258	51,405	13,668
Pseudo R^2	0.611	0.563	0.659
Individual-level controls	YES	YES	YES
Deal × County	YES	YES	YES
Deal × Plant	YES	YES	YES
Deal × Role	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large manufacturing new plant opening announcements on individual-level total compensations. Individuals are defined as 'high' skill if their roles are at job zone of 4 and 5 according to ONETS. Individual-level controls include predicted gender, predicted ethnicity, the highest degree earned, and tenure within firm. The sample period includes 3 years before the announcement and 4 to 7 years after the announcement. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table IA.8: Industry-level Pay

	Average annual pay		
	All industries	Low skill industries	High skill industries
Emission-reducing industry × Post opening	0.072	-0.035	0.170
	(0.907)	(-0.224)	(1.070)
Emission-non-reducing industry × Post opening	0.120**	0.042	0.194**
	(2.167)	(0.397)	(2.068)
County-level controls	YES	YES	YES
Observations	3,038	1,030	814
Pseudo R^2	0.643	0.527	0.623
Deal × County × Industry	YES	YES	YES
Deal × Year × Industry	YES	YES	YES

Notes: The table presents results from Poisson regressions analyzing the impact of large manufacturing new plant opening announcements on average annual wage at the industry-level in manufacturing industries (NAICS codes 31-33) using the Quarterly Census of Employment and Wages (QCEW). Emission-reducing industries refer to industries whose average toxic releases during the 3 years on or after the announcement of new plant openings are lower than those 3 years in advance. Emission-non-reducing industries are the remaining industries. Industries are designated as 'low' skill industries if the percentage of workers with high skill in the 4-digit NAICS codes is lower than the median in the full sample in the year before the announcement of new plants. The percentage of workers with high skills is measured by multiplying the percentage of workers in each occupation within the industry by the percentage of high-skilled workers in each occupation. 'High' skill industries are remaining industries. County-level control variables include GDP growth and GDP of the previous year. GDP Growth is the difference between the GDP of the year and the previous year, divided by that of the previous year. GDP Growth is the difference between the GDP of the year and the previous year divided by that of the previous year. The sample period includes 4 years on or before the announcement and 4 to 7 years after the announcement. Standard errors are clustered at the county level, and t-statistics are presented in parentheses. Statistical significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

IA.1 Mathematical Proofs

IA.1.1 Proof of Theorem 1 (Labor Market Equilibrium)

Each firm k maximizes profit $\pi_k = (A_k - w_k)L_k$ where $L_i = \frac{1}{2} + \alpha[(w_i - w_n) + \theta(\tau_n - \tau_i)]$.

Step 1: First-Order Conditions

Firm i's profit: $\pi_i = (A_i - w_i)L_i$ where $L_i = \frac{1}{2} + \alpha[(w_i - w_n) + \theta(\tau_n - \tau_i)]$

Taking the derivative: $\frac{\partial \pi_i}{\partial w_i} = \frac{\partial}{\partial w_i}[(A_i - w_i)L_i]$

Using the product rule: $\frac{\partial \pi_i}{\partial w_i} = -L_i + (A_i - w_i)\frac{\partial L_i}{\partial w_i}$

Since $\frac{\partial L_i}{\partial w_i} = \alpha$, the FOC becomes: $-L_i + (A_i - w_i)\alpha = 0$

This gives us: $(A_i - w_i)\alpha = L_i$, or equivalently $A_i - w_i = \frac{L_i}{\alpha}$

Similarly for firm n: $(A_n - w_n)\alpha = L_n$

Step 2: Market Clearing

Since $L_i + L_n = 1$: $(A_i - w_i)\alpha + (A_n - w_n)\alpha = 1$, so:

$$w_i + w_n = A_i + A_n - \frac{1}{\alpha} \tag{IA.1}$$

Step 3: Strategic Interaction

Substituting the FOC into the labor demand: $\alpha(A_i - w_i) = \frac{1}{2} + \alpha[(w_i - w_n) + \theta(\tau_n - \tau_i)]$

Dividing by α: $A_i - w_i = \frac{1}{2\alpha} + (w_i - w_n) + \theta(\tau_n - \tau_i)$

Rearranging: $A_i - \frac{1}{2\alpha} - \theta(\tau_n - \tau_i) = 2w_i - w_n$

Similarly for firm n: $A_n - \frac{1}{2\alpha} - \theta(\tau_i - \tau_n) = 2w_n - w_i$

Which gives: $A_n - \frac{1}{2\alpha} + \theta(\tau_n - \tau_i) = 2w_n - w_i$

Step 4: Solving the System

From the firm i equation: $w_n = 2w_i - A_i + \frac{1}{2\alpha} + \theta(\tau_n - \tau_i)$

Substituting into the market clearing condition: $w_i + 2w_i - A_i + \frac{1}{2\alpha} + \theta(\tau_n - \tau_i) = A_i + A_n - \frac{1}{\alpha}$

Simplifying: $3w_i = 2A_i + A_n - \frac{3}{2\alpha} - \theta(\tau_n - \tau_i)$

Therefore: $w_i^* = \frac{2A_i + A_n}{3} - \frac{1}{2\alpha} - \frac{\theta(\tau_n - \tau_i)}{3}$

And: $w_n^* = \frac{A_i + 2A_n}{3} - \frac{1}{2\alpha} + \frac{\theta(\tau_n - \tau_i)}{3}$

Step 5: Labor Allocations

Substituting back into the demand functions: $w_i^* - w_n^* = \frac{2A_i + A_n - A_i - 2A_n}{3} - \frac{2\theta(\tau_n - \tau_i)}{3} = \frac{A_i - A_n}{3} - \frac{2\theta(\tau_n - \tau_i)}{3}$

Therefore:

$$L_i^* = \frac{1}{2} + \alpha \left[\frac{A_i - A_n}{3} - \frac{2\theta(\tau_n - \tau_i)}{3} + \theta(\tau_n - \tau_i) \right] \tag{IA.2}$$

$$= \frac{1}{2} + \alpha \left[\frac{A_i - A_n}{3} + \frac{\theta(\tau_n - \tau_i)}{3} \right] \tag{IA.3}$$

$$= \frac{1}{2} + \frac{\alpha}{3}[(A_i - A_n) + \theta(\tau_n - \tau_i)] \tag{IA.4}$$

Step 6: Profit Functions

From the first-order condition, we know $A_k - w_k^* = \frac{L_k^*}{\alpha}$, so the equilibrium profit is:

$$\pi_k^* = (A_k - w_k^*)L_k^* = \frac{L_k^*}{\alpha} \cdot L_k^* = \frac{[L_k^*]^2}{\alpha} \tag{IA.5}$$

This is the standard result for Bertrand competition with linear demand. □

IA.1.2 Proof of Theorem 2 (Optimal Toxic Release Level)

In the symmetric case ($A_i = A_n \equiv A$, $\tau_n = \bar{\tau}$), from Theorem 1:

$$L_i^*(\tau_i, \bar{\tau}) = \frac{1}{2} + \frac{\alpha}{3}[\theta(\bar{\tau} - \tau_i)] = \frac{1}{2} + \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} \tag{IA.6}$$

Step 1: Profit Function Derivation

The incumbent's equilibrium profit is:

$$\pi_i^* = \frac{[L_i^*]^2}{\alpha} \tag{IA.7}$$

Substituting the labor allocation:

$$\pi_i^* = \frac{1}{\alpha} \left(\frac{1}{2} + \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} \right)^2 \tag{IA.8}$$

Step 2: Expanding the Squared Term

Let $u = \frac{1}{2}$ and $v = \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3}$, so we need to expand $(u + v)^2$:

$$\left(\frac{1}{2} + \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} \right)^2 = \left(\frac{1}{2} \right)^2 + 2 \cdot \frac{1}{2} \cdot \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} + \left(\frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} \right)^2 \tag{IA.9}$$

$$= \frac{1}{4} + \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} + \frac{\alpha^2\theta^2(\bar{\tau} - \tau_i)^2}{9} \tag{IA.10}$$

Step 3: Complete Profit Expression

Therefore:

$$\pi_i^* = \frac{1}{\alpha}\left(\frac{1}{4} + \frac{\alpha\theta(\bar{\tau} - \tau_i)}{3} + \frac{\alpha^2\theta^2(\bar{\tau} - \tau_i)^2}{9}\right) \tag{IA.11}$$

$$= \frac{1}{4\alpha} + \frac{\theta(\bar{\tau} - \tau_i)}{3} + \frac{\alpha\theta^2(\bar{\tau} - \tau_i)^2}{9} \tag{IA.12}$$

Step 4: Total Payoff Function

The incumbent's total payoff including abatement cost is:

$$\Pi_i(\tau_i) = \frac{1}{4\alpha} + \frac{\theta(\bar{\tau} - \tau_i)}{3} + \frac{\alpha\theta^2(\bar{\tau} - \tau_i)^2}{9} - \frac{\gamma(\bar{\tau} - \tau_i)^2}{2} \tag{IA.13}$$

Step 5: First-Order Condition

Taking the derivative with respect to τ_i:

$$\frac{\partial \Pi_i}{\partial \tau_i} = \frac{\theta \cdot (-1)}{3} + \frac{\alpha\theta^2 \cdot 2(\bar{\tau} - \tau_i) \cdot (-1)}{9} - \frac{\gamma \cdot 2(\bar{\tau} - \tau_i) \cdot (-1)}{2} \tag{IA.14}$$

$$= -\frac{\theta}{3} - \frac{2\alpha\theta^2(\bar{\tau} - \tau_i)}{9} + \gamma(\bar{\tau} - \tau_i) \tag{IA.15}$$

Setting equal to zero:

$$-\frac{\theta}{3} - \frac{2\alpha\theta^2(\bar{\tau} - \tau_i)}{9} + \gamma(\bar{\tau} - \tau_i) = 0 \tag{IA.16}$$

Step 6: Solving for Optimal Toxic Release Level

Rearranging:

$$(\bar{\tau} - \tau_i)\left(\gamma - \frac{2\alpha\theta^2}{9}\right) = \frac{\theta}{3} \tag{IA.17}$$

Therefore:

$$\bar{\tau} - \tau_i = \frac{\theta/3}{\gamma - 2\alpha\theta^2/9} = \frac{3\theta}{9\gamma - 2\alpha\theta^2} \tag{IA.18}$$

And the optimal toxic release level is:

$$\tau_i^* = \bar{\tau} - \frac{3\theta}{9\gamma - 2\alpha\theta^2} \tag{IA.19}$$

Step 7: Second-Order Condition

Taking the second derivative:

$$\frac{\partial^2 \Pi_i}{\partial \tau_i^2} = (-1)\left(\gamma - \frac{2\alpha\theta^2}{9}\right) = -\gamma + \frac{2\alpha\theta^2}{9} \tag{IA.20}$$

This is negative when $\gamma > \frac{2\alpha\theta^2}{9}$, confirming the solution is a maximum. □

IA.1.3 Proof of Propositions

Proposition 1: Since $\tau_i^* = \bar{\tau} - \frac{3\theta}{9\gamma - 2\alpha\theta^2} < \bar{\tau}$ when $\theta > 0$ and $\gamma > \frac{2\alpha\theta^2}{9}$, the incumbent reduces toxic releases below baseline. $\square$

Proposition 2: For $\tau_i^* = \bar{\tau} - \frac{3\theta}{9\gamma - 2\alpha\theta^2}$:

1. $\frac{\partial \tau_i^*}{\partial \theta} = -\frac{\partial}{\partial \theta}\left[\frac{3\theta}{9\gamma - 2\alpha\theta^2}\right] = -\frac{3(9\gamma - 2\alpha\theta^2) - 3\theta(-4\alpha\theta)}{(9\gamma - 2\alpha\theta^2)^2} = -\frac{27\gamma + 6\alpha\theta^2}{(9\gamma - 2\alpha\theta^2)^2} < 0$
2. $\frac{\partial \tau_i^*}{\partial \alpha} = -\frac{\partial}{\partial \alpha}\left[\frac{3\theta}{9\gamma - 2\alpha\theta^2}\right] = -\frac{3\theta \cdot 2\theta^2}{(9\gamma - 2\alpha\theta^2)^2} = -\frac{6\theta^3}{(9\gamma - 2\alpha\theta^2)^2} < 0$ $\square$

Proposition 3: The incumbent's first-order condition from Theorem 2 is:

$$-\frac{\theta}{3} - \frac{2\alpha\theta^2(\tau_n - \tau_i^*)}{9} + \gamma(\bar{\tau} - \tau_i^*) = 0 \tag{IA.21}$$

This implicitly defines τ_i^* as a function of τ_n. Define:

$$F(\tau_i, \tau_n) \equiv -\frac{\theta}{3} - \frac{2\alpha\theta^2(\tau_n - \tau_i)}{9} + \gamma(\bar{\tau} - \tau_i) = 0 \tag{IA.22}$$

By the Implicit Function Theorem:

$$\frac{d\tau_i^*}{d\tau_n} = -\frac{\partial F / \partial \tau_n}{\partial F / \partial \tau_i} \tag{IA.23}$$

Computing the partial derivatives:

$$\frac{\partial F}{\partial \tau_n} = -\frac{2\alpha\theta^2}{9} \tag{IA.24}$$

$$\frac{\partial F}{\partial \tau_i} = \frac{2\alpha\theta^2}{9} - \gamma = -\left(\gamma - \frac{2\alpha\theta^2}{9}\right) \tag{IA.25}$$

Therefore:

$$\frac{d\tau_i^*}{d\tau_n} = -\frac{-2\alpha\theta^2/9}{-(\gamma - 2\alpha\theta^2/9)} = \frac{2\alpha\theta^2}{9\gamma - 2\alpha\theta^2} \tag{IA.26}$$

Under the parameter restriction $\gamma > \frac{2\alpha\theta^2}{9}$, we have $9\gamma - 2\alpha\theta^2 > 0$, so:

$$\frac{d\tau_i^*}{d\tau_n} > 0 \tag{IA.27}$$

To show $\frac{d\tau_i^*}{d\tau_n} < 1$, note that:

$$2\alpha\theta^2 < 9\gamma - 2\alpha\theta^2 \iff 4\alpha\theta^2 < 9\gamma \tag{IA.28}$$

which holds since $\gamma > \frac{2\alpha\theta^2}{9}$. Thus $0 < \frac{d\tau_i^*}{d\tau_n} < 1$.

For the emission gap $G = \tau_n - \tau_i^*$:

$$\frac{dG}{d\tau_n} = 1 - \frac{d\tau_i^*}{d\tau_n} = 1 - \frac{2\alpha\theta^2}{9\gamma - 2\alpha\theta^2} = \frac{9\gamma - 4\alpha\theta^2}{9\gamma - 2\alpha\theta^2} \tag{IA.29}$$

Since $\gamma > \frac{2\alpha\theta^2}{9}$ implies $9\gamma > 4\alpha\theta^2$, we have $\frac{dG}{d\tau_n} > 0$. When the entrant becomes cleaner (lower τ_n), the emission gap narrows. □

Proposition 4: From the equilibrium wages:

$$w_n^* - w_i^* = \frac{\theta(\tau_n - \tau_i)}{3} + \frac{\theta(\tau_n - \tau_i)}{3} = \frac{2\theta(\tau_n - \tau_i)}{3} \tag{IA.30}$$

This confirms that firms with higher toxic releases ($\tau_i > \tau_n$) must pay higher wages to compensate workers. □