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Real effects of climate policy: Financial constraints and spillovers ☆

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A B S T R A C T

We document that localized policies aimed at mitigating climate risk can have unintended consequences due to regulatory arbitrage by firms. Using a difference-in-differences framework to study the impact of the California cap-and-trade program with U.S. plant-level data, we show that financially constrained firms shift emissions and output from California to other states where they have similar plants that are underutilized. By contrast, unconstrained firms do not make such adjustments. Overall, unconstrained firms do not reduce their total emissions, whereas constrained firms increase their total emissions after the cap-and-trade rule, undermining the effectiveness of the policy.

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1. Introduction

Climate change is among the most intensely debated socioeconomic issues of current times.[1] As a response to potential catastrophe risks from climate change, governments around the world are pushing for various forms of regulations to curb greenhouse gas emissions.[2] However, no consensus has been reached on optimal policy approaches; thus, climate policies are highly fragmented across the jurisdictions in which they are designed and implemented. More importantly, whether such localized yet uncoordinated policies are able to internalize potential externalities that may impede addressing climate change as a global phenomenon or simply distort allocations in the economy is unknown. An example is the U.S., where at the beginning of 2013, California became the first and only state to put a comprehensive mandatory carbon regulation in place in the form of a cap-and-trade system that applies universally to all industrial greenhouse gas emissions.[3] Exploiting the introduction of the California cap-and-trade rule, we investigate the internal resource allocation responses by firms and the real but unintended spillover effects of localized climate policies that arise from the importance of financial constraints. Our study helps us understand the interplay between climate policy and firm behavior, and informs policymakers regarding the effectiveness of climate regulation.

Using detailed data on plant-level greenhouse gas emissions from mandatory reporting to the United States Environmental Protection Agency (EPA) hand-matched to Compustat covering 2,806 industrial plants of 511 publicly listed firms over the period 2010 to 2015, we show that the 2013 California cap-and-trade rule has real spillover effects across the United States due to firm financial constraints. Specifically, we employ a difference-in-differences (DID) framework and find that while financially constrained firms reduce greenhouse gas emissions from plants located in California by 33% relative to plants in other states, they significantly increase emissions of plants in other states by 29% more than those owned by firms without a presence in California. By contrast, we find no evidence that unconstrained firms adjust emissions in response to the new regulation, either in California or in other states. The differences in responses between constrained and unconstrained firms are statistically significant across a host of financial constraint measures.

Our economic hypothesis is that financially constrained firms reallocate their emissions away from California to other states in the face of heightened regulatory costs that alter the relative net expected returns across plants. The cost of external capital for constrained firms renders profitable emission projects mutually exclusive, and they reallocate as net returns from emitting at alternative locations become relatively more attractive than the returns from continuing to emit in California after the regulatory change.[4] Based on back-of-the-envelope calculations, the additional costs of emissions to constrained firms under the California cap-and-trade rule is equivalent to a 9% increase in tax expenses or a 4% increase in interest expenses. For the subset of firms that reallocate their emissions the most in response to the policy, the impact of the policy on costs is more severe, equivalent to a 15% (11%) increase in taxes (interest expenses). We posit that this increase in the regulatory cost distorts the ranking of net returns on capital across plants, incentivizing constrained firms to reallocate even though emitting in California might remain profitable.

Our conjecture and findings are consistent with criticisms by the media and small business owners that the regulatory costs from the cap-and-trade rule are not large enough to constitute significant deterrents to emissions for firms with deep pockets, but raise the burden for less financially capable players causing emission leakages.[5] Anecdotal evidence also supports the economic importance of the spillover effects we uncover. For example, a major petroleum products company recovering from large operating losses after the financial crisis in the early 2010s strongly objected to the implementation of the cap-and-trade rule. It rallied other firms and warned citizens against the legislation with placards at their California gas pumps that it would cost jobs and consumer welfare. After the rule went into effect at the beginning of 2013, the company reduced emissions by one of its largest Califor-

[1] The economic consequences of climate change have recently garnered much interest among financial economists. See, among others, Addoum, Ng, and Ortiz-Bobea (2020), Akey and Appel (2021), Bernstein, Gustafson, and Lewis (2019), Engle, Giglio, Kelly, Lee, and Stroebel (2020), Forster and Shive (2020), Krueger, Sautner, and Starks (2020), and Painter (2020).

[2] See Fig. A.1 in the Internet Appendix for recent trends in global temperatures and carbon emissions from the use of fossil fuels, and Fig. A.2 for a map of implemented or planned carbon pricing regulations around the world, as of 2016.

[3] Most climate regulations in the U.S. thus far have left states with much discretion in implementing federal standards (e.g., Clean Air Act) or have largely been confined to the electricity production industry. Since 2009, nine states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont) have been part of the Regional Greenhouse Gas Initiative, a cap-and-trade program that applies only to fossil fuel power plants generating 25MW or more. States have also been adopting varying versions of Renewable Portfolio Standards requiring increased production of energy from renewable energy sources. From 2003 to 2010, the Chicago Climate Exchange was available for voluntary emissions trading, but ceased trading due to inactivity.

[4] This conjecture is rooted in studies of the relationship between financial frictions and the value of internal capital allocation, which argue that the contribution of internal capital markets to firm value, and hence, the value of corporate diversification is greater when external financial constraints are higher (see Billett and Mauer, 2003; Matvos and Seru, 2014; Matvos, Seru, and Silva, 2018). Research documents that the propagation of economic shocks through firm internal networks are stronger with tighter financial constraints, consistent with optimal resource reallocations (see Giroud and Mueller, 2019).

[5] In July 2017, as the cap-and-trade rule was about to be extended, the California state executive director of the National Federation of Independent Business stated on behalf of 22,000 small business members that as “California has been experimenting with cap-and-trade policies… jobs are moving to neighboring states with much more relaxed laws… Some believe cap-and-trade only impacts big businesses that buy and sell carbon credits, but the truth is that small businesses and consumers all pay the ultimate price.” An October 2017 Wall Street Journal opinion piece, “The fatal flaw in California’s cap-and-trade program” by Richard Sexton and Steven Sexton, criticizes the cap-and-trade rule for its inability to effectively curtail carbon leakage and its failure to levy large enough burdens to large firms.

nian refineries by 8% over the next three years but sharply increased emissions by some of its largest refineries in other states, for example, Louisiana and Texas, by more than 10%.

We explore the economic mechanisms for our results and find that constrained firms reallocate their emissions from their plants in California primarily to plants with similar functions in other states, rather than to plants that play different roles within their organizational structure. We also show that constrained firms are more likely to carry excess capacity at their plants, consistent with the hangover of surplus capacity built up during favorable times (see Von Kalckreuth, 2006; Dasgupta et al., 2019). In response to the cap-and-trade rule, they tend to reallocate their emissions toward plants outside of California with greater excess capacity, avoiding large fixed costs associated with capacity adjustments. We find that such emission reallocations across plants are the result of changes in production activity rather than production efficiency.

Constrained firms also reallocate their emissions more toward states that are nearby or less regulated, and more likely to do so when they had invested little in abatement technologies prior to the regulation. Finally, we provide evidence that firms affected by the regulation do not reduce their firm-wide emissions. In fact, constrained firms increase their total emissions by as much as 21%. Overall, our main results suggest corporate internal reallocation of pollutive activities and resources to avoid regulatory costs in the face of limited access to external financing, highlighting the hidden costs of environmental policies through financial channels.

We interpret our findings as optimal responses by firms to increased regulatory costs as a function of their financial constraints. Hence, we are comfortable with the fact that firms are not randomly assigned their constraint characteristics, insofar as the assignment is not related to whether firms own plants covered by the California cap-and-trade rule. Nevertheless, we exclude a number of alternative channels that may confound the interpretation of our results. To eliminate the possibility of reverse causality whereby financial constraints are affected by the introduction of the cap-and-trade rule or firm responses to it, or omitted variables simultaneously affecting constraints and firm responses, we measure financial constraints at least three years before the effective start date of the cap-and-trade rule.

We also rule out explanations concerning observed or unobserved plant characteristics such as their industry purpose, maximum capacity, or technological obsoleteness, by controlling for plant fixed effects, and preclude the effects of common time trends within plant industries by controlling for industry-by-year fixed effects. Finally, we also control for firm characteristics that may be related to how much greenhouse gas firms are prone to release, such as firms' asset size, investment opportunities, profitability, leverage, or accumulated research and development (R&D) stock. In short, we set a high bar to refute our conclusion that the cap-and-trade rule entails spillover effects due to the internal reallocation by financially constrained firms.

Our study contributes to a recent and growing body of research on climate risk and firm behavior by focusing on the internal allocation of plant-level emissions within firms driven by their financial constraints, thus providing a unique channel for the real effects of climate regulation. In particular, our findings highlight the importance of climate-related regulatory risks for firms, consistent with concerns by institutional investors (see Krueger et al., 2020). Also closely related to our work are recent papers linking financial incentives and corporate environmental policies. For example, Forster and Shive (2020) find that short-termist pressure for financial performance from outside investors force public firms to emit more greenhouse gases than private firms. Kim and Xu (2020) show that financial constraints exacerbate toxic pollution by firms due to the costs of waste management, and this effect is stronger when regulatory monitoring is weak. In a similar vein, Akey and Appel (2021) find that firm subsidiaries are more likely to increase toxic emissions when parent companies have better liability protection for their subsidiaries' environmental clean-up costs, consistent with the binding effects of higher financial burdens associated with abatement. Complementing these studies, our paper highlights the reallocative effects of financial constraints that induce firms to internally shift their pollutive resources across plants under heightened regulatory costs, which in turn distort the outcome of regional environmental policies. Interestingly, while Akey and Appel (2021) find the effects of limited liability are driven by lower "green" investments rather than by reallocation across plants, we show that the reallocations of greenhouse gas emissions across plants are prominent responses by firms to climate policy.

More broadly, our study makes important contributions to the debate on policy remedies to climate change and the effects they have on economic activity and welfare (see Nordhaus, 1977a; 1977b; Fabra and Reguant, 2014; Marin et al., 2018). Part of this debate focuses on coordination problems of locally implemented climate policies and the impact of their externalities on global emission levels (see Nordhaus and Yang, 1996; Martin et al., 2014; Nordhaus, 2015; Fowlie et al., 2016; Bushnell et al., 2017). The severity of such externalities depends on the costs imposed by regulations, which are challenging to identify (see Jorgenson and Wilcoxen, 1990; Jaffe et al., 1995). Recent studies find that environmental regulations can have costly effects on industrial economic activity, employment, and productivity (see Becker and Henderson, 2000; Greenstone, 2002, Greenstone et al., 2012, Ryan, 2012; Walker, 2011; 2013).[6] These costs imply that local climate policies can result in unintended and significant spillover effects in the form of emission leakages, undermining their objectives to prevent global warming.[7] Building on this literature, we utilize mandatorily reported data on plant-level carbon dioxide equivalent (CO_2e) greenhouse gas emissions in a DID analysis to explore both within-

[6] See also Currie and Walker (2019), Schmalensee and Stavins (2019), and Keiser and Shapiro (2019) for synopses of the impacts of the Clean Air and Water Acts.

[7] See Ederington, Levinson, and Minier (2005), Levinson and Taylor (2008), Wagner and Timmins (2009), and Ben-David, Jang, Kleimeier, and Viehs (2020) for aggregate-level or survey-based analysis of such spillover effects.

and between-plant variation in emissions induced by a local policy whose clear mandate is to curb greenhouse gas emissions. Our analysis identifies firm financial constraints as an important economic channel that generates unequally distributed incentives to reallocate emissions and productive activities.

Policy remedies to climate change are heatedly debated. Such policies have important implications for the behavior of industrial firms and how they respond to regulatory frictions, which are of key interest to financial economists. Understanding these effects is important to guide policymakers to internalize externalities that may otherwise result in unintended consequences and to more effectively coordinate solutions to climate change. Given the importance of a sound evaluation of the efficacy and real effects of climate policy, this paper aims to take the debate on climate change, climate policy, and corporate environmental responsibility one step closer in this direction.

2. Background and hypotheses development

2.1. California's cap-and-trade program

At the beginning of 2013, the state of California's Air Resources Board started enforcing a state-wide carbon cap-and-trade rule to reduce greenhouse gas emissions. Covering all electric power plants and industrial plants that emit 25,000 t or more of CO_2e per year, the California cap-and-trade rule was the first multi-sector cap-and-trade program in North America.[8] The cap-and-trade rule is based on an allocation of capped allowances with specific year vintages and the market trading of those allowances. At the allocation stage, allowances are distributed to plants through a combination of quarterly held auctions and free allowances. Firms are then required to pay off their plants' emissions using these and additional allowances they may buy via market transactions, according to a vintage-specific schedule laid out by the program.[9] Given this institutional structure, the question is whether the cap-and-trade rule constitutes a significant regulatory cost for affected firms. We demonstrate in a number of ways that it likely does for firms that are financially constrained.

According to statistics published by the California Air Resources Board, current vintage allowances are completely sold out in every quarterly allowance auction starting in November 2012, bids outnumber available current vintages, and the settlement prices for current vintages are always higher than the initial reserve price despite the reserve price being increased every year. Furthermore, the free allowance allocations leave substantial room for further incentives to bid in auctions or purchase at market prices. For example, in 2014, the average plant received free allowances to emit 350,000 t of greenhouse gas, which is less than what constrained firms emitted from their plants in California. The aggregate magnitudes of market transactions are comparable to those of the free allocations or auctions, in which the transaction prices not only exceed the contemporaneous auction settlement prices but also steadily increase over time. Increasing allowance futures prices also corroborate these trends.[10]

Plants that emit more than the free allowance must acquire the rights to emit the difference either by bidding in auctions or buying them from other market participants. For our sample of constrained firms with such high emission plants, the cost of doing so amounts to $20 million, based on a back-of-the-envelope calculation assuming an average price on carbon of $12 per metric ton. This cost is non-trivial, and is in the order of 9% of the tax expense or 4% of the interest expense of the average firm. For the top 10 firms that reallocate their emissions the most in response to the policy, the incremental cost is equivalent to a 15% increase in their tax expenses or an 11% increase in their interest expenses.

Together, the increase in costs of emitting greenhouse gases due to the introduction of the California cap-and-trade rule is substantial and sufficiently high for financial constraints to matter. Given the magnitude of the estimated costs, we conjecture that although it may be large for firms with high incremental financing costs, it may not be important for firms with deep pockets. This possibility motivates our hypotheses for how the California cap-and-trade rule will affect firms' greenhouse gas emissions, and the role of financial constraints as the economic channel. We elaborate on the hypotheses in the following section.

2.2. Hypotheses development

Economic theory posits that profit maximizing firms allocate resources to where net returns are positive as long as they are financially unconstrained. If firms are financially constrained, however, they can only allocate resources to a limited set of profitable options among several mutually exclusive investment opportunities. For these firms, the distribution and ranking of the net returns of projects are important, even when they are all economically viable. Regional regulation, such as the statewide cap-and-trade rule in California, introduces perturbations to the distribution of net returns across regions and thus motivates resource reallocation by financially constrained firms. Our hypotheses concern the direction and magnitude of this reallocation.

In our context, firms that have a plant presence both in California and in other states are geographically diversified, and thus can use their internal networks to reallocate resources when the profile of net expected returns change across their geographic segments due to the increase in regulatory costs from the new cap-and-trade rule. How-

[8] In 2014, the California cap-and-trade program was linked with the cap-and-trade program in Quebec, Canada. As of 2015, total aggregate emissions covered by the rule in California (Quebec) was approximately 400 (60) million metric tons. In 2015, the program was extended to fuel distributors emitting more than 25,000 metric tons.

[9] Emissions in any year are required to be paid off in full within the following calendar year. Firms can purchase future vintage allowances in advance but are not allowed to use future vintage allowances to pay for current emissions.

[10] See the Internet Appendix for publicly available aggregate data on quarterly allowance auctions, free allocations, and market transactions made available by the California Air Resources Board (Table A.2), as well as the time series of emission allowance futures prices for each vintage (Fig. A.3).

ever, if firms have access to frictionless borrowing, they would accommodate the change without shifting resources across plants, since their costs of external capital would be low enough to afford all emission projects as long as their net expected returns remain positive. By contrast, financially constrained firms that are geographically diversified would reallocate resources away from plants that are subject to higher regulatory costs to plants they own elsewhere, as their costs of external capital would be too high to finance costly emissions when the net returns from internally reallocating their resources would be greater.

To further clarify why financially unconstrained firms would not reallocate emissions whereas constrained firms would, note a natural corollary to their capital budgeting decisions: unconstrained firms are likely to be operating at capacity wherever producing is profitable, whereas constrained firms are likely to have excess capacity at relatively less profitable locations. Several studies provide empirical support for this notion. Von Kalckreuth (2006), for example, uses U.K. survey data to show that financially constrained firms have more persistent capacity gaps. Dasgupta et al. (2019) demonstrate that constrained firms are more likely to carry an inventory surplus over to unfavorable times. As such, to the extent that the reallocation of emissions is achieved by shifting production resources, unconstrained firms have neither the need nor means to reallocate emissions across plants they have in place as long as emitting in California remains profitable. By contrast, constrained firms find it necessary and possible to internally shift emissions by closing capacity gaps without incurring large and fixed capacity adjustment costs. Indeed, we document that plants owned by financially constrained firms have greater excess capacity than plants owned by unconstrained firms, and that they close capacity gaps at non-California plants as they reallocate their emissions.

Fig. 1 illustrates our intuition by plotting the revenues and costs from varying quantities of emissions. Suppose an imperfectly competitive market with downward sloping marginal (average) revenues *mr* (*ar*) and costs that depend on the locale of production. Firms that operate a plant in California face marginal (average) costs mc_{ca} (ac_{ca}) and an optimum point *I* with average costs *a* and emission quantity *d*. The net return from the California plant is equal to the size of the blue area bordered by *a* and *d*, denoted *A*. Once the California cap-and-trade rule is implemented, the cost functions move upward to mc'_{ca} and ac'_{ca} for quantities above the amount of the free allocations, shifting the optimum to *I'*, where average costs are higher at *b* and quantity is lower at *e*. The net return remains positive, but it is smaller than before and equal to the size of the lighter blue area bordered by *b* and *e*, denoted *A'*. Because the net return is still positive, firms with unlimited access to capital will continue to emit despite the higher costs, as they will continue to allocate capital to all profitable projects.[11]

However, *I'* is an undesirable equilibrium for financially constrained firms because the net returns are smaller than before (i.e., $A' < A$), so they reallocate their resources from California to other states where there are investment opportunities with larger net returns that previously did not seem as attractive. For example, if the costs from emitting in other states follow cost functions mc_{oth} and ac_{oth}, constrained firms will reallocate from *I* to *I''* because the size of its net return, denoted *B*, is greater than *A'* (i.e., $A' < B < A$). On the other hand, *I* and *I''* are not mutually exclusive options for unconstrained firms to begin with, so they would have invested in both projects ex ante because they are both profitable. Therefore, unconstrained firms would not reallocate, because the relative ranking of *I'* and *I''* is irrelevant for them. Empirically, these predictions imply that the cap-and-trade rule will push constrained firms to not only reduce emissions from plants in California by more than unconstrained firms (*d* for constrained firms vs. *d*–*e* for unconstrained firms), but also increase emissions from plants in other states by more (*f* for constrained firms vs. no increase for unconstrained firms), under the hypothetical cost functions for California and other states.[12]

In other words, the value of internal reallocation would be greater for financially constrained firms when the costs of emissions are increased due to policy changes. The motivation of this hypothesis is grounded in the literature in finance on the value of internal capital markets in the presence of financial frictions (for early studies, see Gertner et al., 1994; Lamont, 1997; Stein, 1997; Shin and Stulz, 1998). Research in this literature shows that the contribution of internal capital markets to firm value and hence the value of corporate diversification is greater when external financial constraints are higher, for example, when large dislocations occur in financial markets (see Billett and Mauer, 2003; Matvos and Seru, 2014; Matvos et al., 2018). Our hypothesis is also consistent with Giroud and Mueller (2019), who find that the propagation of economic shocks through firm internal networks is stronger with tighter financial constraints, consistent with a model of optimal within-firm resource allocation.

This economic rationale leads to three key research questions regarding the effect of climate policy on firms: (1) Does local climate policy (e.g., the California cap-and-trade rule) affect firms' allocations of internal resources and greenhouse gas emissions across plants? (2) Are firms' reallocation responses to policy affected by their financial constraints? (3) Do such policies achieve their goal of reducing aggregate emissions? In the following sections, we describe the data and construction of our sample, and

[11] The assumption that the net return from emitting in California after the implementation of the cap-and-trade rule remains positive is supported by state-level GDP growth data. In Table 8, we document that California not only exhibits higher growth than other states by a large margin during the years when the cap-and-trade rule is in effect, but also that the acceleration in GDP growth compared with the previous period is greater in California than in other states.

[12] In Fig. 1, the cost curve in other states lie below that of California. If they did not, and if mc_{oth} were identical to mc_{ca}, the figure would still suggest a sharper decrease in California emissions by constrained firms than by unconstrained firms, and a corresponding sharp increase in emissions from other states by constrained firms by the amount of ***d*** instead of ***f***. The central prediction that motivates our main hypothesis remains unchanged, and unconstrained firms would still not reallocate. Fig. 1, however, raises the possibility that the overall level of firm emissions could increase as a result of the regulation, due to the reallocation by constrained firms. We formally test this hypothesis in Section 5.3.

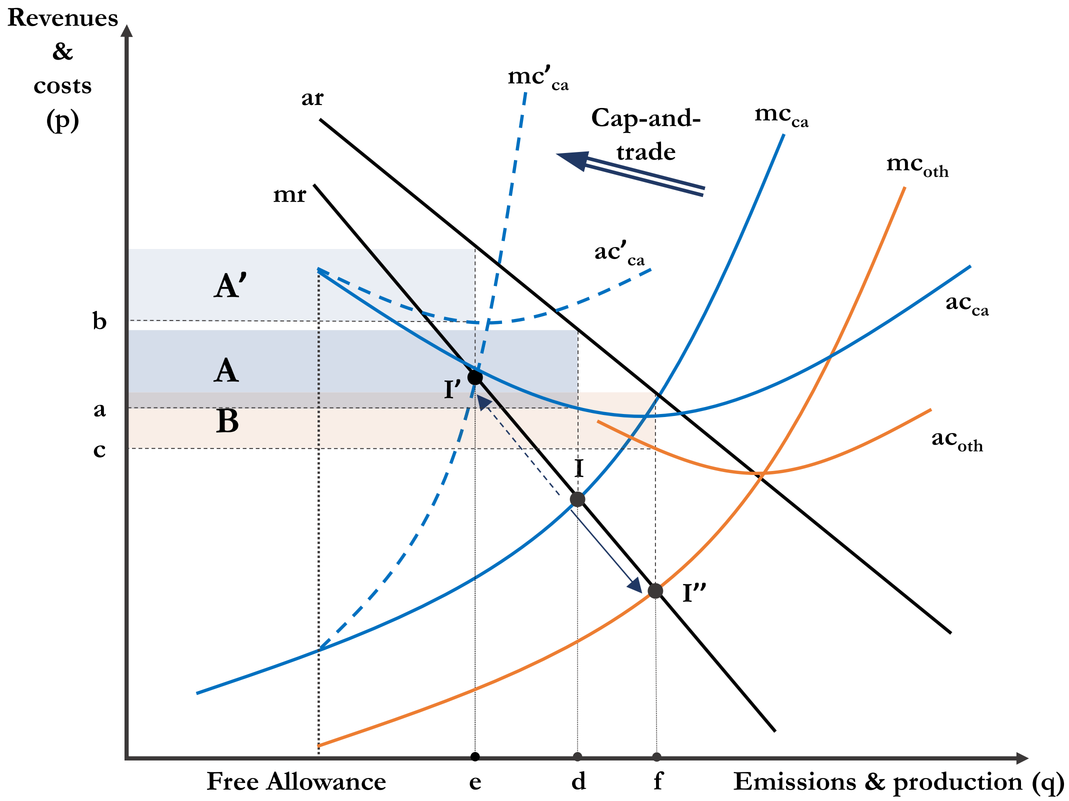

Fig. 1. Economic framework. The figure illustrates the economic channel of the main hypotheses. Revenues and costs (p) are plotted on the vertical axis, and emissions and production quantities (q) are plotted on the horizontal axis. Marginal and average revenue curves (solid black), denoted *mr* and *ar*, are downward sloping, consistent with an imperfectly competitive market. Marginal and average cost curves are plotted for three scenarios. In particular, mc_{ca} and ac_{ca} represent the pre-cap-and-trade costs of producing and emitting in California. mc'_{ca} and ac'_{ca} denote the post-cap-and-trade costs of emitting in California, which are tilted upward from the pre-policy curves for emission quantities above the free allocation amount. mc_{oth} and ac_{oth} are the cost curves should firms reallocate their emissions exceeding the free allocation amount to other states. *I, I'*, and *I''* denote the equilibrium with the optimal amount of emissions in California before the cap-and-trade rule, in California after the cap-and-trade rule, and in other states, respectively. The rectangular shaded areas A and A' show the profits for producing in California before and after the cap-and-trade rule, respectively, whereas the shaded area B shows the profit of producing in other states.

formulate the empirical methodology that we use to test these hypotheses.

3. Data and sample

3.1. Data

In October 2009, the EPA published the Greenhouse Gas Reporting Program (GHGRP) mandating that sources that emit 25,000 t or more of CO_2e greenhouse gases per year must report their emissions, compliant with the estimation methodologies prescribed by the EPA.[13] Once the submitted information is verified by the EPA, the data are made publicly available through the Facility Level Information on GHGs Tool (FLIGHT), providing plant-level information on the identity, geographic location, parent company ownership, North American Industry Classification System (NAICS) industry code, and the quantity of greenhouse gas emissions of the plant on an annual basis starting in 2010. Our sample period extends from 2010 to 2015 — three years before and after the beginning of the California cap-and-trade program — and the initial sample covers approximately 9,200 unique plants.[14]

To analyze the impact of financial constraints, we hand-match the EPA plant-level dataset with annual financial accounting data from Compustat based on the names of parent companies. To be included in our sample, we require that firms have positive total assets and sales greater than \$10 million. Although utilities and governmental firms

[13] Although GHGRP reporters have some discretion over which of the EPA-approved methods to use when reporting emission quantities, this selection is unlikely to affect our conclusion, as the reporting responsibility falls to the plant rather than the parent company. Moreover, it is difficult to explain why plants would change reporting methods resulting in not only a decline in reported emissions from California, but also an increase in reported emissions from other states.

[14] We do not include the years 2016 and 2017, which include potentially confounding events such as the signing of the Paris Agreement and the subsequent withdrawal by the U.S., as well as additional legislative packages signed by the state of California seeking to reduce greenhouse gas emissions and other air pollutants.

may be significant greenhouse gas emitters, common measures of financial constraints are not likely to elicit strategic responses to climate policies from such firms in the same way as they do for typical industrial firms, because they are regulated locally by local public service commissions and also federally regarding interstate service transmissions. For this reason, we exclude not only financial firms (Standard Industrial Classification codes (SIC) 6000–6999), but also utilities (SIC 4900–4999) and governmental firms (SIC 9000–9999).[15] The final sample is an unbalanced panel of 2,806 plants of 511 firms over the sample period 2010 to 2015.

We use Compustat data to construct various variables to be used as controls or to measure financial constraints such as total assets, Tobin's q, profitability, short-term debt, long-term debt, cash, cash flow, dividends, repurchases, long-term (i.e., bond) and short-term (i.e., commercial paper) credit ratings, property, plant, and equipment (PP&E), and capital expenditures. We take the difference between the observation year and founding year as firm age as in Jovanovic and Rousseau (2001). We also compute R&D stock using the perpetual inventory method, where we initialize R&D capital stock at zero and accumulate R&D expenses with a depreciation rate of 15% (see Hall et al., 2005). All continuous financial variables are winsorized at the top and bottom 1%.

In addition, we obtain plant-level sales and employment data from the National Establishment Time Series (NETS) database produced by Walls & Associates. This survivorship bias-free data provide historical information on publicly listed firms' sales and employment at each of its establishments on an annual basis from 1990 to 2015. We take plant-level sales as a proxy for the value of its annual production output. We also compute excess capacity as the end-of-current-year number of employees at the plant per million dollars of sales generated by the plant in the current year. A plant that has a higher employment-to-output ratio than the median plant is classified as having high excess capacity in a given year.

We manually link the three datasets by matching on parent company names. To ensure a high-quality match, we corroborate the matching process with Capital IQ and extensive google searches, to take into account parent-subsidiary linkages in case parent company names are recorded differently in the three datasets. Plant-level data are then matched on the address, latitude, longitude, and industry of the plant, as well as the identity of the parent company each year. To complement plant-level sales and employment data, we further use the Compustat Segment database to apportion residual segment sales and employment to plants if they are the only remaining plant in an industry segment that cannot be matched to the NETS data. Finally, we equally apportion residual firm sales and employment to plants that still do not have valid sales or employment data.

Lastly, we map vertical (i.e., upstream and downstream) and horizontal linkages across plants within firms using plant-level NAICS codes and the Bureau of Economic Analysis (BEA) input-output accounts. We start by computing the share of NAICS goods produced or consumed by NAICS industries using the 2007 make and use tables. When a plant's NAICS industry consumes or produces more than 10% of another plant's NAICS industry goods, where the two NAICS industries are distinct at the two-digit NAICS level, these two plants are classified as vertically linked to each other. If two plants have the same NAICS code, they are classified as horizontally linked. If two plants belong to distinct two-digit NAICS industries that do not consume or produce more than 10% of the other industry's goods, they are classified as unrelated.

3.2. Measuring financial constraints

To establish an economic channel through which financial constraints determine how firms respond to climate policy, measuring financial constraints is a critical step in our study. Based on financial accounting information from Compustat, we construct six alternative measures of financial constraints commonly used in the literature. They are the Kaplan-Zingales index (see Kaplan and Zingales, 1997; Lamont et al., 2001), the Hadlock and Pierce (2010) index, the Whited and Wu (2006) index, firm size, payout, and credit (i.e., bond or commercial paper) ratings (see Almeida et al., 2004). In addition, we combine the six proxies into a composite indicator as our primary measure of financial constraints.

For the Kaplan-Zingales, Hadlock-Pierce, and Whited-Wu indices, as well as firm size and payout, firms are assigned percentile rankings based on each measure every year. We then use the six years strictly before our sample period (i.e., fiscal years 2003–2008) to compute time series average percentile rankings for each firm and each measure. Based on these average rankings, firms are categorized as financially constrained if they are above the median for the Kaplan-Zingales, Hadlock-Pierce, and Whited-Wu indices, and if they are below the median for firm size and payout. For credit ratings, we first examine long-term bond ratings and short-term commercial paper ratings separately. If a firm did not have a bond (commercial paper) rating as of the most recent year of the 2003–2008 pre-sample period but had, on average, positive long-term (short-term) debt during this period, the firm is categorized as "long-term (short-term)" financially constrained. If the firm did have a bond (commercial paper) rating as of the most recent year of the six-year pre-sample period or had, on average, zero long-term (short-term) debt during this period, the firm is "long-term (short-term)" unconstrained. If a firm is either long-term or short-term credit constrained, the firm is classified as constrained based on ratings and unconstrained otherwise.

For the composite indicator of financial constraints, a firm is categorized as constrained if the majority of the six proxies classify the firm as being constrained; otherwise, the firm is unconstrained. Since firms are classified strictly before they enter the sample period, we rule out reverse causality concerns or omitted variables simultaneously affecting the evolution of constraints and firm responses to

[15] We conduct a robustness test by including utilities in our sample and find similar results as in our baseline analysis (see Table 3).

policy. A detailed list of all variable names and definitions is included in the Internet Appendix (Table A.1).

3.3. Sample statistics

Our sample of plants and firms owning these plants covers virtually all states.[16] Over the sample period, the average annual emissions per plant is approximately 289,000 t, implying an aggregate average annual amount of 810 million metric tons. According to the EPA, the average amount of greenhouse gas emissions from the U.S. industrial sector over this period was 1430 million metric tons. Hence, approximately 57% of all industrial greenhouse gas emissions can be attributed to plants in our sample.

The focal state of our study, California, ranks third among all states in terms of the number of sample firms (i.e., 85 firms, or 17% of all firms), fourth in terms of the number of greenhouse gas emitting plants (i.e., 161 plants), and seventh in terms of average annual emissions per plant (i.e., 398,000 t). In short, California is a significant source of greenhouse gas emissions and takes up a sizable portion of the plants and firms in our sample, despite its dominance in the high-tech industry. The two largest states in the sample are Texas and Louisiana. Approximately 14% of our sample firms (i.e., 70 out of 511) and 82% of firms with a plant in California (i.e., 70 out of 85) are geographically diversified in the sense that they have a presence both in California and in other states. This final observation motivates our hypothesis that a policy curbing emissions in California alone could very well have spillover effects to other states that do not have such a comprehensive program in place.

Table 1 describes the characteristics of the sample firms and plants, separately for the set of financially constrained and unconstrained firms based on the composite measure of financial constraints. As shown in Panel A, the size of firms and amount of greenhouse gas they emit are positively skewed, consistent with the fact that a smaller number of large firms own more emission generating plants. Our sample is well balanced in terms of the composition of financially constrained and unconstrained firms. Financially constrained firms account for approximately 63% of all firm-years in our sample and about 48% of the firm-years of geographically diversified firms. As one would expect, constrained firms tend to be smaller, younger, more levered, equipped with less cash reserves, less profitable in terms of cash flows and return on assets (ROA), less valuable relative to book value, less R&D intensive, and more encumbered with physical assets. Due to their smaller size, constrained firms tend to emit less greenhouse gasses than unconstrained firms at the firm level. Notably, constrained firms are substantially less likely to have credit ratings on their long-term and short-term debt, consistent with Almeida et al. (2004).

Both constrained and unconstrained firms are highly likely to have a plant presence across different states conditional on also having a presence in California (i.e., 66% and 74%, respectively), although unconstrained firms are more likely to be diversified given the larger number of plants they operate both in California and in other states. Notwithstanding, the median firms with California plants are geographically dispersed for both groups of firms. For almost all plants, ownership is concentrated in one firm; that is, rarely do multiple firms share and operate the same plant.

Panel B of Table 1 shows the distribution of plant-level emissions, excess capacity, sales, and employment for the entire sample as well as separately for California and non-California plants owned by geographically diversified firms. Similar to firm-level emissions, plant emissions are also positively skewed. Interestingly, constrained firms are more emission intensive at the plant level, despite having lower sales and fewer employees at each plant, and despite emitting less at the firm level due to owning fewer plants. Importantly, plants owned by constrained firms also tend to have higher excess capacity, consistent with constrained firms being less able to maximally exploit profitable production and emission opportunities than unconstrained firms, leading them to rank-order projects and allocate resources accordingly. The increase in regulatory costs due to the California cap-and-trade rule shifts the ranking of projects, motivating constrained firms to reallocate toward low-cost production locations where they have excess capacity without incurring high capacity adjustment costs.

4. Empirical methodology: difference-in-differences

Our empirical strategy tests the hypothesis that the California cap-and-trade rule incentivizes financially constrained firms to reallocate emissions. It exploits variation in treatment of the California cap-and-trade rule in the cross section (i.e., plants in California vs. other states; or firms that own plants in California vs. firms that do not) and time series (i.e., before and after 2013) to implement DID regressions at the firm-plant-year level. If the trends in emissions for treated plants and non-treated plants are parallel prior to the implementation of the California cap-and-trade rule, the DID estimates will plausibly isolate the effects of the rule itself, insofar as no confounding events occur coincidentally with the introduction of the cap-and-trade rule. During our sample period from 2010 to 2015, the 2013 California cap-and-trade rule was indeed the only notable climate policy introduced to curb industrial greenhouse gas emissions.[17] Anticipation about the cap-and-trade rule prior to its implementation is also unlikely an

[16] See Table A.3 in the Internet Appendix for a detailed distribution of plants and firms across states.

[17] It was the first major regulation enforced to achieve the emission reduction objectives initially outlined and required by the landmark California state law AB 32, which was signed in 2006. After 2015, AB 32 was further strengthened by several subsequent legislative bills (e.g., SB 32 and AB 197 in 2016; AB 398 and AB 617 in 2017). Aside from AB 32, the governor of California signed SBX1 2 in 2011, requiring that one-third of the state's electricity come from renewable sources by 2020, and in 2014, the energy efficiency requirements for newly constructed buildings were tightened pursuant to updated Green Building Standards. However, these policies are distinct from the cap-and-trade rule in their enforcement targets, intensity, and timing. Hence, the emission shifting between industrial plants that we identify around 2013 primarily correspond to the impact of the introduction of the cap-and-trade rule.

Table 1
Firm and plant characteristics.
The table presents sample summary statistics of firm characteristics (Panel A) and plant characteristics (Panel B). In Panel A, emissions (in thousands of metric tons) are summed across plants owned by a firm and reported at the firm level. Total assets are in $ billion. Firm age is the difference between the observation year and founding year as in Jovanovic and Rousseau (2001). Short-term/long-term/total debt, cash, and cash flow are shown as fractions of total assets. Payout ratio is cash dividends plus repurchases divided by income before extraordinary items. Tobin's q is the market value of assets divided by the book value of assets. Profitability is return on assets (ROA). R&D is scaled by sales. R&D stock is calculated using the perpetual inventory method (Hall et al., 2005). PP&E and capital expenditures are shown as fractions of total assets. Rated is a dummy variable for whether the firm has a credit rating on either its long-term or short-term debt. DivFirm|CA plant is an indicator for whether the firm is geographically diversified conditional on having a plant in California. The number of plants owned by the firm is shown for all plants as well as separately for California and non-California plants conditional on the parent firm being geographically diversified. The panel reports the number of firm-year observations, average, median, and standard deviation (std. dev.) of these variables separately for the subsamples of financially constrained and unconstrained firms, classified based on the composite financial constraint measure. Panel B presents similar summary statistics for plant-level characteristics such as carbon emissions (thousand metric tons), excess capacity (measured as workers per $ million of sales), sales (in $ billion), and employment. These plant characteristics are summarized separately for constrained and unconstrained parent-firm subsamples, and also separately for California and non-California plants conditional on the parent firm being geographically diversified, that is, having plants both in California and in other states. All firm-level financial accounting data are from Compustat. Plant emissions and ownership data are from the EPA. Plant-level sales and employment data are from the NETS database, complemented with Compustat/Compustat segments. The sample period is 2010–2015.

Panel A: Summary statistics of firm characteristics

	Constrained firms				Unconstrained firms			
	Firm-year obs.	Average	Median	Std. dev.	Firm-year obs.	Average	Median	Std. dev.
Carbon emissions (thousands of metric tons)	1,257	1,342.99	288.04	3,847.42	728	1,822.30	306.21	3,754.36
Total assets ($ billions)	1,257	6.23	2.56	10.20	728	41.90	29.01	36.77
Firm age	1,257	23.27	18.00	17.10	728	43.09	50.00	18.89
Short-term debt	1,256	0.02	0.00	0.05	728	0.04	0.02	0.05
Long-term debt	1,250	0.30	0.28	0.20	727	0.23	0.21	0.12
Total debt	1,249	0.32	0.30	0.21	727	0.27	0.25	0.13
Cash	1,256	0.08	0.06	0.09	728	0.10	0.08	0.10
Cash flow	1,254	0.13	0.12	0.11	728	0.15	0.14	0.08
Payout ratio	1,257	0.39	0.11	1.40	728	0.72	0.60	1.03
Tobin's q	1,180	1.40	1.27	0.56	709	1.54	1.44	0.51
Profitability (ROA)	1,254	0.03	0.04	0.11	728	0.07	0.06	0.06
R&D	1,257	0.01	0.00	0.04	728	0.04	0.01	0.06
R&D stock	1,257	0.08	0.00	0.36	728	0.13	0.04	0.19
PP&E	1,256	0.52	0.48	0.24	728	0.35	0.28	0.22
Capital expenditures	1,253	0.11	0.06	0.12	728	0.06	0.04	0.06
Rated (long-term, >1 yr)	1,257	0.47	0.00	0.50	728	0.91	1.00	0.29
Rated (short-term, <1 yr)	1,257	0.01	0.00	0.07	728	0.71	1.00	0.45
DivFirm | CA plant	181	0.66	1.00	0.48	195	0.74	1.00	0.44
Number of plants owned by a firm	1,257	5.08	3.00	9.28	728	7.75	3.00	11.95
California | DivFirm	119	1.68	1.00	0.99	145	2.98	1.00	4.72
Other states | DivFirm	119	7.11	5.00	6.23	145	13.30	8.00	16.55

Panel B: Summary statistics of plant characteristics

	Constrained firms				Unconstrained firms			
	Plant-year obs.	Average	Median	Std. dev.	Plant-year obs.	Average	Median	Std. dev.
Carbon emissions (thousands of metric tons)	6,382	264.52	62.14	588.63	5,637	235.34	53.22	578.00
California | DivFirm	200	430.19	58.24	843.28	432	333.36	76.52	702.11
Other states | DivFirm	845	641.73	132.99	1,038.92	1,929	231.49	53.68	564.88
Excess Capacity (workers/$ millions of sales)	6,327	2.36	1.51	2.64	5,637	2.33	1.27	2.69
California | DivFirm	200	2.66	1.98	2.61	432	2.12	1.00	2.56
Other states | DivFirm	846	2.56	2.43	2.29	1,929	2.02	0.86	2.78
Sales ($ billions)	6,390	0.43	0.08	1.58	5,640	1.51	0.31	3.37
California | DivFirm	200	0.55	0.06	1.28	432	0.82	0.90	0.93
Other states | DivFirm	846	0.62	0.08	1.69	1,929	0.80	0.27	1.91
Employment	6,327	613	87	2,733	5,637	2,312	325	6,195
California | DivFirm	200	424	100	903	432	872	744	1,090
Other states | DivFirm	846	629	130	1,626	1,929	954	297	3,304

issue, as firms derive no economic benefit from preemptively reallocating their emissions when profits from emitting in California are still high before the onset of regulatory costs. The absence of such anticipatory adjustments is empirically evident in the emission trends.

In particular, we first compare the emissions of plants in and outside of California (see Panel A of Fig. 2). As our main hypotheses are aimed at examining the reallocation of emissions within firm internal networks, we focus our inspection on the sample of firms that are geographically

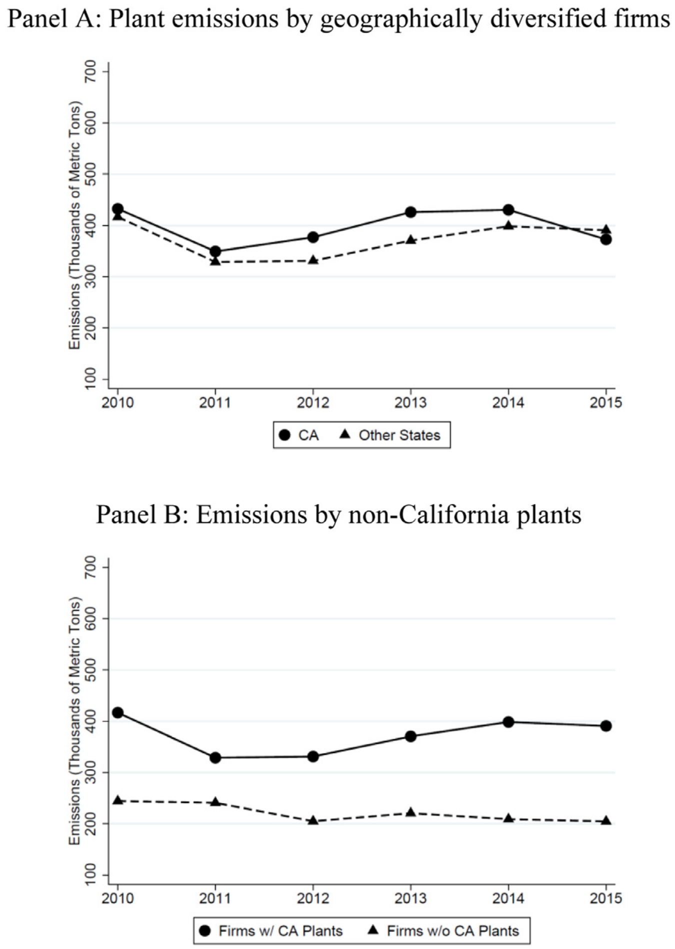

Fig. 2. Unconditional average emission responses to cap-and-trade rule. The figure shows average plant emissions (in thousands of metric tons) during the sample period 2010–2015, that is, before and after the enactment of the California cap-and-trade program at the beginning of 2013. Emissions of the treatment and control group are plotted as solid and dotted lines, respectively. Panel A shows emissions of plants in California and in other states based on geographically diversified firms. Panel B shows emissions of non-California plants for firms with and without plants in California.

diversified. The time trends show that emissions from California and non-California plants are closely aligned and parallel to each other prior to treatment. However, unconditionally, no visible divergence occurs after the rule is implemented.

This picture changes dramatically when we split the sample of geographically diversified firms into financially constrained and unconstrained firms (see Panel A of Fig. 3). For unconstrained firms, emissions from California and non-California plants move in parallel before the implementation of the cap-and-trade rule and largely maintain this pattern after 2013. In sharp contrast, for constrained firms, the parallel trends before 2013 begin to diverge afterwards, when California plants owned by constrained firms reverse their prior upward trend and start reducing emissions, whereas non-California plants sharply increase emissions. These trends illustrate how financial constraints condition the impact of the cap-and-trade rule on the allocation of emissions by firms across their plants in California and in other states.

Motivated by these trends, we formally test whether California and non-California plants adjust their emissions differentially in response to the cap-and-trade rule, using the following regression specification:

$$Log\left(1+Emissions_{i,j,t}\right) = \alpha + \beta CalPlant_j \times After_t + \gamma' X_{i,t} + a_j + b_{k,t} + \varepsilon_{i,j,t}, \qquad (1)$$

where $Log(1{+}Emissions_{i,j,t})$ is the logarithm of metric tons of CO_2e emitted by firm i at plant j in industry k. $CalPlant_j$ is an indicator variable equal to 1 if plant j is located in California, and 0 otherwise. $After_t$ is an indicator equal to 1 if the year is 2013 or after, and 0 otherwise. $X_{i,t}$ denotes a vector of firm-level control variables. Finally, a_j and $b_{k,t}$ each denote plant fixed effects and industry-by-year fixed effects, respectively. Industry is defined at the plant level using their NAICS industry codes. The variables $CalPlant_j$ and $After_t$ are not included by themselves in the regressions, as they are subsumed by the fixed effects. We adjust standard errors for clustering at the firm and state levels. To study the impact of financial constraints on

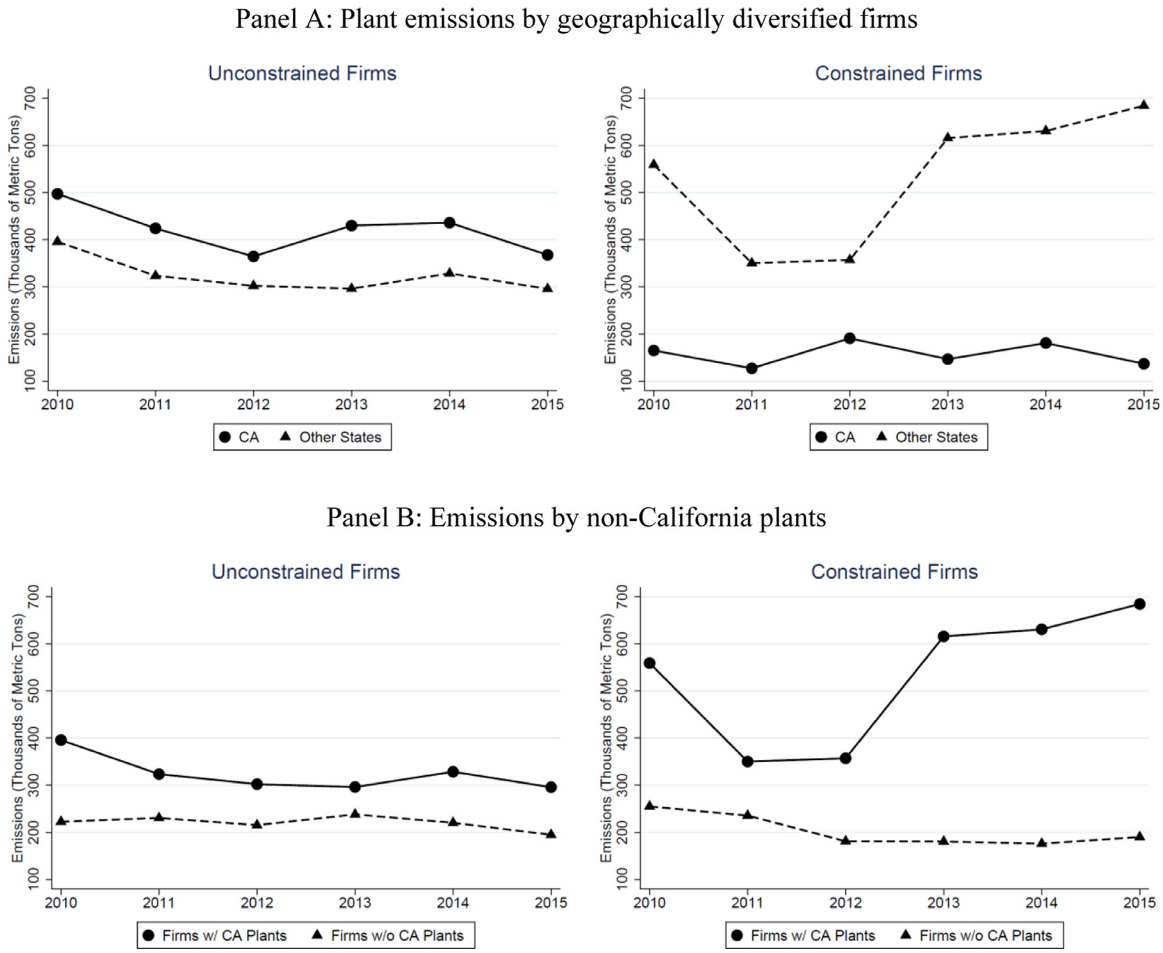

Fig. 3. Average emission responses of constrained vs. unconstrained firms. The figure shows average plant emissions (in thousands of metric tons) separately for constrained and unconstrained firms during the sample period 2010–2015, that is, before and after the enactment of the California cap-and-trade program at the beginning of 2013. Emissions of the treatment and control group are plotted as solid and dotted lines, respectively. Separately for constrained and unconstrained firms, the figure shows two sets of graphs: Panel A shows emissions of plants in California and in other states based on geographically diversified firms. Panel B shows emissions of non-California plants for firms with and without plants in California.

how firms respond to the cap-and-trade rule, we estimate Eq. (1) separately for constrained and unconstrained firms, and evaluate whether the coefficients on the interaction term $CalPlant_j \times After_t$ are significantly different in the two models.

To study emission spillovers to plants in other states that would not have occurred otherwise, it is useful to compare the emissions from plants outside of California owned by firms that also have plants in California with a control group of non-California plants owned by firms without any operations in California. A visual comparison of the emissions of these groups of plants shows that the parallel trend assumption holds, but unconditionally, no visible changes exist in the post-trends either (see Panel B of Fig. 2). However, constrained firms with California plants substantially increase emissions from their non-California plants during the post-2013 period, whereas no changes occur for plants owned by constrained firms without exposure to California or unconstrained firms regardless of their California exposure (see Panel B of Fig. 3), suggesting a strong spillover effect from constrained firms exposed to the California cap-and-trade rule shifting their emissions to other states.[18]

To test these spillover effects formally, we replace the plant-level treatment dummy $CalPlant_j$ in Eq. (1) with a firm-level dummy $DivFirm_{i,t}$, which is an indicator for whether a firm owns plants both in California and in other states during a given year:

$$Log(1 + Emissions_{i,j,t}) = \alpha + \beta_1 DivFirm_{i,t} + \beta_2 DivFirm_{i,t} \times After_t + \gamma' X_{i,t} + a_j + b_{k,t} + \varepsilon_{i,j,t}. \tag{2}$$

As $DivFirm_{i,t}$ is not subsumed by fixed effects, it is also included as a regressor by itself. This firm-plant-year-level

[18] Moreover, paired t-tests as suggested by Roberts and Whited (2013) reveal that the average emission growth rates during the pre-cap-and-trade period of 2010–2012 are not statistically different between treatment and control plants, but are significantly different during the post-period of 2013–2015.

regression is run on the subsample of non-California plants to assess whether their changes in emissions after the cap-and-trade rule depend on whether the parent companies' assets are affected. The model is estimated separately for constrained and unconstrained firms. Standard errors are clustered at the firm level.

As an alternative to comparing coefficients from separate DID regressions on constrained and unconstrained subsamples, we run pooled regressions by including a $Constrained_i$ dummy in an expanded triple-difference framework. The triple-difference specifications can be written as follows:

$$\begin{aligned} Log(1+Emissions_{i,j,t}) &= \alpha + \beta_1 Constrained_i \\ &+ \beta_2 After_t \times Constrained_i + \beta_3 CalPlant_j \times Constrained_i \\ &+ \beta_4 CalPlant_j \times After_t \\ &+ \beta_5 CalPlant_j \times After_t \times Constrained_i \\ &+ \gamma' X_{i,t} + a_j + b_{k,t} + \varepsilon_{i,j,t} \end{aligned} \tag{3}$$

and

$$\begin{aligned} Log(1+Emissions_{i,j,t}) &= \alpha + \beta_1 Constrained_i + \beta_2 DivFirm_{i,t} \\ &+ \beta_3 After_t \times Constrained_i + \beta_4 DivFirm_{i,t} \times Constrained_i \\ &+ \beta_5 DivFirm_{i,t} \times After_t \\ &+ \beta_6 DivFirm_{i,t} \times After_t \times Constrained_i \\ &+ \gamma' X_{i,t} + a_j + b_{k,t} + \varepsilon_{i,j,t}. \end{aligned} \tag{4}$$

This method overcomes issues related to model fit or misspecification that may be compounded by comparing coefficients across multiple models, and enables the econometrician to control for differences across other coefficients in the model as well. We use both the subsample and pooled regressions for the analyses on emissions and focus on the pooled regression method in subsequent analysis.

5. Results

5.1. Impact of financial constraints

5.1.1. Reallocation of emissions and spillover effects

In Table 2, we report results from regressing the logarithm of emissions (*Log(1+Emissions)*) on treatment indicators, plant and industry-by-year fixed effects, as well as firm controls. In Panel A, we examine how geographically diversified firms that operate plants both in and outside of California respond to the California cap-and-trade rule by adjusting their emissions in California relative to their emissions elsewhere. In Panel B, we further explore spillover effects induced by emission reallocations following the cap-and-trade rule, by focusing on non-California plants comparing plants owned by firms affected by the new regulation with those of firms that are not. In each panel, we first discuss unconditional results without exploiting heterogeneity in financial constraints across firms to understand the overall effects of the California cap-and-trade rule, and then further explore the financial constraints channel through which they manifest.

In Panel A, we start by estimating Eq. (1) on the sample of geographically diversified firms. The key coefficient is on the interaction term *CalPlant* × *After*, which captures the differential treatment effect of the introduction of the cap-and-trade rule on emissions. The first column controls for plant and year fixed effects but does not include any firm-level controls, whereas the second column additionally controls for plant industry-by-year fixed effects as well as firm size, Tobin's *q*, ROA, total debt, and R&D stock. The sign on the interaction term's coefficient is consistently negative across the first two columns, and the magnitude is also similar despite the addition of controls in the second column. In the second column, the coefficient on the interaction term is negative (−0.151) and significant at the 1% level. In terms of economic magnitude, the result indicates that firms reduce emissions from California plants by 15% more than from non-California plants.

The next four columns in Panel A examine whether this effect is different for plants owned by financially constrained firms and those operated by unconstrained firms. These subsample regressions show that constrained firms reduce their emissions from California plants more than from plants in other states, whereas unconstrained firms do not. This result holds controlling for plant and year fixed effects (columns (3) and (4)), and is also robust to additionally controlling for industry-by-year fixed effects (columns (5) and (6)). As reported in columns (5) and (6), constrained firms reduce emissions from California plants by 28% more (significant at the 1% level) compared with non-California plants, whereas this effect is economically and statistically insignificant for unconstrained firms. The difference between the responses by constrained and unconstrained firms is statistically significant with a one-sided *p*-value of 0.01.

In column (7) of Panel A, we pool the samples of constrained and unconstrained firms and include a *Constrained* dummy in a triple-difference regression following Eq. (3), instead of running separate regressions and comparing coefficients across the two models. The main coefficient of interest is the triple-interaction term *CalPlant* × *After* × *Constrained*, which captures how firms change their emissions from plants in California relative to plants in other states, depending on whether they are financially constrained. We expect the coefficient on this term to be negative, as constrained firms are expected to reduce emissions in California by more. Also relevant is the coefficient on *CalPlant* × *After*, which in this context measures how unconstrained firms behave. Because we find virtually no responses by unconstrained firms based on the results reported in the previous columns, we do not expect this coefficient to be significantly different from zero. The results confirm that it is indeed insignificant. Column (7) shows that for firms with plants both in and outside of California, the coefficient on the triple-interaction term is economically large and negative and statistically significant at the 1% level. The magnitude of the coefficient, −0.39, is also consistent with the size of the difference between the coefficients of constrained and unconstrained firms in columns (5) and (6) of −0.28 and 0.09, respectively. The coefficient on *CalPlant* × *After*, on the other hand, is small and insignificant, consistent with our prior.

In Panel B of Table 2, we investigate whether the treatment effect identified in Panel A can be explained by reallocations or spillovers to plants outside of California, by estimating Eq. (2) on the sample of non-California plants. In the first two columns, the results indicate unconditionally significant spillover effects, where the coefficients on *DivFirm* × *After* are positive and significant at the 10% level. Controlling for plant and industry-by-year fixed effects as well as firm-level variables, non-California plants owned by firms exposed to the California cap-and-trade rule increase emissions by 14% more than plants of non-diversified firms.

Next, we run this regression separately for the sample of financially constrained and unconstrained firms, and formally compare the coefficients on *DivFirm* × *After* across the two models. The results in columns (3)–(6) of Panel B are consistent with a strong spillover effect whereby constrained firms significantly increase their emissions from plants outside California if they are exposed to the increased regulatory burden of the California cap-and-trade rule. Specifically, these firms increase their non-California plant emissions by 29% more (significant at the 5% level) than those without plants in California when we control for plant and year fixed effects. Controlling for industry-by-year fixed effects, the relative increase is 18% (significant at the 10% level). For unconstrained firms, the relative change in emissions is not statistically significant. The difference between the responses by constrained and unconstrained firms is significant at the 5% level or better.

In column (7) of Panel B, we examine the coefficient on *DivFirm* × *After* × *Constrained* and *DivFirm* × *After* by estimating Eq. (4). Based on the results in the previous columns, we expect the triple-interaction term to be positive and significant because constrained firms are more

Table 2
Plant emission responses to California cap-and-trade rule.
The table presents results from plant-level DID regressions. Panel A compares California and non-California plants of geographically diversified firms. Panel B studies spillovers to non-California plants comparing plants of geographically diversified and non-diversified firms. The dependent variable is log (1+Emissions). The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. The indicator variable After is equal to 1 if the time period is 2013 or onward, and 0 otherwise. The firm-level dummy variable DivFirm is an indicator for whether a firm owns plants both in California and in other states during a given year. The firm-level dummy variable Constrained is an indicator for whether a firm is financially constrained according to our composite measure. Columns (1)–(2) present unconditional results. Columns (3)–(6) present conditional results for subsample splits based on financial constraints, also reporting *p*-values from testing the statistical difference of the CalPlant x After coefficients between the constrained and unconstrained subsamples. Column (7) presents conditional analysis by pooling the constrained and unconstrained samples and including the Constrained dummy variable instead. Control variables include firm size (log of total assets), Tobin's *q*, ROA, total debt, and R&D stock as well as plant and year or industry-by-year fixed effects. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variable: Log(1+Emissions)						
			Financial constraint subsamples				
			Const.	Unconst.	Const.	Unconst.	Pooled
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
CalPlant × After	−0.161***	−0.151***	−0.334***	0.079	−0.282***	0.094	0.075
	(0.014)	(0.019)	(0.053)	(0.080)	(0.096)	(0.118)	(0.073)
p: Const.<Unconst.			[0.00]		[0.01]		
CalPlant × After × Const.							−0.390***
							(0.094)
CalPlant × Const.							0.778
							(0.934)
After × Const.							0.030
							(0.098)
Const.							−2.459***
							(0.891)
Size		0.101	0.066	−0.349***	0.020	−0.340**	−0.167
		(0.110)	(0.201)	(0.116)	(0.110)	(0.143)	(0.137)
Tobin's q		0.132	0.138	0.159	0.162	0.201	0.196
		(0.206)	(0.120)	(0.269)	(0.175)	(0.318)	(0.227)
ROA		0.553**	1.802**	1.194**	1.836**	1.900***	1.589**
		(0.269)	(0.688)	(0.458)	(0.747)	(0.588)	(0.630)
Total debt		−0.021	1.568*	2.729	1.647**	3.081	2.294*
		(0.524)	(0.826)	(1.878)	(0.725)	(2.135)	(1.224)
R&D stock		−5.920	2.069	−3.461	2.065	−4.449	−3.165
		(6.320)	(2.819)	(4.893)	(2.889)	(5.613)	(5.304)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	No	No	No
Industry-by-year FE	No	Yes	No	No	Yes	Yes	Yes
Observations	3,961	3,592	963	2,187	961	2,178	3,149
Adjusted R^2	0.862	0.865	0.905	0.832	0.904	0.832	0.858

(*continued on next page*)

Table 2
(*continued*)

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variable: Log(1+Emissions)						
			Financial constraint subsamples				
			Const.	Unconst.	Const.	Unconst.	Pooled
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DivFirm × After	0.140*	0.139*	0.285**	−0.089	0.175*	−0.094	−0.040
	(0.072)	(0.078)	(0.124)	(0.066)	(0.093)	(0.082)	(0.089)
p: Const.>Unconst.			[0.00]		[0.02]		
DivFirm × After × Const.							0.304**
							(0.130)
DivFirm × Const.							−0.614**
							(0.272)
After × Const.							−0.344***
							(0.115)
Const.							0.147
							(0.263)
DivFirm	−0.155	−0.182	−0.365*	0.006	−0.445**	−0.049	0.011
	(0.176)	(0.175)	(0.200)	(0.185)	(0.176)	(0.134)	(0.192)
Size		0.022	0.048	0.025	0.115	0.029	0.053
		(0.052)	(0.135)	(0.210)	(0.155)	(0.222)	(0.095)
Tobin's q		0.079	0.438**	0.019	0.361*	0.050	0.229*
		(0.106)	(0.199)	(0.137)	(0.193)	(0.167)	(0.124)
ROA		0.003	0.302	0.333	0.057	0.248	−0.024
		(0.265)	(0.404)	(0.369)	(0.445)	(0.437)	(0.326)
Total debt		0.268	0.524	1.444	0.421	1.500	0.731
		(0.341)	(0.534)	(1.163)	(0.473)	(1.183)	(0.450)
R&D stock		0.435	0.702	−0.728	1.126	−0.865	0.947
		(0.381)	(1.090)	(1.627)	(1.101)	(1.669)	(0.755)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	No	No	No
Industry-by-year FE	No	Yes	No	No	Yes	Yes	Yes
Observations	12,521	11,272	5,466	4,854	5,457	4,842	10,401
Adjusted R^2	0.745	0.742	0.716	0.779	0.724	0.781	0.733

likely to shift their emissions to other states if their assets are exposed to the California cap-and-trade rule. We also expect the double-interaction term to not be significantly different from zero, because unconstrained firms should not exhibit differential changes in their plants outside of California. Consistent with these predictions, the coefficient on *DivFirm* × *After* × *Constrained* is positive and large in magnitude, and also statistically significant at the 5% level. The magnitude of the coefficient, 0.30, closely matches the difference in the coefficients for the constrained and unconstrained firm subsamples. The coefficient on *DivFirm* × *After* is indistinguishable from zero, also consistent with our prediction.

Overall, the results in Table 2 suggest unintended consequences of the cap-and-trade rule in the form of spillover effects due to reallocation motives of firms whose assets are affected by the regulation. Importantly, our findings provide an economic channel for such reallocations and spillover effects, highlighting that financial constraints constitute an important friction that motivates firms to shift resources internally across their plants. Without such frictions, firms would simply raise additional capital to absorb the increased costs of emissions as long as operating in California yields positive net returns.

5.1.2. Alternative specifications, samples, and placebo tests

Table 3 provides results from a number of robustness tests using alternative measures of financial constraints, using alternative specifications and samples, studying plant sales and acquisitions, and conducting placebo tests. Similar to the previous table, the results comparing emissions from California and non-California plants owned by geographically diversified firms are reported in Panel A, and the tests for spillover effects comparing non-California plant emissions by diversified and non-diversified firms are reported in Panel B. To streamline presentation, we discuss Panels A and B together.

In the first column, we reiterate our results from column (7) of Table 2 as the baseline benchmark. In columns (2)–(7), we classify constrained and unconstrained firms based on six alternative proxies, instead of using our composite measure. These proxies, which are the basis for our composite measure, are the Kaplan-Zingales index, Hadlock-Pierce index, Whited-Wu index, firm size, payout, and credit rating availability. Our main result is qualitatively robust across all of these measures yielding economically meaningful and consistent estimates, the majority of which are also statistically significant. Panel A shows that for firms with plants both in and outside of California, the coefficient on the triple-interaction term, *CalPlant* × *Af-*

Table 3

Firm financial constraints and plant emission responses: alternative specifications.

The table reports results from pooled triple-difference regressions. Results in Panel A compare California and non-California plants of geographically diversified firms. Panel B studies spillovers to non-California plants comparing plants of geographically diversified and non-diversified firms. The dependent variable is log (1+Emissions). The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. The indicator variable After is equal to 1 if the time period is 2013 or onward, and 0 otherwise. The firm-level dummy variable DivFirm is an indicator for whether a firm owns plants both in California and in other states during a given year. The firm-level dummy variable Constrained is an indicator for whether a firm is financially constrained according to each financial constraint measure, that is, alternatively, our composite measure (column (1)), the Kaplan-Zingales (KZ) index (column (2)), Hadlock-Pierce (HP) index (column (3)), Whited-Wu (WW) index (column (4)), firm size (column (5)), payout ratio (column (6)), and credit rating (column (7)). Control variables include firm size (log of total assets), Tobin's *q*, ROA, total debt, and R&D stock, all possible interactions between CalPlant (Panel A), DivFirm (Panel B), After, and Constrained, as well as plant and industry-by-year fixed effects. In column (8), we further include firm-by-year fixed effects (Panel A) or firm fixed effects (Panel B). In column (9), the sample is extended to include firms in the utilities industry (i.e., two-digit SIC code 49). In columns (10)–(11), the dependent variable is replaced by indicator variables for whether the firm reduces (i.e., Plant sales) or increases (i.e., Plant acquisitions) its ownership in a plant. In columns (12)–(13), California plants are dropped from the sample, and the treatment variables, CalPlant and DivFirm, are each replaced by a dummy variable indicating whether the plant is located in a placebo state and a dummy variable indicating whether a non-placebo state plant is owned by a firm that also has a placebo state operation, respectively, where Texas and Louisiana are used as alternative placebo states. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variable: Log(1+Emissions)												
		Alternative constraint measures						Alt. specifications and samples		Plant sales and acquisitions		Placebo states	
	Composite (1)	KZ (2)	HP (3)	WW (4)	Size (5)	Payout (6)	Rating (7)	Firm-year FE (8)	Include utilities (9)	Plant sales (10)	Plant acq. (11)	Texas (12)	Louisiana (13)
CalPlant × After × Const.	−0.390***	−0.189**	−0.512***	−0.184	−0.590**	−0.303**	−0.133	−0.270	−0.455***	0.088***	−0.028	−0.152	−0.151
	(0.094)	(0.080)	(0.170)	(0.145)	(0.237)	(0.145)	(0.111)	(0.195)	(0.084)	(0.017)	(0.019)	(0.091)	(0.115)
CalPlant × After	0.075	−0.026	−0.001	−0.083	0.015	−0.055	−0.053	0.001	0.102	0.008	0.027	−0.100***	−0.031
	(0.073)	(0.082)	(0.059)	(0.062)	(0.071)	(0.120)	(0.072)	(0.092)	(0.078)	(0.018)	(0.021)	(0.037)	(0.067)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm-by-year FE	No	No	No	No	No	No	No	Yes	No	No	No	No	No
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,149	3,059	3,149	3,078	3,134	3,149	3,149	3,159	3,564	2,692	2,923	6,105	4,425
Adjusted R^2	0.858	0.861	0.854	0.856	0.860	0.856	0.856	0.891	0.863	0.431	0.185	0.731	0.749

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variable: Log(1+Emissions)												
		Alternative constraint measures						Alt. specifications and samples		Plant sales and acquisitions		Placebo states	
	Composite (1)	KZ (2)	HP (3)	WW (4)	Size (5)	Payout (6)	Rating (7)	Firm-year FE (8)	Include utilities (9)	Plant sales (10)	Plant acq. (11)	Texas (12)	Louisiana (13)
DivFirm × After × Const.	0.304**	0.446**	0.124	0.236	0.356*	0.064	0.254*	0.156	0.234**	−0.029	−0.012	−0.133	0.006
	(0.130)	(0.211)	(0.166)	(0.169)	(0.202)	(0.160)	(0.150)	(0.138)	(0.112)	(0.055)	(0.060)	(0.133)	(0.226)
DivFirm × After	−0.040	−0.043	0.042	0.058	0.036	0.110	−0.037	0.056	−0.017	0.034	0.055	0.211**	0.082
	(0.089)	(0.110)	(0.086)	(0.070)	(0.080)	(0.084)	(0.100)	(0.084)	(0.085)	(0.035)	(0.045)	(0.086)	(0.157)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	No	No	No	Yes	No	No	No	No	No
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,401	10,074	10,395	9,968	10,346	10,183	10,401	10,397	15,582	8,231	9,318	8,317	9,373
Adjusted R^2	0.733	0.734	0.732	0.728	0.733	0.730	0.733	0.754	0.779	0.289	0.219	0.752	0.730

ter × *Constrained*, is economically large and negative (at least statistically significant at the 5% level for four of the six measures), whereas the coefficient on *CalPlant* × *After* is small and insignificant for all of the alternative financial constraint measures. Panel B shows for the sample of non-California plants that the coefficient on the triple-interaction term, *DivFirm* × *After* × *Constrained,* is economically large and positive (at least statistically significant at the 10% level for three of the six measures), whereas the coefficient on *DivFirm* × *After* is indistinguishable from zero across all measures.

In column (8), we report the result from a stringent specification with firm-by-year (Panel A) or firm (Panel B) fixed effects, which subsumes the impact of any observed and unobserved firm characteristic that may be time-varying or persistent. Although this regression makes heavy demands on the data, we find economically consistent point estimates for the coefficients on the interaction terms. In Panel A, the key term *CalPlant* × *After* × *Constrained* loads negatively with a point estimate of –0.27, whereas the coefficient on the *CalPlant* × *After* term remains close to zero. In Panel B, the coefficient on *DivFirm* × *After* × *Constrained* is 0.16, whereas that on *DivFirm* × *After* is less than 0.06. In column (9), we run a robustness check by including utility firms (i.e., firms with two-digit SIC codes 49) in our sample. Although the strategic responses by utilities to a local climate policy are unlikely to resemble those of unregulated industrial firms, due to the fact that utilities are regulated both locally by local public service commissions and federally regarding any interstate service transmissions, we nonetheless find our results are robust to including them in the sample.

In columns (10) and (11), we ask whether firms also shift their emissions by reconfiguring the geographical distribution of their plants in response to the cap-and-trade rule. If future regulatory costs are expected to exceed the adjustment costs of selling or acquiring plants, firms may choose to reallocate emissions on the extensive margin. On the other hand, changes in variable operating costs imposed by the cap-and-trade rule may not be sufficient to induce large investments or divestments of fixed assets. To answer this question, we define two binary variables, each indicating whether the firm reduces or increases ownership in a plant, respectively, and use them as dependent variables in a linear probability model analogous to the pooled regression models in Eqs. (3) and (4). All plant ownership reductions in our sample are transfers of plant ownership to other firms, and none of them are physical closures. Hence, we denote the dummy variable indicating a plant ownership reduction as *Plant Sales*. Increases in plant ownership are indicated by the dummy variable *Plant Acquisitions*.[19] The results show that although financially constrained firms are more likely to sell plants in California, we find no effect on firms' decisions to acquire plants in California or to sell or acquire plants in other states. Unconstrained firms are unaffected in their likelihood of adjusting plant ownership. Overall, the only external margin on which constrained firms adjust plant ownership is the sale of California plants, which is consistent with these firms selling less profitable assets to improve financial flexibility.

In columns (12) and (13), we conduct placebo tests to rule out concerns of spurious effects that may affect California and other heavy greenhouse gas emitting states similarly. We drop California plants from the sample and use two alternative states that are the most important greenhouse gas emitters aside from California, namely Texas and Louisiana, as placebo states. We test whether geographically diversified firms (i.e., firms with a presence both in the placebo state and in other states) reduce plant emissions in the placebo state relative to other states, whether these firms create emission spillovers in other states, and whether these effects are related to firm financial constraints. For both placebo states, we run regressions following Eqs. (3) and (4) and do not find results similar to our main findings. We find no indication that plants in placebo states owned by constrained firms significantly reduce emissions by more than plants in other states, nor any evidence of spillover effects from placebo states to other states that are driven by financial constraints. Given the large number of observations in the placebo tests, the lack of significance is unlikely a result of low statistical power. In short, our main results are not driven by confounding factors coinciding with the introduction of the California cap-and-trade rule that affect other major greenhouse gas emitting states in similar ways.

In summary, our results provide strong and consistent evidence that (a) firms owning plant operations both in California and in other states reduce emissions from their plants in California relative to plants in other states, (b) that these firms increase emissions from their plants in other states relative to firms with no presence in California, and (c) that these effects are almost exclusively due to their financial constraints.

5.2. Economic mechanisms

In this section, we perform several additional tests to corroborate and sharpen the interpretation of our main results, and discuss the potential of alternative confounding explanations. In particular, we focus on examining how financially constrained firms reallocate emissions in response to the California cap-and-trade rule.

5.2.1. Economic role of plants within the supply chain

In Table 4, we study whether the role of plants within a firm's organizational structure, or supply chain, matters for the emission reallocations by financially constrained firms. If firms are responding to the cap-and-trade rule by shifting economic activity, emissions should be reallocated from plants in California to plants in other states that play similar economic roles. To test this hypothesis, we identify whether plants owned by the same firm are "horizontally linked," "vertically linked," or "unrelated" with each other, using the BEA input-output accounts. Horizontally linked plants are presumed to have similar functions in the firm's production network, whereas vertically linked or unrelated plants are assumed to have distinct functions.

[19] Most ownership changes in our sample are discrete, either changing from complete ownership to zero ownership, or from zero ownership to complete ownership. Fractional ownership changes are rare.

Table 4
Emission reallocations within the supply chain.
The table reports results from triple-difference regressions testing emission reallocations toward plants outside of California that play similar (i.e., horizontally linked) or dissimilar (i.e., vertically linked or unrelated) roles to those in California owned by the same firm, identified using plant-level NAICS codes and the 2007 make and use tables from the BEA input-output accounts. Results in Panel A compare emissions from California plants with non-California plants with which they are horizontally linked (column (1)) or vertically linked/unrelated (column (2)). Panel B studies non-California plants owned by geographically diversified and non-diversified firms, comparing plants horizontally linked (column (1)) or vertically linked/unrelated (column (2)) to California plants with other plants owned by firms unaffected by the cap-and-trade rule. *p*-values from comparing the triple-interaction terms across the two samples (columns (1) and (2)) are also reported. Columns (3)–(8) perform similar analysis, further controlling for the emissions, number, and fraction of vertically linked or unrelated (horizontally linked) plants when analyzing horizontal (vertical or unrelated) reallocations. The dependent variable is log (1+Emissions). The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. The indicator variable After is equal to 1 if the time period is 2013 or onward, and 0 otherwise. DivFirm is an indicator variable for whether a firm owns plants both in California and in other states during a given year. Constrained is an indicator variable for whether a firm is financially constrained according to our composite measure. Control variables include firm size, Tobin's *q*, ROA, total debt, and R&D stock, all possible interactions between CalPlant (Panel A), DivFirm (Panel B), After, and Constrained, as well as plant and industry-by-year fixed effects. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variable: Log(1+Emissions)							
	Supply chain linkage with California plant							
	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CalPlant × After × Const.	−0.359***	−0.154*	−0.359***	0.030	−0.351***	0.011	−0.370***	−0.005
	(0.103)	(0.078)	(0.105)	(0.142)	(0.109)	(0.125)	(0.102)	(0.152)
p: Hor<Ver	[0.06]		[0.01]		[0.01]		[0.02]	
CalPlant × After	0.048	0.075	0.049	−0.095	0.052	−0.075	0.044	−0.045
	(0.105)	(0.093)	(0.097)	(0.122)	(0.106)	(0.133)	(0.104)	(0.151)
Other network plant emissions			−0.001	−0.109**				
			(0.014)	(0.050)				
Other network plant number					−0.087	−0.554**		
					(0.070)	(0.239)		
Other network plant fraction							0.196	−1.114
							(0.246)	(0.759)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,307	1,711	2,307	1,711	2,307	1,711	2,307	1,711
Adjusted R^2	0.869	0.851	0.869	0.868	0.869	0.868	0.869	0.857

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variable: Log(1+Emissions)							
	Supply chain linkage with California plant							
	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated	Horizontal	Vertical or unrelated
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DivFirm × After × Const.	0.332**	0.073	0.315**	0.026	0.316**	0.017	0.318**	0.038
	(0.154)	(0.141)	(0.148)	(0.133)	(0.149)	(0.131)	(0.149)	(0.130)
p: Hor>Ver	[0.11]		[0.07]		[0.07]		[0.08]	
DivFirm × After	−0.005	−0.117	0.018	−0.060	0.021	−0.050	0.011	−0.079
	(0.103)	(0.115)	(0.098)	(0.103)	(0.098)	(0.097)	(0.098)	(0.100)
Other network plant emissions			0.017	−0.066*				
			(0.017)	(0.040)				
Other network plant number					0.135	−0.362		
					(0.117)	(0.244)		
Other network plant fraction							0.311	−0.509
							(0.245)	(1.024)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,152	2,552	8,152	2,552	8,152	2,552	8,152	2,552
Adjusted R^2	0.717	0.841	0.717	0.848	0.718	0.847	0.717	0.842

Using this mapping of plant networks within firms, we analyze whether constrained firms reallocate their emissions in response to California's cap-and-trade rule more toward plants in other states that play roles similar to their California plants. In Panel A of Table 4, we estimate the triple-difference regression of Eq. (3) for subsamples in which we compare emissions from California plants with a subset of non-California plants with which they are horizontally linked (column (1)) or vertically linked/unrelated (column (2)). The results indicate that California plants owned by financially constrained firms reduce their emissions significantly more than plants outside California that are horizontally linked to plants in California, but not as much when compared with vertically linked or unrelated non-California plants.

In Panel B, we study non-California plants owned by geographically diversified and non-diversified firms, comparing plants that are horizontally linked (column (1)) or vertically linked/unrelated (column (2)) to California plants with other plants of firms unaffected by the cap-and-trade rule. These results show that among non-California plants that share horizontal linkages with other plants of the same firm, plants that are horizontally linked to California plants increase their emissions significantly more than plants that are linked this way to other plants of firms that have no exposure to California. By contrast, we find non-California plants that are vertically linked or unrelated to California plants do not differentially increase their emissions compared with plants that are linked in this way to other plants of firms that do not have operations in California.

Columns (3)–(8) of Table 4 perform similar analysis, further controlling for the emissions, number, and fraction of vertically linked or unrelated (horizontally linked) plants when analyzing horizontal (vertical or unrelated) reallocations to take into account the confounding effects of alternative production linkages between plants when assessing emission reallocations through one type of linkage. The results are robust to controlling for such effects.

Notably, the differences between horizontal and non-horizontal reallocations are economically and statistically significant. For example, the coefficients on the triple-interaction terms in columns (3) and (5) are more than 10 times as large as those in columns (4) and (6), respectively. The *p*-value comparing these coefficients is 0.01 in Panel A and 0.07 in Panel B. Together, these results suggest that constrained firms indeed reallocate emissions by shifting production across plants that play similar operational roles, rather than categorically shifting activity toward different types of plants.

5.2.2. Financial constraints and excess capacity

Key to understanding how financially constrained firms shift emissions in response to the cap-and-trade, and why unconstrained firms do not, is the idea that constrained firms' resources are limited, and as a result of rank-ordering and choosing maximally profitable projects, they are more likely to carry excess capacity built up during good times (see Von Kalckreuth, 2006; Dasgupta et al., 2019). Unconstrained firms are likely to be at capacity as long as doing so is profitable, as they do not need to rank-order projects to allocate capital. Consistent with this idea, we find that financially constrained firms have more excess capacity at their plants (see Table 1). This excess capacity motivates and enables constrained firms to reallocate their emissions when the rankings of high excess capacity production locations improve. Plants with high excess capacity are also where increasing production and emissions is the least costly.

In Table 5, we test whether constrained firms reallocate emissions more toward plants with greater production gaps or higher excess capacity. We sort non-California plants owned by firms exposed to California's cap-and-trade rule into high and low excess capacity groups with respect to the cross sectional median based on their ratio of employment to sales. In Panel A, we compare the change in emissions around the cap-and-trade rule from California plants with those from horizontally linked non-California plants with either high or low excess capacity in two separate regressions. Focusing on the interaction term *CalPlant* × *After* × *Constrained*, the results show that constrained firms reduce their emissions at California plants compared with non-California plants with high excess capacity (coefficient of –0.46, significant at the 1% level), but not when compared with non-California plants with low excess capacity (coefficient of –0.02, insignificant). The difference between these coefficients is statistically significant with a *p*-value of 0.03.

Analogously, in Panel B of Table 5, we show that among non-California plants that have horizontal linkages with other plants of the same firm, plants of firms exposed to California's cap-and-trade rule significantly increase emissions compared with plants of unaffected firms, primarily when they have high excess capacity (i.e., coefficient on *DivFirm* × *After* × *Constrained* of 0.41, significant at the 5% level) but not when they have low excess capacity (i.e., coefficient of 0.14, insignificant). Overall, these results suggest that the response by financially constrained firms to California's cap-and-trade rule arises from a distortion in the variable costs of production altering the relative net present value rankings of emission projects across different locations, and are also consistent with theoretical models of investment adjustment costs and financial constraints.

5.2.3. Carbon efficiency vs. production shifting

An important social welfare question is whether plants change emissions by producing the same quantity of goods in a more environmentally efficient manner or by shifting the quantity of production across plants. We answer this question using data on plant-level sales and employment to estimate regression models similar to Eqs. (3) and (4), but use carbon efficiency (i.e., emissions to sales ratio), production output (i.e., sales), employment, and excess capacity (i.e., employment to sales ratio) as dependent variables.

Panel A of Table 6 shows how these metrics evolve at plants in California compared with plants located elsewhere, for plants that are owned by geographically diversified firms. Panel B reports the responses for non-California plants owned by firms exposed to the cap-and-trade rule compared with plants owned by firms without any Cal-

Table 5
Emission reallocations to plants with excess capacity.
The table reports results from triple-difference regressions testing emission reallocations toward plants outside of California that have high or low excess capacity, where excess capacity is measured as end-of-current-year employment divided by current-year sales. Plant-level sales and employment data are from the NETS database, complemented with Compustat/Compustat Segment data as described in Section 3. The analysis considers the sample of plants that share horizontal linkages with other plants owned by the same firm, in particular with California plants if the firm has operations in California. For geographically diversified firms, results in Panel A compare emissions from California plants with non-California plants with higher (column (1)) or lower (column (2)) than median excess capacity in the previous year. Panel B studies non-California plants owned by geographically diversified and non-diversified firms, comparing high (column (1)) or low (column (2)) excess capacity plants owned by firms affected by the cap-and-trade rule with plants owned by firms unaffected by the rule. p-values from comparing the triple-interaction terms across the two samples (columns (1) and (2)) are also reported. The dependent variable is log (1+Emissions). The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. The indicator variable After is equal to 1 if the time period is 2013 or onward, and 0 otherwise. DivFirm is an indicator variable for whether a firm owns plants both in California and in other states during a given year. Constrained is an indicator variable for whether a firm is financially constrained according to our composite measure. Control variables include firm size, Tobin's q, ROA, total debt, and R&D stock, all possible interactions between CalPlant (Panel A), DivFirm (Panel B), After, and Constrained, as well as plant and industry-by-year fixed effects. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variable: Log(1+Emissions)		
	Excess capacity at target non-California plant		
	High (1)		Low (2)
CalPlant × After × Const.	−0.457***		−0.021
	(0.147)		(0.189)
p: High<Low		[0.03]	
CalPlant × After	0.069		0.003
	(0.113)		(0.089)
Plant FE	Yes		Yes
Industry-by-year FE	Yes		Yes
Controls and interactions	Yes		Yes
Observations	1,987		854
Adjusted R^2	0.857		0.880

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variable: Log(1+Emissions)		
	Excess capacity at target non-California plant		
	High (1)		Low (2)
DivFirm × After × Const.	0.409**		0.137
	(0.185)		(0.272)
p: High>Low		[0.20]	
DivFirm × After	−0.159		0.256
	(0.140)		(0.221)
Plant FE	Yes		Yes
Industry-by-year FE	Yes		Yes
Controls and interactions	Yes		Yes
Observations	7,405		7,020
Adjusted R^2	0.713		0.697

ifornia operations. We discuss both panels together for ease of presentation. For comparison, the first column reports our original emission results in Table 2. In the second column for both panels, we find no evidence that carbon efficiency of plants owned by constrained or unconstrained firms are differentially affected by California's cap-and-trade. Therefore, we cannot interpret the reduction in constrained firms' emissions in California as a sign of increased carbon efficiency, nor can we attribute the increase in emissions in other states as an indication of lower efficiency.

In the third column, we find clear evidence that constrained firms significantly reduce output in California compared with their output elsewhere (i.e., coefficient on *CalPlant* × *After* × *Constrained* of −0.49, significant at the 1% level), while increasing output in other states compared with firms that are not affected by the cap-and-trade rule (i.e., coefficient on *DivFirm* × *After* × *Constrained* of 0.42,

Table 6
Carbon efficiency vs. production shifting.
The table reports results from triple-difference regressions. Results in Panel A compare California and non-California plants of geographically diversified firms. Panel B studies spillovers to non-California plants comparing geographically diversified and non-diversified firms. In column (1), the baseline dependent variable is log (1+Emissions). In column (2), the dependent variable is replaced by plant-level carbon efficiency measured as log (1+Emissions/Sales). In column (3), the dependent variable is plant-level output measured as log (1+Sales). In column (4), the dependent variable is plant-level labor input measured as log (1+Employment). In column (5), the dependent variable is plant-level log (1+Excess Capacity), where excess capacity is measured as end-of-current-year employment divided by current-year sales. Plant-level sales and employment data are from the NETS database, complemented with Compustat/Compustat Segment data as described in Section 3. The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. The indicator variable After is equal to 1 if the time period is 2013 or onward, and 0 otherwise. DivFirm is an indicator variable for whether a firm owns plants both in California and in other states during a given year. Constrained is an indicator variable for whether a firm is financially constrained according to our composite measure. Control variables include firm size, Tobin's *q*, ROA, total debt, and R&D stock, all possible interactions between CalPlant (Panel A), DivFirm (Panel B), After, and Constrained, as well as plant and industry-by-year fixed effects. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variables				
	Log(1+Emissions) (1)	Log(1+Emissions/Sales) (2)	Log(1+Sales) (3)	Log(1+Employment) (4)	Log(1+Excess capacity) (5)
CalPlant × After × Const.	−0.390***	0.118	−0.491***	−0.165***	−0.237
	(0.094)	(0.092)	(0.080)	(0.037)	(0.154)
CalPlant × After	0.075	0.051	0.044	0.079***	0.354***
	(0.073)	(0.086)	(0.071)	(0.021)	(0.085)
Plant FE	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes
Observations	3,149	3,149	3,149	3,149	3,135
Adjusted R^2	0.858	0.899	0.871	0.831	0.832

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variables				
	Log(1+Emissions) (1)	Log(1+Emissions/Sales) (2)	Log(1+Sales) (3)	Log(1+Employment) (4)	Log(1+Excess capacity) (5)
DivFirm × After × Const.	0.304**	−0.178	0.418**	−0.017	−0.402**
	(0.130)	(0.195)	(0.169)	(0.055)	(0.167)
DivFirm × After	−0.040	−0.088	0.043	0.047	0.047
	(0.089)	(0.133)	(0.110)	(0.043)	(0.074)
Plant FE	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes
Observations	10,401	10,401	10,411	10,368	9,693
Adjusted R^2	0.733	0.861	0.874	0.862	0.835

significant at the 5% level). The magnitude of the reallocation of output is comparable to if not larger than that of emissions. Therefore, the natural interpretation for the emission reallocation is that firms are shifting their production activity to outside California, rather than making their production more carbon efficient.

Results in the fourth column of Table 6 document a reduction in employment at California plants owned by constrained firms (i.e., coefficient on *CalPlant* × *After* × *Constrained* of −0.17, significant at the 1% level), whereas no changes occur in employment at their non-California plants (i.e., coefficient on *DivFirm* × *After* × *Constrained* is insignificant). Finally, the fifth column shows that excess capacity declines at plants located outside California owned by constrained firms (i.e., coefficient on *DivFirm* × *After* × *Constrained* of −0.40, significant at the 5% level). Altogether, these results indicate that constrained firms respond to the cap-and-trade rule primarily by shifting production away from California toward other states where they have more surplus production capacity, thereby reducing their cost exposure in California while closing their capacity gaps elsewhere without incurring substantial adjustment costs due to reallocations. This production shift partially results in a decline in employment in California but does not manifest itself in an improvement or deterioration in carbon efficiency.

5.2.4. Impact of reallocation and compliance costs

If financially constrained firms reallocate emissions across states to avoid the increase in regulatory costs from the cap-and-trade rule in California, the costs associated with reallocating emissions (e.g., distance, regulation at target state) could undo the benefits of avoiding tighter emission rules in California and dampen the spillover effects. On the other hand, additional costs associated with efforts to comply with the California cap-and-trade rule, such as the development or acquisition of abatement technology, would exacerbate leakage.

To explore these predictions within the limitations of the data, we conduct indirect tests using proxies for reallocation and compliance costs. Specifically, we assume that reallocation costs are lower when firms shift emissions toward plants located in states near California or states where environmental or climate-related regulatory standards are lower. We also conjecture that firms that had previously not invested in R&D or capital expenditures beyond normal business needs should shift emissions more sharply as they would otherwise likely incur additional costs from R&D investments to generate new abatement technology (see Aghion et al., 2016) or to adopt existing technology for a second abatement-related use (or "face") (see Cohen and Levinthal, 1989; Griffith et al., 2004) to comply with the new regulation in California.

In the first six columns of Table 7, we estimate regressions according to Eqs. (3) and (4) on subsamples consisting of plants in California and different sets of control plants located elsewhere conditional on whether reallocating to those states is likely cheaper or costlier. In the first two columns, the subsamples are based on the distance of plants from California. The control plants in the "Close" sample are located in nearby states defined as being within three states adjacent from California. The control plants in the "Far" sample are in distant, or nonnearby, states. In columns (3)–(4) and columns (5)–(6), the control samples are based on the environmental regulation stringency of states according to the 50 State Index of Energy Regulations published by the Pacific Research Institute for Public Policy (PRI), or, alternatively, the 2005 Census Pollution Abatement Costs & Expenditures (PACE) survey rankings, respectively. The control plants in the "Low" or "High" samples are located in lower- or higher-ranked (i.e. less or more regulated) states, respectively. We hypothesize that firms reallocating emissions to plants in the "Close" or "Low" sample shift emissions more intensely due to lower reallocation costs than firms reallocating to plants in the "Far" or "High" samples, respectively.[20]

The regression results provide empirical support for this hypothesis. In particular, in regressions comparing emissions from California and non-California plants of geographically diversified firms (Panel A), California plants reduce emissions more sharply when compared with plants in nearby versus distant states (i.e., coefficient on $CalPlant \times After \times Constrained$ of –0.57 for "Close" sample, as compared to –0.33 for "Far" sample). The same is true when they are compared with plants in low-regulation than high-regulation states (e.g., coefficient on $CalPlant \times After \times Constrained$ of –0.51 for "Low" sample, versus –0.33 for "High" sample, based on PRI index).

Similar or even stronger contrasts are found in the spillover analysis comparing emissions from non-California plants owned by geographically diversified and non-diversified firms (Panel B). The emission spillovers are much more pronounced for plants located in closer than in farther states (i.e., coefficient on $DivFirm \times After \times Constrained$ of 0.55 for "Close" sample, versus 0.16 for "Far" sample) and also much sharper to plants in low-regulation than in high-regulation states (e.g., coefficient on $DivFirm \times After \times Constrained$ of 0.58 for "Low" sample, versus 0.04 for "High" sample, based on Census PACE survey). The differences between the spillover effects in the low and high reallocation cost samples are mostly significant.

In the last four columns of Table 7, we similarly run regressions on subsamples consisting of plants owned by firms that made negative ("Low") or positive ("High") abnormal R&D and capital expenditure (Capex) investments prior to entering the sample. In columns (7) and (8), abnormal ex-ante R&D and Capex investments are computed for each firm by taking the time series average of the residuals from the following firm-year-level regression over the pre-sample period from 2003 to 2008,

$$\frac{R\&D_{i,t} + Capex_{i,t}}{Assets_{i,t-1}} = \alpha + \beta_1 Constrained_{i,t-1} + \beta_2 \log(Assets_{i,t-1}) + \beta_3 ROA_{i,t-1} + a_{k,t} + \varepsilon_{i,t}, \tag{5}$$

where we control for whether firm i is constrained in a given year t, the firm's asset size and profitability, and its growth opportunities or peer benchmarks in its industry k by including an industry-by-year fixed effect. In columns (9) and (10), we alternatively use industry-demeaned R&D and Capex investment.

Consistent with our hypothesis, firms with low ex-ante abnormal investments in R&D and Capex are more likely to reallocate emissions, resulting in lower emissions from their California plants (i.e., coefficient on $CalPlant \times After \times Constrained$ is –0.65 for the "Low" sample and –0.10 for the "High" sample) and stronger emission spillovers to non-California plants (i.e., coefficient on $DivFirm \times After \times Constrained$ is 0.42 for the "Low" sample and 0.11 for the "High" sample). Although we acknowledge the limitations of our proxies (e.g., no detailed information is available on the precise nature of abnormal R&D and Capex or how much of it is tied to abatement), these results are broadly consistent with the idea that reallocation and compliance costs play an important role in moderating how constrained firms shift emissions to avoid the regulatory cost arising from the California cap-and-trade rule.

5.2.5. Are firms reallocating to chase better growth opportunities?

A potential concern is that our results might be driven by differential growth prospects across plants that are unrelated to the California cap-and-trade rule. For example, if the economies of other states grow faster than California, firms with limited access to external capital could shift their productive resources to these more promising states. To evaluate this "opportunity chasing" story as an alternative explanation, we construct measures of growth opportunities and evaluate the robustness of our results controlling for them.

The first measure is state-level annual real gross domestic product (GDP) growth from industries in the state

[20] As an alternative to the PRI index or PACE survey, we use the political alignment of states based on presidential election outcomes (e.g. Democrat or Republican) as a proxy for environmental or climate regulation stringency, and find consistent results in untabulated analysis.

Table 7

Impact of reallocation and compliance costs on spillovers.

The table presents results from subsample regressions of Eqs. (3) and (4) in the main text. In columns (1)–(2), the subsamples are based on the distance of plants from California. The "Close" sample comprises plants located in California or nearby (i.e., within three adjacent states). The "Far" sample includes plants in California and in distant states. In columns (3)–(4) and columns (5)–(6), the subsamples are based on the stringency of state environmental regulation according to the 50 State Index of Energy Regulations published by PRI and the 2005 Census PACE survey, respectively. The "Low" sample comprises plants located in California and in less regulated states. The "High" sample includes plants in California and in heavily regulated states. In columns (7)–(8), the subsamples are based on abnormal R&D and Capex investments of firms prior to the sample period, where abnormal R&D and Capex investment is computed as the within-firm average of the residuals from regression Eq. (5) over the period 2003–2008. In columns (9)–(10), the subsamples are based on industry-adjusted R&D and Capex investments of firms during 2003–2008. The "Low" sample comprises plants owned by firms with negative ex-ante abnormal or industry-adjusted investments. The "High" sample comprises plants owned by firms with positive ex-ante abnormal or industry-adjusted investments. The dependent variable is log (1+Emissions). Panel A compares California and non-California plants of geographically diversified firms. Panel B studies spillovers to non-California plants comparing geographically diversified and non-diversified firms. The indicator variable CalPlant equals 1 if the plant is located in California, and 0 otherwise. After is an indicator variable equal to 1 if the time period is 2013 or onward, and 0 otherwise. Constrained is an indicator variable for whether a firm is financially constrained according to our composite measure. DivFirm is a dummy variable equal to 1 if a firm owns a plant in California as well as in other states in a given year, and 0 otherwise. Control variables include firm size, Tobin's q, ROA, total debt, and R&D stock, all possible interactions between CalPlant (Panel A), DivFirm (Panel B), After, and Constrained, as well as plant and industry-by-year fixed effects. The table reports coefficients and their respective standard errors adjusted for clustering at the firm and state levels (Panel A) or firm level (Panel B). It also reports p-values from one-sided t-tests comparing the coefficients on the triple interaction terms between subsamples. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: California vs. non-California plants (geographically diversified firms)

	Dependent variable: Log(1+Emissions)									
	Target states						Firms			
	Distance from California		PRI environmental regulation stringency		Census PACE survey regulation stringency		Prior abnormal R&D and Capex		Prior industry-adjusted R&D and Capex	
	Close	Far	Low	High	Low	High	Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
CalPlant × After × Const.	−0.565***	−0.329***	−0.509***	−0.330***	−0.461**	−0.343***	−0.648***	−0.099	−0.506***	−0.058
	(0.172)	(0.037)	(0.170)	(0.064)	(0.173)	(0.059)	(0.191)	(0.089)	(0.119)	(0.209)
p: Close(Low)<Far(High)	[0.09]		[0.16]		[0.26]		[0.00]		[0.03]	
CalPlant × After	0.131	0.038	0.128	0.056	0.094	0.066	0.237	−0.049	0.182	−0.056
	(0.088)	(0.057)	(0.128)	(0.061)	(0.112)	(0.067)	(0.157)	(0.053)	(0.125)	(0.057)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,561	2,191	1,979	1,777	1,921	1,831	1,603	1,530	1,919	1,217
Adjusted R^2	0.863	0.862	0.832	0.894	0.827	0.899	0.889	0.933	0.892	0.919

(*continued on next page*)

Table 7
(*continued*)

Panel B: Spillovers to non-California plants (diversified vs. undiversified firms)

	Dependent variable: Log(1+Emissions)									
	Target states						Firms			
	Distance from California		PRI environmental regulation stringency		Census PACE survey regulation stringency		Prior abnormal R&D and Capex		Prior industry-adjusted R&D and Capex	
	Close	Far	Low	High	Low	High	Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DivFirm × After × Const.	0.551**	0.163	0.467**	0.147	0.577***	0.039	0.415***	0.107	0.441***	0.057
	(0.247)	(0.137)	(0.231)	(0.129)	(0.215)	(0.118)	(0.148)	(0.234)	(0.139)	(0.259)
p: Close(Low)>Far(High)	[0.08]		[0.11]		[0.01]		[0.13]		[0.10]	
DivFirm × After	−0.116	0.024	−0.140	0.050	−0.207	0.116	−0.041	0.069	−0.075	0.116
	(0.160)	(0.109)	(0.179)	(0.084)	(0.161)	(0.084)	(0.084)	(0.108)	(0.065)	(0.162)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls and interactions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,693	6,704	5,039	5,359	5,048	5,343	5,365	5,481	6,121	4,731
Adjusted R^2	0.695	0.757	0.680	0.787	0.681	0.789	0.744	0.762	0.759	0.743

of a plant, using GDP data from the BEA. Although GDP growth captures the overall economic activity and growth within the plant's local economy at the state level, it reflects realized values rather than expectations and is noisy at state-industry levels. A plant's local economy may also not coincide with the firm's product market. Therefore, we construct a second forward-looking measure as the median Tobin's *q* of firms that own plants in the same state and industry as the plant of interest, and also primarily operate in that industry. This market-based measure provides a matched benchmark for growth opportunities reflected in a parent firm's peers in the same industry that also share similar production opportunities at the state-industry level.

Panel A of Table 8 reports the population-weighted cross-state averages of these two measures separately for California and other states, each year over our sample period from 2010 to 2015. According to GDP growth, California outperformed other states by a large margin in terms of economic growth during the post California cap-and-trade rule period of 2013 to 2015. The average annual growth rate of California over this period was 4.1%, the fourth highest of all U.S. states. In the period before the cap-and-trade rule from 2010 to 2012, by contrast, California's average growth rate was 2.1%, ranking below the 20th fastest growing state. In other words, California was not only among the fastest growing states during the period after the introduction of its carbon-trading scheme, but also among the states whose growth rates vastly improved relative to the period before the regulation (i.e., a significant increase of 2 percentage points, in contrast to no significant increase in other states).

According to median Tobin's *q*, which better captures market assessments of the growth prospects of a plant's parent firms and their peers, growth opportunities in California and other states were not very different before (1.32 vs. 1.36) or after (1.38 vs. 1.40) the introduction of the California cap-and-trade rule. Overall, we find no evidence that investment opportunities were better in other states than in California during the latter half of the sample period, inconsistent with the alternative explanation that firms reallocated resources simply to capture better growth opportunities in other states. In fact, the trends are more consistent with constrained firms having reallocated *despite* higher growth in California due to their lack of financial flexibility to exploit such opportunities amid increased regulatory costs. The trends also imply that the net returns from emitting in California remain large enough that unconstrained firms would have little incentive to shift emissions.

In Panel B of Table 8, we employ regressions augmented from Eqs. (3) and (4) to formally examine whether growth opportunities explain plant emissions, irrespective of the cap-and-trade rule itself. The first three regressions compare emissions for California and non-California plants based on the sample of geographically diversified firms. The regressions suggest that neither GDP growth nor Tobin's *q* significantly affect emissions regardless of whether firms are constrained, and that the effects of the cap-and-trade rule on emissions are robust to controlling for both growth measures as well as their interactions with financial constraints. The coefficient on the triple-interaction term *CalPlant* × *After* × *Constrained* is –0.36 and significant at the 1% level, comparable to –0.39 in Table 2. The last three specifications study spillovers to non-California plants, comparing geographically diversified and non-diversified firms. Controlling for both growth opportunity variables and their respective interaction terms, the spillover effect remains both economically and statistically robust. The coefficient on the triple-interaction term *DivFirm* × *After* × *Constrained* is 0.31 and significant at the 5% level, comparable to 0.30 in Table 2. In short, resource shifting by firms is primarily driven by the spillover effects from the California cap-and-trade rule, rather than by unrelated investment opportunities.

5.3. Aggregate outcomes

5.3.1. Firm-level outcomes

A critical policy implication of the results thus far is that the California cap-and-trade rule may not necessarily lead to the desired reduction in greenhouse gas emissions overall, but potentially result in an increase in emissions, undermining the goal of the policy. For example, if the costs of emissions are lower in other states than in California, as illustrated in Fig. 1, the predicted reallocation may result in an overall increase in emissions. We test this possibility by aggregating plant emissions within firms and comparing the changes in total emissions due to the implementation of the cap-and-trade rule between financially constrained and unconstrained firms. The results are reported in Table 9, where we run firm-level regressions as follows:

$$\begin{aligned} Log(1+Firm\,Total\,Emissions_{i,t}) &= \alpha + \beta_1 After_t \\ &+ \beta_2 After_t \times Constrained_i + \gamma' X_{i,t} + c_i + \varepsilon_{i,t}. \end{aligned} \tag{6}$$

$Log(1{+}Firm\ Total\ Emissions_{i,t})$ is the logarithm of metric tons of greenhouse gases emitted by firm i in year t. To test whether financially constrained and unconstrained firms increase or reduce emissions differently, we include $Constrained_i$, $After_t$, and their interaction. $X_{i,t}$ denotes the vector of firm-level control variables. c_i denotes firm fixed effects. Although we are interested in the coefficients for both $After_t$ and $After_t \times Constrained_i$ to infer overall increases or reductions in emissions, we also alter the specification to include industry-by-year fixed effects and drop $After_t$ to control for time-varying industry effects. We estimate this regression for geographically diversified firms that have plants both in California and in other states.

Columns (1) and (2) of Table 9 show that unconstrained firms with plants in and outside of California do not significantly reduce their total emissions, whereas constrained firms actually *increase* their total emissions. The coefficient on *After* × *Constrained* is as large as 0.29 and significant at the 5% level, whereas the coefficient on *After* is –0.08 and statistically insignificant. This finding implies that financially constrained firms significantly increase their firm-wide emissions by approximately 21% after the implementation of the cap-and-trade rule. Controlling for industry-by-year fixed effects, we find the coefficient on *After* × *Constrained* becomes even more pronounced, with a point estimate of 0.30 that is significant at

Table 8
Do emissions chase growth opportunities?
The table examines whether changes in emissions after the implementation of the California cap-and-trade rule are explained by variations in growth opportunities associated with plants. We employ two measures of growth opportunities: (1) Annual industry real GDP growth of the state the plant is located in, and (2) median Tobin's q of firms that own a plant in the same state and industry as the plant and primarily operate in that industry. Panel A reports the population-weighted cross-state average real GDP growth and median Tobin's q (first averaged within states) over our sample period from 2010 to 2015. The averages for the Before (2010–2012) and After (2013–2015) periods are shown, as well as the difference between the two and its corresponding t-statistic. State-level GDP data are from the BEA. The first three columns of Panel B compare emissions for California and non-California plants owned by geographically diversified firms, controlling for GDP growth and Tobin's q. The dependent variable is log (1+Emissions). The first two columns each include either GDP growth or Tobin's q as its explanatory variable as well as its interaction with the firm-level Constrained dummy variable based on our composite constraint measure. The third column includes all growth opportunity variables and adds the main variables: CalPlant (equal to 1 if the plant is located in California, and 0 otherwise), After (equal to 1 if the time period is 2013 or onward, and 0 otherwise), Constrained (indicator variable for whether a firm is financially constrained according to our composite measure), and their interaction terms. The last three columns of Panel B study spillovers to non-California plants comparing geographically diversified and non-diversified firms. The sample is restricted to plants located outside of California, and the variable DivFirm indicates whether a firm owns plants both in California and in other states during a given year. GDP growth and Tobin's q are further interacted with DivFirm x Constrained and DivFirm. Control variables include firm size, Tobin's q, ROA, total debt, and R&D stock, all possible interactions between CalPlant (column (3)), DivFirm (column (6)), After, and Constrained, as well as plant and industry-by-year fixed effects. Standard errors are adjusted for clustering at the firm and state levels (columns (1)–(3) of Panel B) or firm level (columns (4)–(6) of Panel B). ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: Growth opportunities in California and other states

State	2010	2011	2012	2013	2014	2015	Before (2010–2012)	After (2013–2015)	After–Before	t-stat.
State GDP growth (%)										
California	1.60	1.50	3.10	2.90	4.40	4.90	2.07	4.07	2.00	2.52
Other states	2.70	2.01	2.43	1.99	2.68	2.79	2.38	2.49	0.11	0.34
Difference	−1.10	−0.51	0.67	0.91	1.72	2.11	−0.31	1.58	1.89	3.00
Median Tobin's q										
California	1.29	1.36	1.31	1.34	1.42	1.38	1.32	1.38	0.06	1.94
Other states	1.34	1.41	1.34	1.35	1.43	1.43	1.36	1.40	0.04	1.04
Difference	−0.05	−0.05	−0.03	0.00	0.00	−0.06	−0.04	−0.02	0.02	1.12

Panel B: Controlling for growth opportunities

	Dependent variable: Log(1+Emissions)					
	California vs. non-California plants (geographically diversified firms)			Spillovers to non-California plants (diversified vs. undiversified firms)		
	(1)	(2)	(3)	(4)	(5)	(6)
CalPlant × After × Const.			−0.364***			
			(0.108)			
CalPlant × After			0.075			
			(0.085)			
DivFirm × After × Const.						0.305**
						(0.135)
DivFirm × After						−0.052
						(0.097)
%ΔGDP	0.002		−0.000	0.006		0.000
	(0.009)		(0.013)	(0.015)		(0.015)
%ΔGDP × Const.	−0.021		−0.014	−0.018		−0.008
	(0.016)		(0.016)	(0.019)		(0.019)
%ΔGDP × DivFirm				0.007		0.011
				(0.020)		(0.026)
%ΔGDP × DivFirm × Const.				−0.008		−0.008
				(0.026)		(0.030)
Median q		−0.060	−0.070		−0.227**	−0.319**
		(0.101)	(0.098)		(0.107)	(0.135)
Median q × Const.		−0.095	−0.043		0.585***	0.621***
		(0.215)	(0.157)		(0.177)	(0.210)
Median q × DivFirm					0.018	0.290
					(0.152)	(0.238)
Median q × DivFirm × Const.					−0.338*	−0.569*
					(0.191)	(0.309)
Plant FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Interactions	No	No	Yes	No	No	Yes
Observations	3,143	3,149	3,143	10,382	10,401	10,382
Adjusted R^2	0.858	0.858	0.858	0.730	0.732	0.733

Table 9
Firm-level outcomes.
The table presents results from firm-level regressions testing whether firms affected by the California cap-and-trade rule increase their overall emissions, whether their operational efficiency is affected, and whether financial constraints affect these responses. The responses of geographically diversified firms with plants both in California and in other states are tested. After is an indicator variable equal to 1 if the time period is 2013 or onward, and 0 otherwise. Constrained is an indicator variable for whether a firm is financially constrained according to our composite measure. In columns (1)–(3), the dependent variable is log(1+firm total emissions), where firm total emissions are computed by summing emissions across all plants owned by a firm in a given year. In column (3), an alternative sample of undiversified firms that either do not have plants in California or do not have operations in other states is used. In columns (4)–(5), the dependent variable measures operational efficiency at the firm level using ROA (column (4)) and Tobin's q (column (5)). Control variables include firm size, Tobin's q, ROA, total debt, and R&D stock, as well as firm and industry-by-year fixed effects. The table reports coefficients and standard errors adjusted for clustering at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

	Dependent variables				
	Log(1+Firm total emissions)			Operational efficiency	
			Placebo sample	ROA	Tobin's q
	(1)	(2)	(3)	(4)	(5)
After × Constrained	0.293**	0.300***	−0.053	0.015	−0.041
	(0.114)	(0.108)	(0.088)	(0.013)	(0.057)
After	−0.084				
	(0.078)				
Firm FE	Yes	Yes	Yes	Yes	Yes
Industry-by-year FE	No	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Observations	249	222	1532	217	217
Adjusted R^2	0.975	0.976	0.886	0.715	0.932

the 1% level. These regressions fail to show an overall reduction in firm-level emissions in response to the cap-and-trade rule, but highlight an increase for constrained firms. This observation contrasts with the insignificant changes for a placebo group of undiversified firms (in column (3)) that either do not have plants in California, and are thus unaffected by the cap-and-trade rule, or do not have operations in other states to reallocate emissions to (i.e., coefficient on *After* × *Constrained* of −0.05, not statistically significant).[21]

We also examine whether constrained firms experience improvements in ROA or Tobin's q after implementation of the cap-and-trade rule. We find no such evidence for either measure of operational efficiency. In other words, constrained firms maintain their profitability and valuations when reallocating to locations where the net returns of emissions are relatively higher after the cap-and-trade reduces net returns of emissions in California. This finding is consistent with earlier evidence that the emission reallocations are not associated with changes in production efficiency.

In short, we find no evidence that firms reduce their overall greenhouse gas emissions as a result of the California cap-and-trade rule. To the contrary, the evidence suggests that financially constrained firms with plants both in California and in other states increase their total emissions, consistent with spillover effects resulting in outcomes contradictory to climate policy objectives.

[21] Without industry-by-year fixed effects, the *After* coefficient for the placebo group is insignificant at 0.02, highlighting the lack of evidence of a significant overall reduction in emissions as a result of the California cap-and-trade rule.

5.3.2. Impact on sectoral employment and GDP

We have thus far documented emission spillover effects from the California cap-and-trade rule driven by firm financial constraints, and we have shown its impact on firm-wide total emissions. How are these results related to broad economic outcomes such as economic activity and employment? This question is important for economists and policymakers who are interested in the macroeconomic impact of climate policies. To provide insight into this issue, we conduct state-sector-level analyses using employment and real GDP data from the BEA. Specifically, we draw on our emission reallocation results and hypothesize that the California cap-and-trade rule may differentially lower employment and economic activity in affected industries in California relative to other states. We also conjecture that growth from other industries may compensate for this relative economic contraction from "polluting" industries.

We first define a plant's industry as the narrowest NAICS code with at least 50 plants in the entire cross section each year, and map it to the narrowest available two- to four-digit NAICS industry classification for which the BEA reports state-level employment and GDP. We then collapse the data to state-sector-year level, where we broadly categorize sectors as either an "emission sector" or "non-emission sector." All BEA industries with greenhouse gas emitting plants are pooled to constitute the emission sector, and all remaining industries are grouped as the non-emission sector. We then aggregate employment (total number of full- and part-time wage-earning workers) and GDP (inflation adjusted with respect to 2009 dollars) up to each state-sector-year, and run the following regression:

$$Y_{s,t} = \alpha + \beta Cal_s \times After_t + a_s + b_t + \varepsilon_{s,t}. \quad (7)$$

Eq. (7) is estimated at the state-year level for the emission sector and non-emission sector separately. $Y_{s,t}$ is ei-

Table 10

Impact on sectoral GDP and employment.

The table examines whether the California cap-and-trade rule differentially affects employment and GDP in affected industries in California compared with other states, and whether growth from other industries countervails this effect. A plant's industry is defined as the narrowest NAICS code with at least 50 plants in the entire cross section each year, and mapped to the narrowest available two- to four-digit NAICS industry classification for which the BEA reports state-level employment and GDP. The data are collapsed to state-sector-year level where sectors are categorized as either "emission sector" or "non-emission sector." All BEA industries with greenhouse gas emitting plants are pooled together to constitute the emission sector, and all remaining industries are grouped as the non-emission sector. Employment (number of wage-earning workers) and GDP (inflation adjusted with respect to 2009 dollars) are aggregated up to state-sector-year level. In Panel A, columns (1)–(2) report results with log(1+Wage employment) as the dependent variable, and columns (3)–(4) use log(1+GDP) as the dependent variable. For each outcome variable, separate regressions are run for the emission sector and non-emission sector, also reporting p-values from testing the statistical difference of the Cal x After coefficients between the emission and non-emission sector subsamples. Cal is a state-level dummy variable indicating whether the state is California, and After is an indicator variable for whether the year is 2013 and later. In Panel B, we further split non-California control states into low- or high-regulation states based on the 2005 Census PACE survey, where states are ranked according to the ratio of state-level total abatement operating costs to the total value of manufacturing shipments and sorted into low or high with respect to the median state. The effects of the California cap-and-trade rule on emission and non-emission sector employment and GDP are then compared between California and low-regulation control states, or between California and high-regulation control states. State and year fixed effects are controlled for. Standard errors are adjusted for clustering at the state level. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. The sample period is 2010–2015.

Panel A: Substitution between emission and non-emission sectors

	Dependent variables			
	log(1+Wage employment)		log(1+GDP)	
	Emission sector (1)	Non-emission sector (2)	Emission sector (3)	Non-emission sector (4)
Cal × After	−0.138**	0.092***	−0.046	0.075***
	(0.068)	(0.007)	(0.039)	(0.026)
p: Emission<Non-emission	[0.00]		[0.00]	
State FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	299	288	299	287
Adjusted R^2	0.953	0.997	0.990	0.953

Panel B: Heterogeneity of substitution effect in regulatory stringency

	Dependent variables							
	Log(1+Wage employment)				Log(1+GDP)			
	Emission sector		Non-emission sector		Emission sector		Non-emission sector	
	Control state regulatory stringency based on 2005 Census PACE survey							
	Low (1)	High (2)	Low (3)	High (4)	Low (5)	High (6)	Low (7)	High (8)
Cal × After	−0.308***	−0.184***	0.081***	0.078***	−0.053	0.053	0.056**	0.043
	(0.048)	(0.052)	(0.011)	(0.013)	(0.050)	(0.041)	(0.020)	(0.027)
p: Low<High	[0.04]				[0.05]			
p: Low>High			[0.43]				[0.35]	
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	131	132	120	132	131	132	120	129
Adj R2	0.995	0.980	0.998	0.997	0.996	0.985	0.989	0.988

ther log(1+Employment) or log(1+GDP), Cal_s is a state-level dummy indicating whether the state is California, and $After_t$ is an indicator for whether the year is 2013 or later. We control for state fixed effects, a_s, and year fixed effects, b_t.[22]

Table 10 reports the regression results. The first two columns of Panel A document a sizable impact of the California cap-and-trade rule on sectoral employment. The negative coefficient on *Cal* × *After* in column (1) implies a 14% greater reduction in employment (significant at the 5% level) in the emission sector in California than other states. By sharp contrast, column (2) shows a relative increase in employment by 9% more in the non-emission sector in California. The close-to-zero p-value confirms the statistical significance of the difference between the *Cal* × *After* coefficients in the emission and non-emission sectors.

The next two columns show evidence of differential GDP growth across the two sectors. Column (3) shows a marginal and statistically insignificant reduction of 5% in the economic output from the sector of industries affected by the California cap-and-trade rule. On the other hand, column (4) shows that GDP in the non-emission sector increases significantly by 8% (significant at the 1% level). The

[22] A visual inspection of the parallel trends in both employment and GDP validates the DID design (see Fig. A.4 in the Internet Appendix).

difference between the emission and non-emission sectors is highly statistically significant.

In Panel B of Table 10, we compare emission and non-emission sector employment and GDP in California against those in low- or highly regulated control states, based on Census PACE surveys that provide rankings of state regulatory stringency. The California emission sector suffers disproportionate losses in employment and GDP when compared with low-regulation counterparts (i.e., 31% lower employment growth, 5% lower GDP growth), but not as much when compared with other highly regulated states (i.e., 18% lower employment growth, 5% higher GDP growth). A substitution in employment and GDP growth is observed in California's non-emission sector when it is compared with less regulated control states. These results are consistent with the results in Table 7 of greater plant-level emission reallocations within constrained firms toward less regulated states.

Overall, the results suggest a macroeconomic tradeoff from the California cap-and-trade rule. Industries affected by the regulation in California exhibit decreases in employment and GDP relative to other states, consistent with firms shifting production and employment outside of California. At the same time, we find a countervailing relative growth in employment and GDP in the non-emission sector comprising "clean" industries. However, we are agnostic about the eventual welfare implications of these results and caution the reader that these macroeconomic outcomes should be interpreted as relative reallocations not only across industries but also across regulatory jurisdictions.

6. Conclusion

We use plant-level data to study how financial constraints motivate firms to reallocate emissions and resources in response to the California cap-and-trade rule, resulting in unintended spillover effects and undermining policy effectiveness. We hypothesize that financially constrained firms reallocate their emissions away from California to other states due to heightened regulatory costs that alter the relative net expected returns across plants. The intuition is that the costs of external capital for constrained firms render profitable emission projects mutually exclusive, and these firms reallocate their productive resources as they adjust the rank order of their emission opportunities across different locations. Since constrained firms are more likely to have excess capacity at plants that become relatively more attractive to operate after the regulatory change, they prefer to internally reallocate emissions.

We document strong evidence of reallocations of emissions by financially constrained firms, primarily across plants that are horizontally linked within the firm's supply chain and toward plants with higher excess capacity. The reallocation is largely driven by a shift in output rather than changes in production carbon efficiency, more pronounced toward nearby or less regulated states, and stronger among firms with low prior investments in abatement. The overall consequence of this reallocation is that firms show no evidence of reducing their total emissions. In fact, constrained firms strictly increase their emissions firm-wide. Our results are consistent with the internal reallocation of corporate pollutive activities and resources to avoid regulatory costs when firms face financial constraints, highlighting the hidden costs of environmental policies.

Our study makes a significant contribution to the understanding of the interplay between climate policy and firm behavior, and provides a stepping stone toward more effectively coordinated solutions to climate change by informing policymakers of the potential externalities from regionally segmented climate policies. This contribution is important because if localized climate policies prove ineffective even within one country, they are unlikely to have the intended effect of reducing emissions on a global scale across countries. Our findings point to two policy guidelines: (1) Given the geographically diversified nature of firms' operations, climate policies should be harmonized across jurisdictions to minimize leakage. (2) Given that financially constrained firms have stronger incentives to reallocate, policymakers should carefully devise appropriately differentiated subsidies to mitigate distortions from implementing climate policies (e.g., tax incentives).

Finally, this paper also contributes to the growing literature on corporate environmental policies by focusing on the internal plant-level emission activities and resource allocations within firms, thus providing a unique channel for the real effects of climate policy through the importance of firm financial constraints.

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